FACTORS PREDISPOSING URBAN TREES TO SUNSCALD

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Abstract. A variety of cultural practices such as deep planting and flush-cut pruning, as well as trunk and root injuries, are suspected of being causal factors in the development of sunscald on ornamental trees. Emerald Queen Norway maple (*Acer platanoides* 'Emerald Queen') and Greenspire littleleaf linden (*Tilia cordata* 'PNI 6025') were transplanted with these conditions and injuries, and with current guidelines for transplanting followed. These same species with sunscald injuries were dissected and examined microscopically to determine if a source of the injury could be determined. Trees in all treatment categories developed sunscald except those deep planted and receiving followup watering. Most sunscald injuries were associated with flatheaded borer (*Buprestidae* spp.) damage. Dissections revealed a number of causes of sunscald injuries, including borer damage, canker-causing fungi, and radial cracks in the xylem. Reducing the incidence of sunscald injury may be as simple as adequate watering the first growing season after transplanting.

Key Words. *Buprestidae* spp.; flush-cut pruning; Nectria canker; radial cracks; root injury; sunscald injury; transplanting; trunk injury; watering.

Sunscald is described as the dying of bark and cambium on the south to southwest side of trees in northern latitudes due to rapid temperature fluctuation during late winter. It is thought that frozen tissue on the southwest side of the trunk is heated by the sun, thaws, and then cools rapidly and refreezes as temperatures drop following sunset (Mix 1916; Sinclair et al. 1987; Tattar 1989; Manion 1991). Differences as great as 25°C (77°F) have been recorded between the north and south sides of tree trunks (Harvey 1923), with the southwest side incurring the greatest variation in temperature within the shortest period of time.

A species characteristic thought to play a role in the development of sunscald is bark thickness. Thick bark may act as insulation or even contain a considerable amount of stored heat to buffer the effects of warming and rapid late-day cooling (Mix 1916; Savage 1970). Young, thin-barked species appear to be more susceptible to sunscald injury but become less susceptible to sunscald as they mature and develop thicker bark (Tattar 1989). Reduced susceptibility with age may also be related to other age-dependent factors such as recovery from transplanting stress.

Sunscald is rarely encountered in undisturbed forests; however, trees on the edge of a recent clearing sometimes develop sunscald after sudden exposure to direct sunlight (Huberman 1943; Tattar 1989). Once tissues are damaged, they may also become more susceptible to other problems such as canker-causing fungi (Davis and Peterson 1980; Lloyd 1997). Urban trees are typically planted in the open and are more susceptible to bark temperature fluctuation than forest trees, which may be further augmented by reflection from buildings, snow, and pavement (Tattar 1989).

Rapid cooling and refreezing of warm cambial tissues may stress or possibly kill affected tissues, but rapid temperature fluctuation is not likely the only factor involved in sunscald (Shigo 1991). If it were, all exposed, thin-barked trees growing in temperate climates would be expected to develop this injury. Huberman (1943) suggests predisposing factors such as injury or site disturbance, while Shigo (1983, 1991) implicates injuries associated with improper pruning, and with trunk and root damage incurred during transplanting. Some arborists have reported sunscald injuries that appear to be associated with roots crushed by tree spade blades during transplanting (Wiens 1997).

Trunk injuries and improper pruning wounds are a major source of stress for trees (Shigo 1991). As wounds are compartmentalized, a barrier zone forms that is chemically strong but structurally weak between wood present at the time of injury and newly formed wood (Shigo 1986). If barrier zone tissue is formed within a narrow growth increment that results from transplanting stress, that tissue may separate with fluctuating temperatures, causing the cambium to die.

There is much speculation as to the cause of sunscald but little research that identifies practices that may contribute to the problem. Our objectives were to determine 1) if and which transplanting and cultural practices predispose trees to sunscald, and 2) the source of sunscald injury by dissection.

