Stem and Branch Distribution of Wetwood and Relationship of Wounding to Bleeding in American Elm Trees

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ABSTRACT

Murdoch, C. W., and Campana, R. J. 1984. Stem and branch distribution of wetwood and relationship of wounding to bleeding in American elm trees. Plant Disease 68: 890-892.

Frequent bleeding from wounds made to inject chemicals into elm stems indicated a need to investigate the distribution and development of wetwood. A study was made to determine the location and distribution of wetwood in stems of varying ages and to evaluate the relationship of bleeding to types and depths of wounds made to inject chemicals. Cross-sectional area of wetwood, volume of wetwood per meter of bole, and surface-to-volume ratio of the wetwood cylinder were higher in injected trees than in noninjected trees. Frequency of bleeding increased with depth of injection wound. Topical application of a bactericide to wounds did not prevent bleeding.

Bacterial wetwood of elm was first investigated by Carter (3) and later by Seliskar (11). Both authors described bleeding or fluxing from wounds. The bleeding liquid originates from a core of discolored wetwood within the stem. After the exudate is colonized by secondary microorganisms not usually associated with wetwood, it is called "slime flux" (3,6), or more properly, wetwood slime (8). Gas production by some bacteria inhabiting the wetwood causes abnormally high positive gas pressure to develop (3,7). This forces liquid out of the tree if the wetwood core is punctured by wounds, tissue tears in branch crotches, or cracks or holes made to inject systemic fungicides (2). Bleeding is also associated with longitudinal stem cracks (10).

With the increased use of stem injection (5,12) of pesticides, bleeding from injection wounds has become conspicuous. Some of this bleeding is related to cell necrosis from wounding and to phytotoxicity of injected chemicals (1). The purposes of this study were to investigate the relationship of xylem necrosis at wound sites to bleeding and to determine the distribution of wetwood in American elm trees.

MATERIALS AND METHODS

Distribution of wetwood. The distribution of wetwood in stems and branches was studied in 35 large American elms (38–96 cm in diameter at 1.3 m) that had been injected 3 yr previously with systemic fungicides to control Dutch elm disease and in 35 large (25–95 cm) and 40 small (10–22 cm) trees that had not been injected. Trees were felled and bucked at 1-m intervals and diameter of cross section (inside bark), diameter of wetwood within cross section, number of rings of nondiscolored sapwood and wetwood, and tree age were recorded. For noninjected trees, two measurements of wetwood diameter from the outermost discolored growth ring of the wetwood cylinder through the pith were made perpendicular to each other and the values averaged. A similar procedure was used for injected trees, except areas of discolored wetwood associated with injection wounds to the sapwood were ignored and measurements were made from the outermost ring of the continuous wetwood cylinder through the pith. The same rationale was used when sapwood ring counts were made on injected trees. In large trees, data were taken from the stump top (0.0–0.25 m above ground level), top of the main bole, and from branch bases 28–51, 13–27, and 2–12 cm in diameter. For small trees, data were taken at ground level, at 1 m up the main stem, and from five branch bases (1–4 cm in diameter) chosen at random above 1 m in the crown. Additional measurements of wetwood patterns and distribution in the 40 small trees were made at 5-cm intervals from ground level (0.0 m) to 0.25 m.

Relationship of wounding to bleeding. Injection holes, pruning wounds, and other wounds on 198 elm trees (19–98 cm in diameter at 1.3 m) on the University of Maine campus at Orono were examined for bleeding. Data on bleeding wounds were classified by location (bole or crown), type of injection wound site, and tree vigor. Three classes of tree vigor were defined: class I—healthy, vigorous-appearing trees; class II—less than 30% dieback evident in crown; and class III—tree under severe stress as evidenced by widespread dieback in crown or the presence of Dutch elm disease symptoms. In addition, 632 holes (1 cm deep, 0.9 cm in diameter) made in 40 trees were examined for bleeding 30 and 60 days after injection with systemic fungicides.

To determine if control of bleeding was possible by the topical application of chemicals, 228 injection wounds on 20

Supported in part by the U.S. Forest Service, Northeastern Forest Experiment Station, Delaware, OH. Portion of a dissertation submitted by the first author in partial fulfillment of the requirements for the Ph.D. degree, University of Maine, Orono.

Accepted for publication 19 April 1984.

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trees (54–87 cm in diameter at 1.3 m) were studied. Fifty-seven wounds each received one of the following treatments immediately after injection: 1) a bactericide, 2) a bactericide and lanolin, or 3) lanolin only (benzylalkonium chloride). An equal number of wounds served as untreated controls. Treatments were made consecutively on wounds, with a mean of 11.4 wounds treated per tree. The wounds were examined for bleeding 60 days after treatment.

To determine if removal of bark and phloem would control bleeding, three simulated injection wounds (0.9 cm in diameter) were made in each of 40 trees (12–64 cm in diameter at 1.3 m) to xylem depths of 1, 3, or 5 cm at 0.5 m above ground. Twenty holes were bored through the bark and 20 directly into the xylem after removing a wafer of bark 2.5 cm in diameter. After 90 days, the wounds were examined for bleeding. The trees were then felled, bucked, and the patterns of wetwood recorded.

