23. Watschke, T.L. 1982. The effect of N fertility and mowing on the quality of Kentucky bluegrass previously treated with growth retardants. Agron. Abs. p. 146.

24. Watschke, T.L. 1985. Turfgrass weed control and growth regulation 63–79. Proc. 5th International Turfgrass Res. Conf., Auignon France.

25. Wehner, D.J. 1980. Growth regulation of Kentucky bluegrass and tall fescue. Proc. North East Weed Sci. Soc. 34:382–388.

26. Youngner, V.B., and F.J. Nudge. 1973. Growth retardant effects on various grass tissues and organs. p. 458–462. International E.C. Roberts (ed.) Proc. 2nd International Turfgrass Res. Conf., Madison, WI.

Cambial Peroxidase Enzymes Related to Graft Incompatibility in Red Maple[1]

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Abstract

Two major anodal peroxidase isozyme bands occurred with high frequency (70-80%) in the cambial tissue of red maple (*Acer rubrum* L.) stems and roots. Some red maples, and all silver maples (*A. saccarinum* L.) tested lacked the lower enzyme band. The presence or absence of the lower enzyme band was not related to the geographic origin of the plants. Because of varying degrees of polyploidy in red maples and hybrids between red and silver maples, the staining intensity of the enzyme bands, especially the lower band, varied considerably. Still, bark-ring grafts between 2-banded and 1-banded red maples exhibited incompatibility symptoms similar to other tree combinations with dissimilar cambial peroxidase isozymes. During the extended time period of 3 to 5 years required for complete envelopment of the severed stock stub in budded red maples, zones of poorly lignified cells are formed at the boundary between incompatible stock and scion cambia. After the increased growth of the scion has developed a large crown, various stresses such as wind and freezing temperatures may combine to fracture the graft union along the zone of unlignified cells. Isozyme patterns are given for many red maple cultivars, and most have both A and B bands; some data are provided on isozyme inheritance. Nurserymen may significantly reduce problems of graft compatibility in these cultivars by collecting seed for seedling rootstock production only from parent trees with AB enzyme phenotypes or, for any cultivar, by creating seed orchards that will provide seedlings of the desired enzyme properties.

Index words: *Acer, A. rubrum, A. saccharinum*, budding, lignification, isozymes

Introduction

Research on the variability of cambial isoperoxidase banding patterns in red maple (*Acer rubrum* L.) and silver maple (*A. saccharinum* L.) both preceded and followed our study of such variation throughout the genus *Acer* (6). It was found that there was virtually no variation in major anodal bands among cultivars or origins of *A. platanoides* L. (Norway maple) or *A. saccharum* Marsh. (sugar maple), two widely grown and grafted species that apparently had never exhibited graft incompatibility problems. The enzyme patterns differed between these two species, and were characteristic of the botanical Sections (*A. platanoides*-Section Platanoidea; *A. saccharum*-Section Saccharina) of the genus to which they had been assigned by taxonomists.

Red maple and silver maple are both classified in the same Section (Rubra) and may hybridize readily in the wild and in cultivation (5). However, silver maple consistently lacked a major enzyme band that occurred in most of the red maples, and there had been reports of reduced growth and graft breakage of red maple propagated on silver maple rootstocks. Some red maples also lacked this band, and a number of nurserymen had observed intraspecific graft incompatibilities in red maple.

In 1978, we conducted a survey of nurserymen who propagated or used budded cultivars of red maple. The survey was accomplished with the assistance of Duane F. Jelinek (Administrator) and the membership of the WNGA (Wholesale Nursery Growers of America, Inc.). Of about 20 usable replies, one-half of the respondents reported that they had, at one time or another, experienced a "commercial" failure in cultivar propagaton. However, nearly two-thirds of the growers had received reports of graft failures after the trees had left the propagating nursery. Data on individual cultivar performance varied widely and the cultivar considered most successful by one grower could be among the worst in another nursery. Of the 4 respondents who noted that they had used both red maple and silver maple understocks, only one reported significant problems. The timing of this survey coincided with the change-over to cutting propagation of red maple cultivars, perhaps precipitated by the work of Orton (4). So, there were propagation problems, but they were being overcome. However, the large number of cultivars of red maple and their potentially high graft incompatibility remained an interesting area of research.