MATERIALS AND METHODS

Transplanting and Cultural Practice

The City of Milwaukee, U.S., Forestry Division, provided the trees and their tree nursery for the transplanting portion of this study. Emerald Queen Norway maple (*Acer platanoides* 'Emerald Queen') and Greenspire littleleaf linden (*Tilia cordata* 'PNI 6025') were selected for this study because both are thin barked and have been reported as susceptible to sunscald by Davis and Peterson (1980), Sinclair et al. (1987), and City of Milwaukee forestry personnel. A total of 165 trees were randomly selected from two plots in the nursery, one containing 120 Norway maples and one containing 45 littleleaf lindens. Norway maples were 5 cm (2 in.) diameter, 4 to 5 m (12 to 15 ft) tall, and 7 years old. Littleleaf lindens were 2.5 cm (1 in.) diameter, 2.5 to 3.5 m (8 to 10 ft) tall, and 5 years old. Trees were tagged, numbered, and randomly assigned treatments. Norway maple had seven treatments and a control group, and littleleaf linden had two treatments and a control group. There were 15 replicates per treatment for both species. Fewer lindens were used because of the limited number available.

The north side of each study tree was marked before lifting to provide an orientation point for replanting. All trees were dug on May 9 and 10, 1996, with a 71-cm (28-in.) diameter hydraulic tree spade and were put into burlap-lined, wire root ball baskets to simulate typical transplanting practices. Each tree received its randomly assigned treatment during or just after planting. Planting locations were laid out in east–west rows using a spacing of 4.5 m (15 ft) within the rows and 6 m (20 ft) between rows to eliminate shading from other trees.

Treatments—Norway Maple

Treatments consisted of cultural practices and injuries, alone and in combinations commonly associated with transplanting and post-planting care. The treatments included flush-cut pruning, target pruning, deep planting, trunk injury, root injury, and following current guidelines for planting. Treatments were chosen due to their suspected relationship to sunscald. All treatments on Norway maples were done in early spring as the trees were beginning to break bud.

Treatment 1, flush-cut pruning, removed the lowest two branch whorls with flush cuts. Flush-cut pruning removes the branch collar, which is part of a tree's natural defense system. When the branch collar is removed, a barrier zone forms in the next growth increment in the vicinity of the injury, a condition that may invite boring insects or pathogens. Stress associated with flush-cut pruning is accentuated when multiple cuts are aligned on one side of the trunk (Shigo 1991).

Treatment 2, target pruning, consisted of removing two of the lowest branch whorls with target cuts. Target pruning removes branch tissue just beyond the branch collar and branch bark ridge so that collar or trunk tissue is not damaged and stressed, as occurs with flush-cut pruning. (Shigo 1986).

Treatment 3, deep planting, represents a common problem encountered with many newly planted shade trees. Proper planting procedures recommend the root flare be even with the soil surface (Himelick 1991; Harris 1992). Sample trees receiving treatment 3 were planted with their root flare approximately 15 to 17 cm (6 to 7 in.) below the soil surface. Deep planting stresses or weakens the root system by reducing growth and lowering energy reserves (Shigo 1991). Stressed root systems in turn stress the trunk tissues they are serving and may result in trunk tissues more susceptible to further injuries such as sunscald.

Treatment 4, trunk injury, simulated injuries caused by lawn mowers and string trimmers, and by careless planting procedures. Injuries of this type typically damage trunk tissue by creating wounds close to the soil surface. As in the case of flush-cut pruning, trees respond by forming a barrier zone in the next growth increment. The injury consisted of cutting away a rectangular-shaped portion of bark approximately 3 cm (1.18 in.) long by 5 cm (1.97 in.) wide approximately 4 cm (1.57 in.) above the soil surface on the south side of the tree (Figure 1).

Figure 1. Norway maple with a portion of the bark removed on the south side (trunk injury, treatment 4).

Treatment 5, root injury, is similar to injuries that might commonly occur due to improper tree handling during transplanting. Root-injury treatments entailed excavating and injuring one major root on the south side of the tree. A rectangular-shaped portion of bark approximately 6 cm (2.36 in.) long and 2 cm (0.79 in.) wide was cut away from the excavated root approximately 5 cm (1.97 in.) away from the trunk (Figure 2).