RESULTS

Distribution of wetwood. The pattern of wetwood in cross sections was always roughly circular in noninjected stems and tended to follow the outline of the cambium. Variation from this pattern was seen in stems where injection wounds had been made. In cross section, wetwood formed discrete areas in the sapwood associated with injection wounds or was continuous with the central core wetwood and presented a stellate pattern 3 yr after injection. The cross-sectional area of wetwood in the bole of large trees was greater (52–56%), although not significantly so, in injected trees than in noninjected trees (45–47%). Cross-sectional areas decreased from the bottom of the bole toward the branches. The average volume of wetwood-affected tissue per meter of bole and surface-to-volume ratio of the wetwood cylinder were also greater in injected trees than in noninjected trees (4,067 vs. 3,594 cm^3; 0.10 vs. 0.08 cm^2/cm^3, respectively).

In small, noninjected stems 10–23 yr old, wetwood patterns in cross section were similar to those in larger trees. In longitudinal stem sections within 40 cm of the ground line, the pattern of wetwood resembled an inverted cone with the apex located at or near ground level (Fig. 1). The proportion of cross-sectional area of the stem in wetwood varied from 0 at ground level to 16% at 25 cm above the ground. Above 25 cm, the pattern of wetwood development was similar to that in larger trees.

Relationship of wounding to bleeding. Wounds in the upper third of the bole bled significantly more than those in the lower third (excluding injection wounds) (Table 1). There was no significant variation in frequency of bleeding related to wound position in the crown or to different types of injection wounds. Bleeding occurred from 68–76% of wounds, regardless of vigor class. Observation of gravity-flow injection holes 30–60 days after wounding showed that more wounds were bleeding at 60 than at 30 days after injection.

Removal of bark around injection holes did not significantly influence the subsequent incidence of bleeding (Table 2). Injection-type wounds 1 cm into the xylem did not show any bleeding after 90 days. Wounds 3 cm into the xylem bled less frequently than those 5 cm deep.

Topical applications of benzylalkonium chloride, with or without lanolin, did not affect the incidence of bleeding. Bleeding occurred from 70–82% of wounds, regardless of treatment.

Relationship of nondiscolored sapwood to stem age. The relationship of the number of rings of nondiscolored sapwood to the age of the stem in large trees is shown in Figure 2. Mean sapwood width was 40 mm for large, injected trees; 29 mm for large, noninjected trees; and 82 mm for small, noninjected trees.

The number of sapwood rings increased with age in noninjected, large elm stems (Fig. 2). Data for injected trees also show that even proper injection techniques, (ie, shallow, clean holes), used once, tend to reduce the number of unaffected sapwood rings. Noninjected trees had an average of five more rings of sapwood than did injected trees. This would seem to explain the small number of sapwood rings (one to five) observed by the authors

Table 1. Relationship of wound type and location to bleeding in 198 American elm trees

Description of wounds	Locations of wounds	Number of wounds	Percent wounds bleeding
Bole[a]			
Trunk cracks, mechanical injuries	Lower one-third	38	39*[b]
	Middle one-third	48	46
	Upper one-third	79	84*
Total		165	62
Crown			
Pruned branches, branch stubs, cracks, mechanical injuries	Lower one-third	274	69
	Middle one-third	435	78
	Upper one-third	147	75
Total		856	75
Injection sites			
Pressure treatment			
Holes 19 mm diam., 13 mm into xylem	0–1 m Above ground	130	65
Gravity flow treatment			
Holes 9 mm diam., 13 mm into xylem	0–1 m Above ground	985	82
	1 m Above ground	192	13
Total		1,037	79
Gravity flow			
30 Days after injection		632	53
60 Days after injection		632	73

[a] Excluding injection sites.
[b] * = Significantly different from each other according to the *t* test ($P = 0.01$).

Table 2. Comparison of bleeding from injection-type wounds made in 20 elm trees with and without bark removal after 90 days

Wound depth (cm)	With bark and phloem at edges		Without bark and phloem at edges	
	Number of wounds	Percent wounds bleeding	Number of wounds	Percent wounds bleeding
1	94	0	94	0
3	96	18*[a]	90	10*
5	85	73*	83	67*

[a] * = Significantly different from the 1-cm wound according to the *t* test ($P = 0.05$).

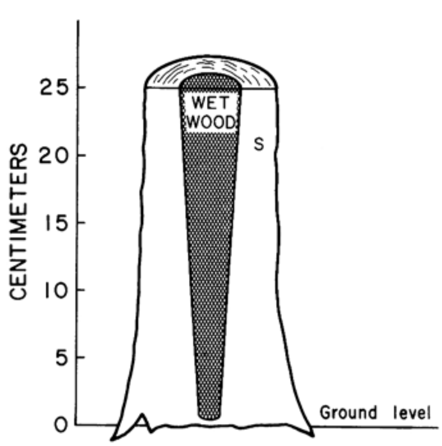

Fig. 1. Spatial pattern of wetwood development in young elm stems, S = nondiscolored sapwood.