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Materials and Methods

Cambial isoperoxidase patterns were determined for various groups of plants: (I) clonally-propagated parent trees and seedling progenies derived from controlled pollination (1939-1940) among red and silver maples in test plantings established by the USDA Forest Service in 1946 in Beltsville, MD; (II) half-sib open-pollinated progenies of red maples from various geographic origins throughout the species' range in plantings of the USDA Agricultural Research Service in Delaware, OH; (III) red maple cultivars rooted from cuttings and supplied by J. Frank Schmidt and sons, Boring, OR; (IV) budded (1979) plants of 'October Glory' and 'Red Sunset' red maples from Schmidt and Princeton Nurseries, Princeton, NJ; (V) open-pollinated seedling progenies from selected trees in the Forest Service Planting; (VI) various selections of Forest Service trees custom-budded by Princeton Nurseries in 1985; and (VII) various small lots of budded 'Red Sunset' from Schmidt in 1982 and 1986. Methods of isoperoxidase analyses were described earlier (6), and utilized starch-gel electrophoresis with 3-amino-9-ethylcarbazole as the peroxidase stain. The faster-moving of the 2 isoperoxidase bands was designated as Band A and the slower as Band B. These bands are illustrated in Figs. 1 and 2.

Reciprocal ring-grafting experiments in 1982 involved seedlings in Group V, cultivar clones in group III, and stump sprouts from felled trees of Group I. The technique of ring-grafting was previously described (5), but fewer grafts were made, all with the bark ring placed in normal cambial orientation.

During the growing seasons of 1986 and 1987, red safranin dye was injected into the stock xylem below the ring-grafts or below the stock-scion union of budded plants in Groups IV and VI. After 3 hours, the injected plants were severed below the point of injection and the bark was peeled to observe dye movement across the zone of union.

Following photography of intact stem segments, the stems were sawed in various ways, the surfaces sanded smooth, and treated with chemicals (iodine, phloroglucinol) to enhance visualization of gross anatomical or biochemical features. Minute wood anatomy was investigated by infiltrating and softening the dry wood tissue with HF, sectioning with a sliding microtome, and staining with safranin-fast green.

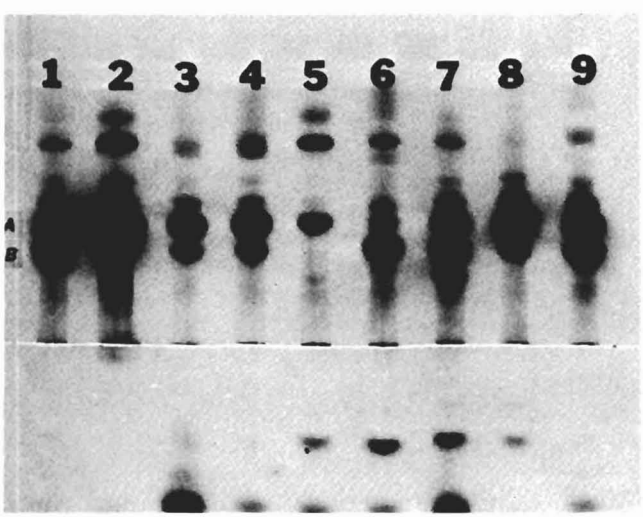

Fig. 1. **Cambial peroxidase banding patterns of red and silver maple cultivars: (1) *A. rubrum* 'Red Sunset', (2) *A. saccarinum* 'Silver Queen', (3) *A. rubrum* 'October Glory', (4) 'Autumn Flame', (5) 'V.J. Drake', (6) 'Scarlet Sentinel', (7) 'Gerling', (8) 'Tilford', and (9) 'Bowhall'.**

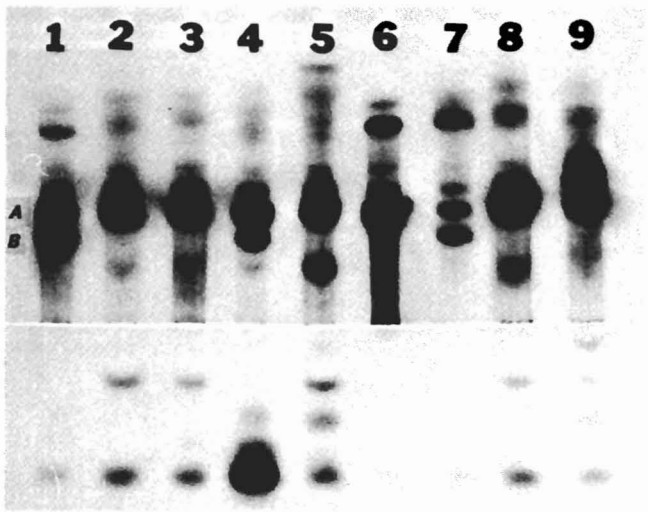

Fig. 2. **Cambial peroxidase banding patterns of red maples used in successful ring-grafts: (1) 'Red Sunset'; (2) 79-24-8, stock for graft in Fig. 3-2; (3) 79-24-9, stock for graft in Fig. 3-1; (4) 'October Glory'; (5) 79-19-12, stock for graft in Fig. 3-3; (6) 79-19-3, ring for graft in Fig. 3-4; (7) 79-19-2, Stock for graft in Fig. 3-4; (8) 79-24-10, ring for graft in Fig. 3-5; (9) 79-24-7, stock for graft in Fig. 3-5.**

Results and Discussion

Isozyme Occurrence. In order to gain some understanding of the frequency and possible inheritance pattern of these enzyme bands, we examined cambia of 225 trees derived from controlled crosses among 9 red maple and 3 silver maples (Group I). Seven of the red maple parents and 1 of the silver maples parents were also available for testing (Table 1).

