TREE WOUND CLOSURE[1]

by Dan Neely

Abstract. Trunk wounds that injure both xylem and phloem can structurally weaken trees, reduce translocation of sap, and provide entry for insects or inoculation sites for disease organisms. Rapid wound closure is beneficial. Illinois data indicate that wound closure is directly related to tree vigor, that large wounds close more in 1 year than small wounds, that wounds less than 12 mm wide are likely to close in 1 year, that annually inflicted wounds less than 25 mm in diameter are not likely to slow tree growth, and that wounds on slow-growing trees close more per unit of radial trunk growth than wounds on fast-growing trees.

Résumé. Les blessures au tronc qui endommagent le xylème et le phloème peuvent affaiblir la structure de l'arbre, réduire le transport de la sève et procurer des entrées aux insectes ou des sites d'inoculation aux pathogènes. Une fermeture rapide des blessures est bénéfique. Des données recueillies en Illinois indiquent que la vitesse de fermeture des blessures est directement reliée à la vigueur de l'arbre, que les grosses blessures se ferment plus au cours d'une année que les petites, que les blessures de moins de 12 mm de diamètre se ferment habituellement en moins d'un an, que les blessures de moins de 25 mm de diamètre infligées annuellement ne causent pas de diminution de la croissance de l'arbre et que les blessures sur les arbres à croissance lente se ferment plus par unité de croissance radiale du tronc que les blessures sur les arbres à croissance rapide.

A tree may receive wounds many times during its lifetime. Most occur as acts of nature—breakage by wind, ice, or snow, and feeding by animals—or as careless acts by people. Some wounds, for example, are created intentionally to improve a plant horticulturally, to make a site safe, or to maintain utility services. Wounds are also made when chemicals are injected or implanted into trees for prophylactic or therapeutic treatment of nutritional deficiencies, insect pests, or disease organisms. Whether intentional or unintentional, wounds heal in a similar manner. The objectives of this paper are to describe the process by which wounds close (heal) and to provide data on studies related to the time needed for closure. The wounds discussed are those derived from mechanical injury that severs the bark and exposes the wood. Repair of wounds that injure the bark but do not penetrate the wood are described by Hudler (4).

Wounds can injure a tree directly and indirectly. Direct damage occurs when large and/or deep wounds inhibit or greatly curtail the translocation functions of the wood and bark (xylem and phloem). Growth will generally be slowed when 50 percent of the bark around the circumference of a stem or trunk is removed; dieback and decline can be expected when 75 percent of the bark is removed. Wounds are indirectly damaging when they serve as entry or inoculation sites for disease organisms and insects. Fresh wounds in May and June that are visited by insect vectors subject elm to Dutch elm disease (2) and oak to oak wilt (5).

Wood reacts to injury both internally and at the surface. Shigo and Marx (14) have described the internal reactions of wood in their CODIT hypothesis and have conducted numerous experiments that support it. Plant propagators have carefully described the wound reactions and anatomical changes that occur in stems excised from plants and used as cuttings. Wound reactions at the wood surface occur through the production of callus tissue. Callus most often originates at the vascular cambium but can be initiated by ray cells or other parenchyma cells. Initially, callus cells are nondistinct parenchyma cells, but with age they differentiate into xylem, vascular cambium, phloem, and outer bark. Over time, callus tissue closes wounds. Shigo and his co-workers (15) observe that closure is a minor part of the wound response. Our own studies, particularly those focusing on temporal aspects of the closure process, indicate that closure is a significant component of the wound response. Time for closure, however, does not appear related to the extent of internal discoloration initiated by wounding (16).

The time required for closure by callus tissue varies with size of the wound, species of the tree, and vigor of the tree. Very small wounds made in

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the spring or summer may close within a few weeks. Callus that attempts to close freeze cracks (frost cracks) may never succeed if winter temperatures continue to open the wound year after year (7). In those cases, a rib of callus alongside the wound is continually enlarging.