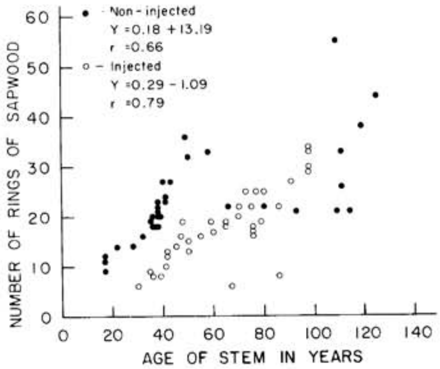

Fig. 2. Relationship of the number of rings of nondiscolored sapwood to stem age in elm trees.

in large trees that had been injected several times. Improper injection techniques, too many injection sites, holes deeper than 1 cm, and holes not drilled cleanly, would expand wetwood size while reducing the sapwood ring number.

DISCUSSION

Single-year fungicide injections in elm stems did not significantly increase either the cross-sectional area or the total bole volume of wetwood. However, mortality of cells at injection sites after fungicide injection (1) can cause localized spread of wetwood outward to the current year's growth ring. Continuous vertical columns of wetwood were often noted 1.8 m or more above injection sites (1). This type of wetwood development indicates the importance of staggering injection sites when treating previously treated trees so that chemicals may enter unaffected sapwood.

There were fewer rings of nondiscolored sapwood in injected than in noninjected trees; however, the average ring width was larger in injected trees. Depth of injection holes in small trees was a determinant of bleeding (Table 2). Holes 1 cm into the xylem showed no bleeding after 90 days. Generally, the deeper the hole the greater the probability of bleeding. Holes that entered the wetwood always bled. Removal of bark and phloem had little influence on frequency of bleeding (Table 2). Efforts to control bleeding from injection wounds with external applications of chemicals were unsuccessful.

Injected trees were shown to have an average of five fewer rings of sapwood than did noninjected ones. If several rings of sapwood are lost each time an elm is injected, this would explain large, apparently healthy trees with three or fewer rings of sapwood as are common where widespread injection of fungicides has been implemented over a period of several years (2). Because the ring-porous elm conducts most of its water through the current year's growth ring (13) and direct phytopathogenicity of bacteria associated with wetwood has not been proven (4,9), it is unlikely that increased wetwood size would directly affect water flow through the xylem, but this is not known. Decreased sapwood width, however, would decrease the amount of starch, sugars, and other materials stored in the axial and radial ray parenchyma system and available to the tree in times of stress (13).

LITERATURE CITED

1. Andersen, J. L., Murdoch, C. W., Cameron, R. L., and Campana, R. J. 1980. Necrosis of elm tissue following chemical injection for Dutch elm disease control. (Abstr.) Phytopathology 70:458.
2. Campana, R. J., Murdoch, C. W., and Andersen, J. L. 1980. Increased development of bacterial wetwood associated with injection holes made for control of Dutch elm disease. (Abstr.) Phytopathology 70:460.
3. Carter, J. C. 1945. Wetwood of elms. III. Nat. Hist. Surv. Bull. 23:407-448.
4. Dye, D. W. 1969. A taxonomic study of the genus *Erwinia*. IV. Atypical erwinias. N.Z. J. Sci. 12(4):834-839.
5. Gregory, G. F., and Jones, T. W. 1975. An improved apparatus for pressure injection of fluid into trees. U.S. For. Serv. Res. Note NE-214. 6 pp.
6. May, C. 1942. A note on slime flux in American elm. Arborist's News 7:52-53.
7. Murdoch, C. W., Biermann, C. J., and Campana, R. J. 1983. Pressure and composition of intrastem gases produced in wetwood of American elm. Plant Dis. 67:74-76.
8. Murdoch, C. W., and Campana, R. J. 1981. Bacterial wetwood. Pages 31-34 in: Compendium of Elm Diseases. R. J. Stipes and R. J. Campana, eds. Am. Phytopathol. Soc., St. Paul, MN. 96 pp.
9. Murdoch, C. W., and Campana, R. J. 1983. Bacterial species associated with wetwood of elm. Phytopathology 73:1270-1273.
10. Murdoch, C. W., Coleman, J. S., and Campana, R. J. 1983. Bark cracks associated with injection wounds in elms. J. Arboric. 9:61-64.
11. Seliskar, C. E. 1950. Some investigations on the wetwood diseases of American elm and Lombardy poplar. Ph.D. dissertation. Cornell Univ., Ithaca, NY. 148 pp.
12. Smalley, E. B. 1978. Systemic chemical treatments of trees for protection and therapy. Pages 34-39 in: Dutch Elm Disease: Perspectives After 60 Years. W. A. Sinclair and R. J. Campana, eds. Cornell Univ. Agric. Exp. Stn. Search Agric. 8. No. 5. 52 pp.
13. Zimmermann, M. H., and Brown, C. L. 1971. Trees: Structure and Function. Springer-Verlag, New York. 336 pp.