Two of the silver maple parents, G-201 and G-202, were given (−) designations even though they were not available for examination. None of more than 20 silver maples we had tested possessed band B. The 2 red maples that were not vegetatively propagated, G-65 and G-303, were left as unknowns (Table 1).

Interpretation of the data in Table 1 was hindered by the variation in chromosome numbers in the parents and progenies (5). All of the silver maples were tetraploids with 2n = 52 chromosomes. Some of the red maples, includng G-60, G-61, G-64, and G-70, were octoploids (2n = 104) with normal meiosis. Both G-28 and G-303 were also octoploids, both they exhibited considerable asynapsis at meiosis and could give rise to both diploid and tetraploid pollen grains. Tree G-62 was a septaploid with 2n = 91 chromosome and G-75 was hexaploid with 2n = 78. No cytological data were available for tree G-65.

The staining intensity of band A was nearly always equal to or stronger than band B in the plants examined. Variation in stain intensity of band B suggested a "dosage" effect. If we assume that the enzymes represented by band A and B are true monomeric allozymes, controlled by codominant alleles at the same locus, it is obvious that the frequency of allele "A" is much higher than that of allele "B" in

Table 1. Frequency of maple trees lacking cambial peroxidase band B among progenies of controlled crosses. Phenotype of parents with regard to band B given in parentheses as: (+) – having band B; (−) lacking band B; and (?) – unknown.

Female Parent	Male Parent: Red Maple							Male Parent: Silver Maple	
	G-28(−)	G-60(+)	G-61(+)	G-62(+)	G-65(?)	G-75(+)	G-303(?)	G-58(−)	G-201(−)
Red Maple									
G-64(+)	0/10	0/10	0/10	0/10	0/10	0/10	0/10	—	—
G-70(−)	6/8	1/10	3/10	3/10	6/10	3/10	5/10	10/10	10/10
Silver Maple									
G-58(−)	—	0/5	—	2/10	—	—	—	—	—
G-201(−)	—	—	3/10	—	—	—	—	—	—
G-202(−)	2/2	0/10	3/10	3/10	—	—	2/10	—	—

this population. Only in one seedling was the intensity of band "B" stronger than that of band A. When "scoring" the gels, we could visually designate band B intensity as equal to that of band A, or medium, weak, very weak, or absent in comparison to band A. The "very weak" category was observed least often.

Octoploid red maples in which band B could not be detected might have 8 "A" alleles and no "B' alleles. The trees in which the band intensity appeared equal could have 4 "A" alleles and 4 "B" alleles and various other ratios could explain the lessened intensity of band B. The various frequencies of trees without band B shown in Table 1 could be explained, with one exception, on the basis of 8 "A" : 0 "B" allelic ratio.

From a practical viewpoint, however, the data do show that there is a high probability that all of the progeny derived from intercrossing among red maples having band B will also have band B. The use of silver maples or red maples that lack band B in crossing would result in a varying, but possibly significant, proportion of the progeny that lack band B. Crosses between silver maples and red maples that lacked band B produced only progenies that also lacked this band.

Later analyses of cultivars (Group III) and other rootstocks (Group VII) did show that there also could be variation in the strength of band A. In the cultivar 'Scarlet Sentinel' (Fig. 1), the staining intensity of band A is about one-third of band B. Two individuals with *only* band B were among other rootstock samples that were sacrificed before gel analysis.

Thus, the potential correlation between cambial isoperoxidases and lignification-related graft incompatibility in red maple may not be as clear-cut as found in *Castanea mollissima* Blume (9) or *Quercus rubra* L. (10) in which there were no (or very few) potential gradations of isozyme concentration.

To determine whether there was any correlation between isozymes and geographic origin, we also examined 4 or 5 seedlings each from 20 seedlots from 12 States throughout the natural range of red maple. Overall, 19 of 91 trees (Group II) sampled lacked band B (20.9%). Trees without band B were found in progenies from Alabama, Mississippi, Tennessee, Ohio, Pennsylvania, New Hampshire, Vermont, Wisconsin, and Minnesota. We presumed that the failure to find trees without band B in progenies from Virginia, Georgia, and Maine was merely a sampling problem and believe the data are sufficient to conclude that the lack of band B in red maple was not dependent on the geographic origin of the trees.