Callus cell division, enlargement, and differentiation occur at the same time of the year as vascular cambium cell division, enlargement, and differentiation. In the stems and trunks of most deciduous trees in the temperate zone, these processes occur in May, June, and July. Very little callus growth occurs during the remaining months of the year. If wounds are to close in the shortest possible time, they should be made just prior to spring growth.

Callus growth is regulated by the basipetal flow of products in the stem that were synthesized in the crown (leaves) of the tree, largely carbohydrates and growth regulators. Whenever sap flow is heavy, both callus growth and vascular cambium division are great. Whenever sap flow is light, vascular cell division is reduced and callus production is limited. We have all observed cross sections of tree stems where the annual ring is greatly expanded on one portion of the circle and quite reduced on another. Rapid closure would be expected where the ring is wide and delayed closure where it is narrow.

Carbohydrates produced in the leaves are utilized by stem tissues as they are translocated to the roots. Thus, the annual vascular ring in trees with high crowns and long trunks is much wider in the crown than it is nearer the ground. Greater callus formation around wounds would, therefore, be expected in the top of a tree compared to that at the base of its trunk. In trees with low or large crowns and short trunks, the annual ring is uniformly wide throughout tree height. In suppressed trees, the annual ring narrows rapidly below the crown and may not show any thickening near the base of the stem.

Measuring wounds to determine the extent of annual closure is not always straightforward. One major complicating factor is the dieback that occurs around the wound margin prior to the initiation of callus growth. The amount of dieback varies with tree vigor, season of wounding, wound location, and location on the wound margin. Dieback is more extensive on the top and bottom of wounds than on the sides of wounds. Dieback is more extensive on suppressed trees or trees low in vigor than on rapidly growing trees. Dieback on the stubs of pruned branches can be extensive. Dieback on wounds made in the fall is greater than on those made on the same tree in the spring, summer, or winter. The correct initial wound opening measurement should be made after dieback has ceased but before callus formation has begun.

A complicating factor in comparisons among wound closure studies is the method of measurement. Surface area, length, and width of wound have each been used. In addition, the rate of closure has been expressed per week, per year, and per unit of diameter (or radial) growth. Wound closure studies reported without presenting accompanying growth rate data are, in my opinion, flawed.

Literature Review

Systemic injection or the implantation of chemicals into trees is being actively researched (6). Most studies, however, report the efficacy and phytotoxicity of the chemical rather than the injury from the wound itself. Costonis (3) compared a drill technique with an insertion-tool technique and concluded that the drill technique was less injurious. Stack (17) concluded that injection holes in roots heal faster than those on the stem. Anderson *et al.* (1) found that the average length and volume of discolored wood following water injection was small compared to injection of thiabendazole or its solvent. Perry and Hickman (12) evaluated wound closure on eucalyptus and reported that wounds made in the spring closed more rapidly than those made during late fall and early winter.

Martin and Sydnor (8) compared closure rates of wounds 10 mm in diameter in 12 tree species at two locations. Most wounds closed within 10 to 20 weeks. Green ash had the most rapid wound closure rate; Callery pear had the slowest. Species was more closely correlated with wound closure than was caliper increase. Within a species, the multiple regression coefficient (R^2) of wound closure and caliper increase 0.760.

Illinois Studies

Five studies on wound closure have recently been conducted in Illinois. Three have been published and two are being prepared for publication. All specifically relate to wound closure; none relates to internal wood injury or chemical phytotoxicity. The primary purpose of the studies is to determine the relationship between tree vigor, measured as annual increase in trunk circumference at or near the wound site, and wound closure, measured as annual decrease in wound width. The studies were conducted at the Morton Arboretum near Lisle, Illinois, 25 miles west of Chicago, and at the Illinois Natural History Survey arboretum near Urbana, Illinois.