Treatment 6 was a combination of the deep-planting and trunk-injury treatments. These treatments were combined because trunk injuries and deep planting are commonly observed on newly planted trees, thus compounding potential stress that may lead to sunscald.

Treatment 7 was transplanting following currently recommended procedures. These procedures included planting with the root flare at the surface, mulching, and care to prevent trunk and root injuries.

Treatment 8 was a group of 15 trees that were planted along the streets of Milwaukee. These trees were originally selected as nontransplanted controls. However, because space was needed in the nursery, they were dug and transplanted at the same time as the rest of the study trees following recommended planting procedures (as prescribed in treatment 7). The only difference between treatments 7 and 8 was planting location and watering pattern. The city planting crew watered these trees at planting time, and adjacent residents were asked via a message hung on the doorknob of the residence to provide followup watering. None of the trees transplanted in the nursery were watered due to wet conditions at planting time. A survey requesting watering information was sent to the 15 adjacent addresses of the transplanted street trees. Seven of nine (78%) returned surveys stated that residents watered their trees during the first growing season.

Figure 2. Excavated Norway maple root with bark removed (root injury, treatment 5).

All treatment trees, except deep-planted trees, were planted at proper depth with their root flare/collar at soil surface.

Treatments—Littleleaf Linden

Thirty littleleaf linden were lifted for transplanting following the same procedures as were used on the Norway maples, but one tree was excluded from the study due to extensive damage during lifting. Trees were dug on May 14, 1996, and half were planted on May 15, 1996. Due to heavy rain and poor planting conditions, the remaining trees were planted on May 23. Fourteen of the transplanted trees were planted deep following the same deep-planting procedures (treatment 3) used for the Norway maples. Planting depth was selected as the treatment because Milwaukee forestry personnel reported a possible relation between sunscald and deep planting for this species. The remaining 15 trees were planted with the root flare at the soil surface. A control group of 15 littleleaf lindens from the same field was not transplanted.

Observations of both species were initiated in early spring of 1997 to look for signs of sunscald, which included discolored, cracking, splitting, or peeling bark. Followup observations continued through late summer of the same season.

Sunscald Dissections

Twenty Norway maples and eight littleleaf lindens with existing sunscald (prior to treatments) were culled for dissection in June 1996 from the Milwaukee Forestry Division Nursery and from Johnson's Nursery, Inc., located in southeast Wisconsin. Samples of trees with sunscald from the transplant portion of the study were included in this group. Cross, tangential, and radial sections were made dependent on the location of the injuries and possible existing clues to their starting points. These sections were observed under a binocular-dissecting microscope to determine the source of the injury.

RESULTS

Transplanting and Cultural Practices

Sunscald was observed on 38% of transplanted Norway maples, with all treatments exhibiting some level of injury (Table 1). Chi-square analysis (0.05) revealed that trees deep planted (treatment 3) and trees planted on Milwaukee streets (treatment 7) had significantly less sunscald damage than all other treatments. A total of 43 (36%) of the Norway maples died. Deep-planting and target-pruning treatments had the highest mortality rates (60%). Of trees that developed sunscald, 77% had flatheaded borer (*Buprestidae* spp.) damage associated with their injuries (Table 2). Borer damage was found only on dead or sunscald-injured trees. Sixty-nine percent of borer-infested trees had

Table 1. Norway maples that died or developed sunscald in the transplanting portion of the study.

Treatment	Number of trees	Dead	Scald
1. Flush-cut pruned	15	6	6 a*
2. Target pruned	15	9	8 a
3. Deep planted	15	9	3 b
4. Trunk injury	15	3	6 a
5. Root injury	15	6	6 a
6. Trunk injury and deep planted	15	5	6 a
7. Recommended procedures	15	5	10 a
8. Street trees	15	0	1 b

*Values followed by the same letter are not significantly different at $P = 0.05$ according to Chi-square test of independence.

sunscald. The remaining 31% of borer-infested trees were dead and had no signs of sunscald. Borer damage was centralized just above the soil line where the graft union was located, with sunscald extending above the attack site. Borer damage was located only on the south to southwest sides, as is typical of flatheaded borer infestation (Solomon 1934; Johnson and Lyon 1991). Treatment groups that did not have borer damage were deep planted, and combination trunk injury and deep planted. Trees in these treatments were planted with the soil line above the graft union.