Further studies on the isoperoxidase constitution of the seeding understocks of budded cultivars (Group IV) showed that 22 of 52 rootstocks (42.3%) of 'Red Sunset' and 17 of 56 rootstocks (30.4%) of 'October Glory' delivered from commercial nurseries lacked band B. Thus, since both cultivars had both enzyme bands (phenotype AB), there could be a significant amount of potential graft incompatibility and failure among the products of both nurseries.

Isozyme analyses of the own-rooted red maple cultivars in Group III and other cultivars represented by mature plants on the Arboretum grounds showed that all of the following were also AB types: 'Armstrong' 'Autumn Flame', 'Bowhall'; 'Gerling', 'Scarlet Sentinel', 'Schlesingeri', and 'Tilford'. Band B was not found in the red maple cultivar 'V.J. Drake' nor, as expected, in 'Silver Queen' silver maple (Fig. 1). With the exception of 'Autumn Flame', which has a weak band B, all of the other cultivars had a band B intensity level from 50% to 100% as strong as band A.

Early in our work, we had determined that the cambial isoperoxidase patterns of the stems and roots of seedlings, with respect to bands A and B, were identical. This similarity was confirmed on the adventitious roots of the own-rooted cultivars of Group III. Thus, in the absence of sufficient above-ground stock plant tissue for sampling, the roots can be utilized, and if stock and scion differ in isozyme pattern, understock roots can be differentiated from any adventitious roots that might develop when the scion stem had been covered with soil.

Ring-Grafting. Only 9 of 75 ring-grafts were successful, and most failures occurred before the end of the growing season in which they were attempted. The bark rings dried up and fell off the stock plants within a week after the grafting rubbers were removed. This high rate of failure of ring grafts of red maple is not without precedent. In 1954, when I was a graduate student with Dr. Karl Sax and Dr. Scott S. Pauley at Harvard, we attempted several hundred bark inversions on stump sprouts of red maple, with almost total failure. Further, W. Cole (1), in discussion following Sax's paper (4) also reported a high degree of failure in red maple ring grafts. Thair and Steeves (12) made ring grafts with various cambial orientations in many species. They achieved sufficient success to obtain data in apple, *Cornus stolonifera* Michx. (= *C. sericea* L.) *Sorbus aucuparia* L., and *Thuja occidentalis* L. Total failure of ring grafts was noted on *Salix alba* L., *Caragana arborescens* Lam., and *Viburnum trilobum* Marsh., and only limited success was obtained with *Betula pendula* Roth and *Syringa vulgaris* L. The reasons for these failures were not investigated, but,

since most of these studies involved self-grafts, incompatibility was probably not a primary cause.

Samples of successful ring-grafts are shown in Fig. 3. The small numbers and high degree of variability of these grafts make any generalizations difficult. The graft in Fig. 3-3 looks like many similar grafts in chestnut (9) and oak (10). No functional xylem differentiated under the scion bark "patch", and the movement of injected dye solution occurred only in xylem regenerated from the stock in the "seam" area (Fig. 4). Regeneration of tissue from the seam was especially vigorous in the grafts in Figs. 3-1 and 3-2 and had almost totally undergrown and displaced the patch tissue up past the patch mid-point (Fig. 5, left). Injected dye moved upward in this regenerated xylem but was prevented from movement above the patch by the lack of vascular continuity in the still-disrupted xylem near the upper portion of the graft union (Fig. 5, right).

The graft in Fig. 3-4 deserves special mention. Apparently, there was no real "seam" area and regeneration of tissue from the stock, although it did take place, for parts of 2 seasons, was not sufficiently vigorous to displace the "patch" tissue. Thus, the dye moved through the graft zone only in the underlying stock xylem, which was completely enveloped by non-vascularized tissue derived from the donor " patch". Fig. 3-5 is only suggestive of grafting problems that may be encountered when one of the members is an inherently weak wound compartmentalizer.

Bud-Graft Unions. Budding *is* a type of grafting, but there are major differences between budding and certain other types of grafting that may alter the expression of graft-incompatibility symptoms and influence the grafter's interpretation of success and failure.

With any grafting technique involving the complete severance and rejoining of stems of similar diameter (apical grafting (2); cleft, splice, whip and tongue, saddle), a complete graft "interface" is formed at the time of grafting. There is complete cross-sectional contact between stock and scion. When the grafting partners are genetically compatible, a continuous cambium should be differentiated during the latter part of the first growing season or early in the second season and vascular continuity is restored nearly all around the circumference of the union.