I. The study published in 1970 (9) used three species (white ash, honeylocust, and pin oak) in 100-tree blocks 5 or 7 meters apart. Average diameters in 1966 were 10.3 cm (oak), 12.3 cm (ash), and 9.0 cm (honeylocust). Several variables were included in the study.

Shape of wounds. Each tree had three wounds: a circle, a square, and an ellipse with pointed ends. All wounds were 50 mm wide and healed at approximately the same rate. The only consistent exception was the square wounds during the first year of treatment. Callus formed first at the corners, with less callusing along the sides.

Facing direction of wounds. Each tree had four pointed elliptical wounds 50 mm wide, one in each of the four cardinal directions. The direction the wound faced had no effect on closure.

Season of wounding. Each tree had four wounds; one made in the spring, another in the summer, another in the fall, and a fourth in winter. Spring wounds healed four times faster than summer wounds during the first season. Dieback was more severe adjacent to summer and fall wounds than winter and spring wounds.

Height of wounds. Each tree had three wounds; one 0.7 m from the ground, one 1.3 m from the ground, and another 2.0 m from the ground. Regardless of height, wounds closed at the same rate.

Branch stub wounds. Six branches were removed from each tree; two with stubs 50 mm long, two with stubs 25 mm long, and two with cuts made through the branch collar almost flush with the stem. Only when the primary cuts were through the branch collar was there consistent, rapid, and regular closure during the 3-year study.

Closure and tree vigor. The width of wound closure was directly correlated with radial tree growth at the wound site. Wounds 50 mm wide closed approximately 2.7 mm for each mm of radial growth on oak, ash, and honeylocust.

II. A second study reported in 1973 (10) was initiated to confirm or refute the hypothesis that wounds on all species of trees close at equal rates based on units of radial growth. Four species of trees were wounded at the Morton Arboretum and four at the Survey arboretum. Each tree had three elliptical wounds; one was 25 mm wide, one was 50 mm wide, and another was 75 mm wide.

Radial growth and wound closure on the ten trees of each species demonstrated biological variability. The lines of regression between closure and radial growth were determined for each species for each size of wound for each of 3 years. In every instance within a species, the slower-growing trees closed wounds more completely than the mean would indicate, and the faster-growing trees closed wounds less completely than the mean would indicate. Within one growing season, large wounds closed more than the medium-sized wounds, which in turn closed more than the small wounds. In the test, the covariance of closure and radial growth was not the same for all species. The amount of healing of soft maple and American elm per unit of radial growth was substantially greater than the amount of other species (white ash, pin oak, tulip tree, and honeylocust). The range of closure for wounds 50 mm wide wounds on all species was from 2.3 to 5.8 mm per mm of radial growth. Tulip tree and pin oak were the fastest growing species, and these two closed wounds in a shorter period of time than the other species. Apparently both species and radial growth influence closure rates.

III. A third study reported in 1983 (11) was initiated to determine if the holes required for injection or implantation of chemicals are injurious to trees, and how rapidly these small wounds close. Wounds were made on four species of trees at the Morton Arboretum and four species at the Survey arboretum. Four whorls of circular wounds or one whorl of elliptical wounds were cut into the trunk at wound widths of 9, 12, 17, and 25 mm. The 25-mm wounds were pointed ellipses; the smaller wounds were cut with a wood bit into the first annual ring of xylem. Each tree had wounds of one size at every 8 cm of tree circumference. Tree diameters at the start of the study averaged from 13.2 to 18.5 cm. The trees were wounded for 4 consecutive years.

Wounded trees grew just as rapidly as untreated trees at each location. The whorls of wounds did not slow growth. Most of the circular wounds closed the same season they were made. The larger the wound, the smaller the percentage that fully closed in one growing season. For any one species, the greater the growth in a particular season, the greater the percentage of circular wounds that fully closed.