Only one street tree (Table 2) had sunscald and flatheaded borer damage. This tree was likely not watered because it was located in an industrial area in front of a warehouse. The remaining trees were planted in residential neighborhoods.

Five of the 29 littleleaf lindens developed what appeared to be sunscald injuries, with small patches of dead bark and cambium on the southwest side of the trunk. Two of the affected trees were deep planted, and three were planted with the root flare at grade. One tree planted at grade with sunscald also had borer damage associated with the injury. There was no significant difference between treatments when analyzed using the Chi-square test at the 0.05 level.

Sunscald Dissections

Norway maples with apparent sunscald injury were dissected and observed under a binocular microscope. A single, specific causal agent could not be observed; rather, these injuries appeared to have several possible origins. Some of the samples had a central column of discolored wood associated with many improper pruning wounds (flush cut with torn bark) made at the end of the first growth increment following grafting. Discoloration associated with each individual pruning wound had coalesced to form a central column of discolored wood within the first growth increment. Healthy wood had grown beyond the barrier zone in subsequent years.

Further examination of these trees revealed radial frost cracks originating at the central column

Table 2. Norway maples with borer damage in the transplanting portion of the study.

Treatment	Number of trees	Borers in live trees	Borers in dead trees
1. Flush-cut pruned	15	5	3
2. Target pruned	15	5	4
3. Deep planted	15	0	0
4. Trunk injury	14	5	1
5. Root injury	15	6	1
6. Trunk injury and deep planted	15	0	0
7. Recommended procedures	15	6	1
8. Street trees	15	1	0

of discolored wood with cambial dieback at the margins of the crack. Frost cracks start at a preexisting injury (in this case, flush-cut pruning) and radiate distally from that point (Shigo 1986).

Examination of what appeared to be sunscald on other specimens revealed fungal fruiting bodies associated with canker-causing fungi. Coral spot Nectria canker *(Nectria cinnabarina)* may have been the cause of the injuries; however, the fruiting bodies were so old that positive identification was not possible. These cankers kill a portion of the cambium, resulting in drying and sloughing bark, much like sunscald. Some canker-causing fungi are opportunistic, nonaggressive pathogens that attack trees under stress, and they are often found associated with sunscald (Savage 1970; Schoeneweiss 1978; Sinclair et al. 1987; Tattar 1989; Watson 1990). Moisture stress has been noted as the primary stress factor in the development of these cankers (Rice and Hall 1979; Sinclair et al. 1987; Schoeneweiss 1981).

Dissected trees from the transplanting portion of this study had a wedge-shaped area of discolored wood behind the sunscald, coalescing with a central column of discolored wood. Trees with borer damage had a similar wedge-shaped area of discolored wood behind the borer damage in the first growing season following transplanting, and a thin plane of discolored wood behind further borer damage during the second growing season (Figure 3).

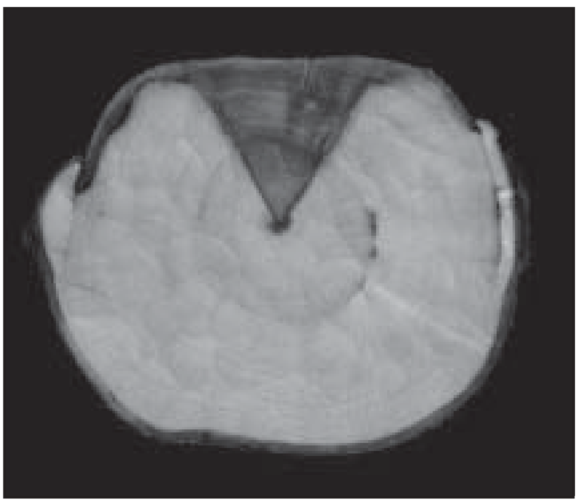

Figure 3. Cross section of sunscald and flatheaded borer injury that developed on a Norway maple during the study. Note wedge of discolored wood in the center of the injury associated with injury the first season and thin bands of discolored wood in the second season growth on either side of the wedge.