For incompatible combinations, this is a "sink or swim" situation and many grafts fail at this point and the scion dies. However, woody plants are capable of adapting to various "insults" (3), and even in incompatible combinations there may be sufficient water transport across the graft interface to allow normal growth of the scion. For instance, we have noted excellent scion growth in the first season following incompatible graft combinations in elm (*Ulmus*), but when the grafting rubbers were removed, the scion fell off. It is possible that water movement occurs across the graft interface when the physical cohesion between the graft partners is strong and the graft zone is well protected from drying out. Elm, among all the genera we have worked with, does produce the most exudate from the end of cut stems.

Fig. 3. Ring-grafted stem sections of red maples grafted July 29, 1982; dye injected and harvested June 20, 1986. Numbers 1 and 2 had AB ('Red Sunset') ring on A stock; number 3 had AB ('October Glory') ring on A stock; number 4 had A ring on AB stock; number 5 had A ring on A stock, but chisel-wounded x-section shows that tree is a weak compartmentalizer and considerable cell necrosis occurred. Both stock trees and donor trees in 1 to 4 were strong compartmentalizers.

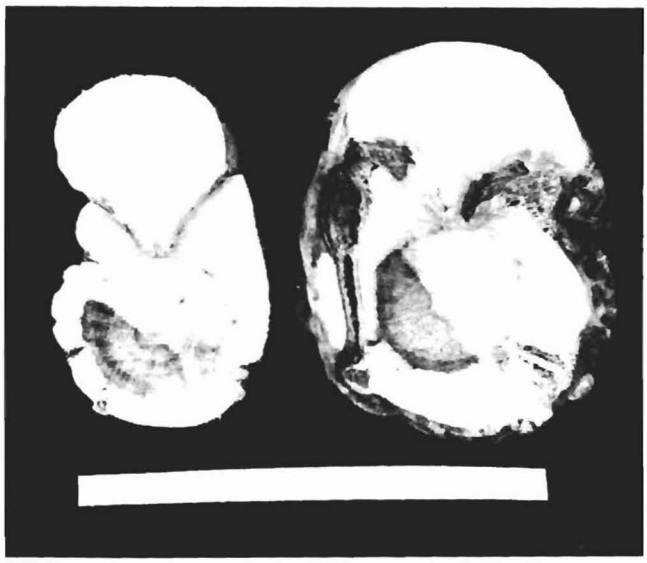

Fig. 4. Cross-sections through middle (left) and top (right) of ring-graft in Fig. 3-3. Only functional xylem was in tissue regenerated from the stock along "seam" (flare in upper portion of section). White bar is 2.6 cm (1 in).

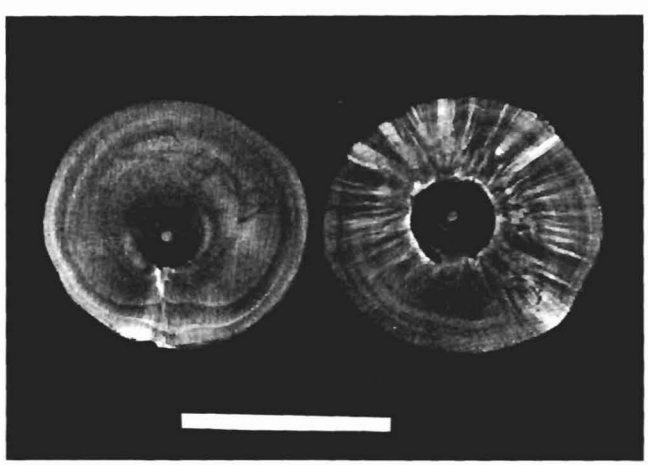

Fig. 5. Cross-sections, stained with phloroglucinol, through middle (left) and top (right) of ring graft in tree pictured in Fig. 3-1. Normal xylem regenerated from stock in "seam" area is above on left and below on right. White bar is 2.6 cm (1 in).

Also, in the absence of a common cambium for stock and scion, irregular instances of "joining" and cell differentiation can result in isolated vascular "bridges" across what might be a genetically incompatible union. Such bridges have often been noted and may be similar to those in the lower portion of the ring-graft in Fig. 3-3. At any rate, there frequently appears to be a sufficient vascular connection between potentially-incompatible budding partners to allow normal growth and development of the scion cultivar for a number of years. But the graft is not complete—yet.

In budding, a complete interface between stock and scion is not formed at the time of budding nor, in fact, for several years. This is a situation that has been given little regard in studies of graft incompatibility. Whether T-budded or chip-budded, the scion occupies only 10% to 25% of the circumference of the stock stem when inserted in August, as in red maples.

Following severance of the top of the stock plant, the stock cambium dies back basipetally all around the circumference of the stock, but for varying distances on the same "side" as the bud insert and on the "side" opposite the bud (Figs. 6 and 7). At the same time the woody stem tissues of the stock also die back, in a wedge-shaped pattern, for varying distances (Figs. 6 and 7). From the illustrations, it might appear that the extent of cambial and stem death is greater in chip-budded unions (Fig. 7) than in those that were T-budded (Fig. 6). However, these two lots of budded 'Red Sunset' maples were grown in different years under different growing conditions and probably should not be compared. There may well be no difference between budding methods in this regard.