Elliptical wounds 25 mm wide required two or more growing seasons to close in almost all instances. The amount of growth required to close wounds of this width varied with species. Oak closed after 7 mm of radial growth, sycamore after 10 mm, ash after 10 mm, tulip tree after 11 mm, and honeylocust after 12 mm. Wounds on the faster-growing trees within a species closed less per unit of radial growth than did those on the slower-growing trees. In slower-growing as compared to faster-growing trees, a larger percentage of the available nutrition apparently was used for wound repair than for radial stem growth.

The area of the tree surface that is wounded during implantation or injection procedures is an extremely small percentage of the total surface area. These results suggest that annual wounding for treatment should not measurably slow tree growth if the chemical itself is not phytotoxic.

IV. The objective of this test (unpublished data) was to clarify some of the ambiguity of earlier studies. Each of 20 trees of ten species were given four elliptical wounds, two 50 mm wide and two 25 mm wide. for each of 4 consecutive years. The amount of closure and the amount of radial growth were measured for 5 years. Correlations were prepared for each year, each wound size, and each species.

A major problem in comparing closure rates among species is to find trees with annual radial growth rings of equal size for all species. A tree or group of trees growing at a rate of 25 mm in diameter per year should close wounds more quickly than a tree or group of trees growing at a rate of 15 mm per year. Preliminary data from this study indicate that species differ in rate of closure. When stems increased 12 mm in diameter, the amount of closure for the ten species on wounds 5 mm wide were as follows: pin oak (26.7 mm), Norway maple (25.6 mm), English elm (25.4 mm), hackberry (23.1 mm), tulip tree (19.3 mm), green ash (19.1 mm), basswood (18.3 mm), sycamore (13.0 mm), honeylocust (11.4 mm), and birch (11.4 mm).

V. In this test (unreported data), I attempted to compare the closure of branch wounds following pruning by two methods: 1) branch removal outside the branch collar as prescribed by Shigo (13) and 2) the conventional cut through the collar but not necessarily flush with the trunk. Four branches were removed from each tree: two with the Shigo method and two with the conventional method. Ten trees of each of three species (pin oak, sugar maple, and sycamore) were pruned. The test was repeated for 3 additional years. Diameter of the branch removed and width of the wood exposed after pruning were recorded, and wound closure and tree trunk growth were measured annually. The trees were 10 to 16 cm dbh in 1983, and trunk diameter growth rate was 12 to 22 mm annually.

The Shigo cut produced a much smaller wound than the conventional cut. Preliminary data indicate that wound size compared to branch size was increased by the Shigo cut by 4 percent in oak, 13 percent in maple, and 9 percent in sycamore. Comparable wound size increase by the conventional cut was 35 percent in oak, 56 percent in maple, and 36 percent in sycamore. Wounds left by the Shigo cut, however, closed much less in the first year than did wounds from the conventional cut. At the end of the first growing season, the width of the wood exposed on the Shigo cuts and the conventional cuts were approximately equal.

Conclusions

These and other data on wound closure indicate the following: 1) wound closure is directly related to tree vigor, i.e., stem diameter increase, but 2) a constant is required in the formula to account for tree condition and location, 3) large wounds close more than small wounds, 4) wounds less than 12 mm in diameter are likely to close in 1 year, and 5) annually inflicted wounds less than 25 mm in diameter are not likely to slow tree growth.

Injection or implantation wounds by themselves are not especially damaging to trees. Trees have physiological functions and morphological structures to repair wounds. The chemicals applied in these wounds are often phytotoxic, resulting in damage more pervasive than the original wound. Girdling of stems is then possible if the injection holes are closely spaced. To establish phytotoxicity, extensive research trials need to be conducted on tree species likely to be injected with chemicals to establish phytotoxicity. Implantation and injection are viable methods of treating trees for control of insects, diseases, suckering, and for growth regulation.

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Section of Botany and Plant Pathology
Illinois Natural History Survey
Champaign, Illinois 61820