DISCUSSION

Transplanting and Cultural Practices

Sunscald on Norway maple appeared to be related more to water stress than to any particular injury or cultural practice. The presence of flatheaded borers in many of the injuries appeared to be a casual agent because the borers are opportunistic and take advantage of stressed trees. Sunscald occurred in all treatments, with significantly lower amounts on trees planted on city streets and the deep-planting-only treatment.

When trees are transplanted, they lose a large percentage of their absorbing root system and consequently are subject to water stress. Additional stress may come from loss of crucial starch reserves depleted for root replacement and compartmentalization when large lateral roots are severed in transplanting (Hamilton 1988). Watering at the time of planting and for at least the first growing season has been observed to be critical for tree survival (Kramer 1987; Clark and Kjelgren 1990; Gilman et al. 1998).

Water stress was compounded in that the nursery-transplanted trees were not watered, and transplanting was followed by an extended dry period in July and August of the first growing season. However, trees planted on streets were watered at the time of planting followed by most adjacent residents watering them throughout the first growing season. Only one tree planted on city streets developed sunscald, significantly less than all but one other treatment. Flatheaded borers attacked this tree as well.

Two treatments involved deep planting, one with no other injury and one with trunk injuries. Trees deep planted with no trunk injury developed significantly less sunscald than other treatments except for those trees planted on city streets. A possible explanation is that nine of the 15 deep-planted-only trees died, leaving few remaining trees to develop sunscald. However, none of 15 deep-planted/trunk injury trees had borer damage, and only five of them died. All of the deep-planted trees were placed with the graft below grade, and because all other treatments with borer damage were attacked at the graft union, perhaps the combination of the graft tissue and heating by the sun invites borer attacks.

Secondary insects, or insects that attack only stressed trees, have been reported to be attracted to volatiles released by stressed tissues (Potter et al. 1988; Dunn and Potter 1991). The Milwaukee Forestry Division Nursery plants its trees deep to eliminate labor costs of staking whips. To compensate for deep planting in the nursery, soil from the tops of root balls is removed to the root flare, indicating proper planting depth. Removing this soil may cause additional stress by exposing tissue to the sun that was buried for 5 years. This should not imply that deep planting is an acceptable practice to reduce the incidence of borers and/or sunscald. Long-term damage from stem-girdling roots and other problems associated with deep planting more than offset any perceived gains from deep planting.

Although five of the 29 littleleaf lindens developed sunscald, there were no significant differences between deep-planted trees and trees planted at grade. Water stress may have played a factor in this species as well, but with no watered trees for comparison, no conclusions can be drawn.

Sunscald Dissections

Dissection of trees with apparent sunscald yielded surprising results. Some specimens with what appeared to be sunscald actually had frost cracks with dieback of the cambium at the margins of the crack. Subsequent woundwood growing over the dead cambium had the appearance of sunscald, and it was not until the tree had been dissected that the source of the injury became apparent.

Other injuries that appeared to be sunscald were likely caused by coral spot Nectria canker. These cankers commonly attack the cambium after it has been injured or stressed by transplanting (Sinclair et al. 1987); however, timing may play a crucial role in the interpretation of the injury. If the injury is observed before the canker produces fruiting bodies, it may be misidentified as sunscald.

Dissection of borer-damaged trees from the transplanting portion of this study revealed that flatheaded borers appeared to have first attacked the trees the summer following transplanting, and they continued to utilize the site during the second growing season. This is consistent with observations that flatheaded borers attack stressed tissue on the south to southwest side of trees. These trees were water stressed due to transplanting and drought, and tissue at the graft union was further stressed by exposure to the sun of previously buried tissue.