We do know that stock dieback is not related to the enzyme phenotype of the stock plant. We do not know whether such dieback is dependent on the genetic potential of the stock plants to compartmentalize wounds (7).

As the budded tree grows and increases in diameter, the stock-scion interface on the scion "side" of the stem, as seen on the bark or wood surface (Fig. 8) or in longitudinal section; resembles a reasonably straight horizontal line from the base of the scion *bud* to the cambium. The interface on the stock "side" is a more or less sloping line that runs from the innermost and highest portion of the dead (severed)

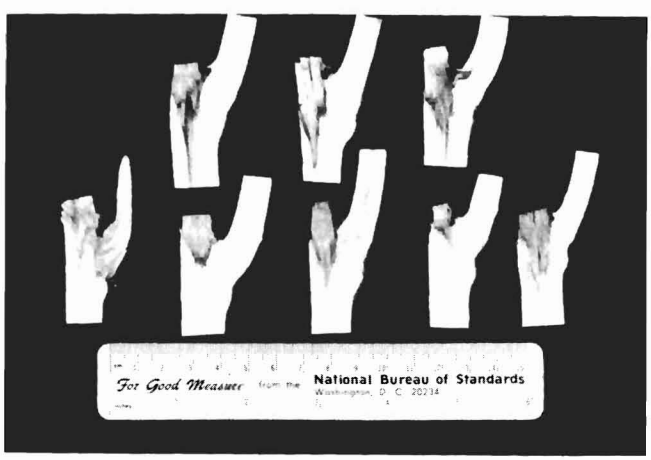

Fig. 6. **Longitudinal median sections through T-budded 'Red Sunset' unions after one season's growth. Upper row on AB rootstocks, lower row on A rootstocks. Lower left scion nearly dead. Stocks severed and plants grown at the National Arboretum.**

Fig. 7. **Longitudinal median sections through chip-budded 'Red Sunset' unions after one season's growth. Upper row on A rootstocks, lower on AB rootstocks. Stocks severed and plants grown at Schmidt's nursery.**

stock plant upward (usually) to the cambium on that side. These two interface lines are connected, as it were, internally, by a vertical void that represents the original cambial zone of the stock plant that died back after the stock was severed.

The scion does not envelop the stock. Cambia of both stock and scion continue to develop actively, and the scion cambium does not intrude upon or displace the stock cambium. In a compatible situation, the cambial regions essentially "merge" into a common cambium in which the components cannot be easily distinguished. In a incompatible situation, the cambia and the cells produced by cambial

Fig. 8. **De-barked graft unions of T-budded (1979) plants of red maple cultivars after 5-years growth under tough field conditions. 'October Glory' (OG) and 'Red Sunset' (RS) both have AB isoperoxidase phenotypes. Left to right: OG-43, RS-18, RS-5, RS-38, OG-38. Rootstocks for all but OG-38 had only isoperoxidase band A. Rootstock for OG-38 was AB, and movement of dye into scion, when injected 17 July 86 below union, occurred only in this plant. Wide, dark, vertical trails (note especially in OG-43 and RS-38) represent tunnels of agromyzid fly larvae (so-called "pith flecks").**

activity remain distinct. The stock cambium, in addition to circumferential growth, also extends acropetally on the side opposite the bud from the point at which the cambium died back after stock severace. Thus, on the side opposite bud insertion the two cambia meet at roughly the level of the dead stock stub.

Illustrations of compatible and incompatible bud-graft unions may make the preceding discussion more intelligible. In Fig. 9 (right), it can be seen that at least 5 years growth of the scion was required before the stock stub was completely covered and stock and scion cambia were totally united. In this compatible combination, the "meeting point" of stock and scion cambia was at roughly the level of the stock stub and when the cambia came in contact functional vascular continuity was restored. In an incompatible bud-graft (Fig. 9 (left)), the contact zone for stock and scion cambia opposite the side of bud insertion is also at the level of the dead stock stub. However, the phloroglucinol stain shows a line of poorly-lignified tissue along the cambial interface from the stub to the bark. A similar line of poorly-lignified cells runs from the point of bud insertion to the bark on the scion side.

It is precisely along this pathway, that true graft failure caused by incompatibility occurs (Fig. 10 (left)). Such failures usually occur only after the stub has been covered up by cambial growth. By this time, the crown of the tree has usually grown large enough that the pressures exerted by strong and shifting winds are transmitted to the areas of non-lignification and limited vascular connections that are perhaps further weakened by cell weakness caused by a freeze-thaw cycle in unlignified cells. Stem breakage on the scion side (Fig. 10 (right)) may be more irregular because of the sporadic and limited vascular links that have maintained water transport to the scion up to the time of graft failure.