CONCLUSION

Sunscald has been defined as the death of cambium on the south to southwest side of trees due to rapid changes in temperature. This study revealed that injuries commonly described as sunscald can have a variety of causes such as trunk cracks, canker-causing fungi, and boring insects (although we did not determine if the borers caused the sunscald or if they took advantage of the injured tissue). A better definition might be that sunscald occurs on the south to southwest side of a tree, results in the dying of the cambium, and is likely related to moisture stress and associated biotic and abiotic factors. The seemingly most crucial factor associated with sunscald development is moisture stress following transplanting, because trees watered following transplanting had a very low incidence of sunscald. The answer to minimizing sunscald injury may be as simple as the timely watering of newly planted trees.

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Résumé. Une variété de pratiques culturales et de dommages, tels plantation en profondeur, coupes rases ainsi que blessures au tronc et aux racines, sont suspectés d'être des facteurs causals dans le développement des insolations sur les arbres ornementaux. Des érables de Norvège Emerald Queen (*Acer platanoides* 'Emerald Queen') et des tilleuls à petites feuilles Greenspire (*Tilia cordata* 'PNI 6025') ont été transplantés dans ce type de conditions et avec ces dommages, et ont été entretenus de façon normale après leur transplantation par la suite. Ces mêmes sujets avec des insolations ont été disséquées et examinées à l'échelle microscopique afin de déterminer si la source des blessures pouvait être établie. Les arbres de toutes les catégories de traitement, à l'exception de ceux plantés en profondeur et qui ont été arrosés par la suite, ont développé des insolations. La plupart des dommages dus aux insolations étaient associés à ceux causés par le scolyte (*Buprestidiae* spp.). Les dissections ont révélé de nombreuses causes aux dommages par insolation incluant des dommages par les perceurs, les chancres et les gélivures. La réduction des incidences de dommages par insolation peut être aussi simple qu'un arrosage adéquat durant la première saison de croissance suivant la transplantation.

Zusammenfassung. Es wird vermutet, dass eine Reihe von Kulturtechniken, wie zu tiefes Pflanzen, flache, stammparallele Schnitte und Stamm- und Wurzelverletzungen die Hauptursachen von der Entwicklung von Sonnenbrand bei Zierbäumen sind. *Acer platanoides* 'Emerald Queen' und *Tilia cordata* 'PNI 6025' wurden unter diesen Bedingungen und mit diesen Verletzungen verpflanzt und mit gegenwärtigen Richtlinien für Verpflanzung nachbehandelt. Die gleichen Spezies mit Sonnenbrand wurden aufbereitet und mikroskopisch untersucht, ob eine Ursache für die Verletzungen bestimmt werden kann. Alle Bäume in der Untersuchung entwickelten Sonnenbrand, außer den zu tief gepflanzten, die anschließend gewässert wurden. Der meiste Sonnenbrand konnte mit Verletzungen durch Bohrinsekten (*Buprestidae* spp.) assoziiert werden. Die Präparate zeigten eine Reihe von Sonnenbrandverletzungen, einschließlich Bohrinsektenschaden, krebsverursachende Pilzinfektionen und radiale Risse im Xylem. Wenn in der ersten Wachstumssaison gewässert wird, reduzieren sich die Verletzungen auf einfache Weise.

Resumen. Se sospecha que una variedad de prácticas culturales y daños, tales como profundidad de plantación, poda a ras y daños a la raíz y tronco son los factores causales del desarrollo de quemaduras por el sol en árboles ornamentales. El maple Emerald Queen Norway (*Acer platanoides*, Emerald Queen') y el tilo Greenspire (*Tilia cordata*, PNI 6025') fueron transplantados con estas condiciones y daños. Estas mismas especies con daños por el sol fueron disectadas y examinadas microscópicamente para determinar si podría ser determinada la fuente del daño. Los árboles en todas las categorías de tratamientos desarrollaron quemaduras excepto aquellos plantados profundamente y que recibieron riego posterior al transplante. La mayoría de las quemaduras estuvieron asociadas con daño por barrenador (*Buprestidae* spp.). Las disecciones revelaron un número de causas de daños de quemaduras incluyendo daño por barrenador, hongos causantes de cancros y grietas radiales en el xilema. La reducción de la incidencia de daño por quemaduras puede ser tan simple como proporcionar un riego adecuado en la primera estación de crecimiento después del transplante.