Fig. 9. Longitudinal sections through potentially incompatible (left, AB on A) and compatible (right, AB on AB) unions of budded plants of 'October Glory' red maple, lightly stained with phloroglucinol-HCL. Plants budded in 1979, outplanted in 1981, and harvested in 1986. Section on right (compatible) sawn at an angle to show the number of years (6) of diameter growth (seen on right side) required for scion to completely cover the severed stub of the stock. Median section on left (incompatible) shows narrow unstained and unlignified band of xylem horizontally from left side to stub, vertically down along stub, and horizontally to right side. This unlignified zone forms the line of fracture in incompatible grafts.

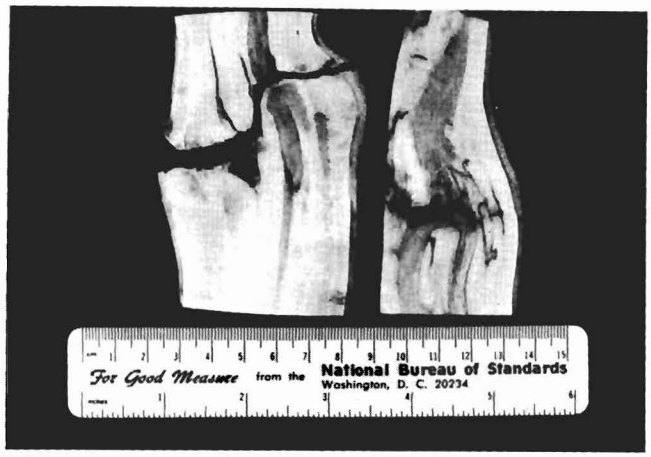

Fig. 10. Longitudinal sections through failed incompatible bud-graft union 5 years after budding. Scion was 'Red Sunset' (AB), stock (A). Section on left shows complete fracture and separation of stock and scion along upper line of unlignified tissue in one-half of stem. Section on right shows incompetely fractured zone along lower unlignified line.

Significance to the Nursery Industry

This research has already had a significant impact on the nursery industry. At the time of our initial studies (1980) on the budded cultivars 'October Glory' and 'Red Sunset' provided by cooperating nurseries, 39 of 108 plants (36%) were potentially incompatible combinations. Our results and hypotheses were shared with these nurserymen and suggestions were made regarding the selection of seedling understocks. As a result, a survey in 1985-86 found only 9% potentially incompatible rootstocks for these cultivars.

Despite the current trend toward the production of red maple cultivars from rooted cuttings, there still may be some advantages now, and in the future, to continued production by budding. We now have the ability to *predict* graft incompatibility, and that problem has been eliminated. The limited data on the occurrence and inheritance of peroxidase isozymes indicate that most trees and most cultivars have both A and B enzyme bands and that most of the seedlings from trees with both bands will possess both bands. In order to insure a continual supply of 2-banded seedling understocks, nurserymen need only develop a "mini-seed orchard" consisting of male (e.g. 'Tilford') and female (e.g. 'October Glory') cultivars or other enzyme-typed plants sufficiently removed from other mature and flowering trees of red maple (or silver maple) to assure interpollination among only the orchard trees. For the production of single (A) - banded seedlings as understocks for 'V.J. Drake' or any other A-type cultivar, a similar scheme could be used.

Literature Cited

1. Cole, W. 1957. *In* Discussion, Proc. Intern. Plant Prop. Soc. 7:154.

2. Garner, R.J. 1979. The Grafter's Handbook (4th Ed.). Oxford Univ. Press, New York.

3. Noel, A.R.A. 1970. The girdled tree. Bot. Rev. 36:162–195.

4. Orton, E.R., Jr. 1978. Single node cuttings: A simple method for the rapid propagation of plants of selected clones of *Acer rubrum* L. The Plant Propagator 24 (3):12–15.

5. Santamour, F.S., Jr. 1965. Cytological studies in red and silver maples and their hybrids. Bull. Torrey Bot. Club 92:127–134.

6. Santamour, F.S., Jr. 1982. Cambial peroxidase isoenzymes in relation to systematics of *Acer*. Bull. Torrey Bot. Club 109:152–161.

7. Santamour, F.S., Jr. 1986. Wound compartmentalization in tree cultivars: Addendum. J. Arboriculture 12:227–232.

8. Santamour, F.S., Jr. 1988. Graft compatibility in woody plants: An expanded perspective. J. Environ. Hort. 6:27–32.

9. Santamour, F.S., Jr. 1988. Graft incompatibility related to cambial peroxidase isozymes in Chinese chestnut. J. Environ. Hort. 6:33–39.

10. Santamour, F.S., Jr. 1988. Cambial peroxidase enzymes related to graft incompatibility in red oak. J. Environ. Hort. 6:87–93.

11. Sax, K. 1957. Dwarf ornamental fruit trees. Proc. Intern. Plant Prop. Soc. 7:146–153.

12. Thair, B.W., and T.A. Steeves. 1976. Response of the vascular cambium to reorientation in patch grafts. Can. J. Bot. 54:361–373.

Preemergent Weed Control in Container-grown Herbaceous Perennials[1]

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Abstract

This study was conducted to evaluate several preemergence herbicides for weed control, effects on plant growth, and phytotoxicity to container-grown herbaceous perennials. Surflan (Oryzalin) was applied at 0, 2.24, 4.48, 6.72 kg ai/ha (0, 2, 4, 6 lb ai/A), Ronstar (Oxadiazon) at 0, 4.48, 8.96, 13.44 kg ai/ha (0, 4, 8, 12 lb ai/A), and Rout (Oxyfluorfen + Oryzalin) at 0, 3.36, 6.72, 10.08 kg ai/ha (0, 3, 6, 9 lb ai/A) to container-grown *Ajuga reptans atropurpurea* L. (carpet bugle), *Campanula garganica major* (Ten.) Fiori (bellflower), and *Liatris spicata* (L.) Willd. (spike gayfeather). Additionally, Devrinol (Napropamide) and Treflan (Trifluralin) were each applied at 0, 4.48, 8.96, 13.44 kg ai/ha (0, 4, 8, 12 lb ai/A) to *Astilbe* × *arendsii* Arends. (false spirea) and *Dicentra spectabilis* (L.) Lem. (bleeding heart). Plants were grown in 2.54 l (#1) containers in a medium of sand, topsoil, and sphagnum peat (1:1:1 by vol). Weed control was acceptable with all herbicides except Surflan at 2.24 kg ai/ha (2 lb ai/A) which did not control shepardspurse. Surflan applied at either 4.48 (4 lb ai/A) or 6.72 kg ai/ha (6 lb ai/A) rate resulted in phytotoxicity of carpet bugle, while the 6.72 kg ai/ha rate (6 lb ai/A) significantly reduced plant growth.

Index Words: herbaceous perennials, herbicides, weed control

Herbicides used in this study: Oxadiazon (Ronstar) 3−{2,4-dichloro-5-(1-methylethoxy)phenyl}-5-(1,1-dimethylethyl)-1,3,4-oxadiazol-2(3H)-one; Oryzalin (Surflan) 3,5-dinitro-N^4,N^4-dipropylsulfanilamide; Oxyfluorfen + Oryzalin (Rout) 2-chloro-1-(3-ethoxy-4-nitrophenoxy)-4(trifluoromethyl) benzene + 3,5-dinitro-N^4,N^4-dipropy sulfanilamide; Napropamide (Devrinol) N,N-diethyl-2-(1-naphthalenyloxy)-propionamide; Trifluralin (Treflan) a,a,a-trifluoro-2,6-dinitro-N,N-dipropyl-p-toluidine

Species used in this study: carpet bugle (*Ajuga reptans atropurpurea*), bellflower (*Campanula garganica major*), spike gayfeather (*Liatris spicata*) false spirea (*Astilbe* × *arendsii*), bleeding heart (*Dicentra spectabilis*)

Introduction

Homeowners are rapidly discovering that herbaceous perennials are very useful in the landscape. This interest has caused a significant increase in production and sales of perennials during the past several years (7). Herbicides are quickly becoming the preferred method of weed control for producers of container-grown landscape plants. Herbicides can reduce costs to 10% hand-weeding (2).

Extensive research has been conducted on tolerance of container-grown woody landscape plants to herbicides (3, 5, 6, 8, 9), but there are only a few herbicides labeled for use with herbaceous perennials. Even among these, researchers have found considerable variation in the response of perennials to preemergence herbicides (1). The objectives of this study were to determine effects of herbicides on several herbaceous plant species and to determine weed control effectiveness.

Materials and Methods

This study was conducted during the growing seasons of 1986 and 1987. Plant material used in 1986 were 5.6 cm (2.2 in) liners of carpet bugle, bellflower, and spike gayfeather. Bareroot false spirea and bleeding heart were used in 1987. Plants were shifted into 2.54 l (#1) containers April 12, 1986 and March 4 and 5, 1987. Growing medium was composed of topsoil, sand, and sphagnum peat (1:1:1 by vol). Plants were topdressed with 15 g per container Sierrablend 17N-2.85P-8.3K (17-6-10) plus micronutrients fertilizer and grown on 60 cm (2 ft) centers.

Approximately 6-8 seeds of each weed species were sown on the container medium surfaces June 2, 1986 and May

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