Temperature and Moisture Effects on Hardening of Apple Roots

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Abstract. Roots of 'Malling (M) 26' and 'Malus robusta (MR) 5' were less hardy than stems in winter; hardened more slowly in fall; and dehardened later in spring. In 1967 roots were harder than in 1963, despite slightly higher soil temperatures. This difference in hardiness was associated with much less rainfall in 1967 leading to a lower level of root hydration. While overall soil temperature-hardiness relationships were unclear, short-term changes in root hardiness were correlated with soil temperature during the preceding week. Hardening in apple roots appeared to be influenced by soil temperature and level of root hydration.

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Cold injury to apple roots can be quite common in colder apple growing regions of the world. Since it is difficult to assess root injury without destroying the tree, winter injury to roots is often noted only when the winter is severe and root injury is fatal or very serious. Little information is available on development and limits of root hardiness because of sampling difficulty, especially in mid-winter when soil is frozen.

Apple roots change appreciably in hardiness during the year. In Missouri Chandler (2) found that roots were as hardy in March as in Jan., and that they were slower to harden in fall and deharden in spring than shoots. In New York Carrick observed that comparable roots that were killed at -8.3°C in Nov. survived -11.7°C in March (1). After April 1 hardiness was slowly lost. In Washington Magness (7) reported a 3.3° increase in root hardiness between Nov. 14 and Dec. 8, and in the Niagara District of Canada Upshall (12) also observed that roots were more tender in Nov. than in mid-winter and that hardiness persisted until late March or early April.

The relationship of stem and root hardiness (if any) has not been established. Translocation of a hardiness promoter between different scions in grafted plants has demonstrated (4, 6), but it is not known if such a promoter influences root hardiness. In Taxus, roots of nongirdled plants increased in hardiness while roots of girdled plants did not (8); but top and root hardiness declined independently of each other in the spring. 'M 26' roots induced earlier hardening and later dehardening in scion cultivars than 'MR 5' roots (14), while scion cultivars appeared to have little or no influence on root hardiness. The ultimate level of stem hardiness was found to be independent of root hardiness or soil...
temp in red-osier dogwood in studies with heated soils.

Soil temp are known to influence root hardiness. Soils are slow to respond to air temp changes. Chandler (2) suggested that this explained why roots were slower to harden and deharden than shoots. Both Magnes (7) and Tumanov (10) have shown that roots uncovered and exposed in the summer became much hardier the subsequent fall and winter than roots left in the soil. Low soil temp were found to be necessary for effective cold acclimation of *Taxus* roots (8).

Soil moisture appears to be important to root hardiness and survival in a variety of ways. Howard (5) and Emerson (3) found greater root injury under dry soil conditions than in moist soils. Excessive irrigation and soil moisture was thought to be the cause of more severe root and crown damage by Magnes (7). Carrick (1) felt that soil moisture content bore no relationship to injury of apple roots, but that roots were more easily injured when they were allowed to absorb water. Roots dried until 5% of their total moisture was removed sustained less freezing injury than turgid roots (9).

*Methods.* 'Delicious', 'Haralson', and 'Columbia Crab' apple scions were budded in 1965 to 'M 26' and 'MR 5' clonal rootstocks. In addition, each of these stock-scion combinations was compared to the unbudded rootstock. Previous hardiness determinations on this material showed that the scion cultivar had no effect on rootstock hardiness (14). Hardy scion cultivars did not appear to translocate a hardiness promotor across the graft union to roots as has been previously shown in grafted scions of dogwood (4) and split plants of apple (6).

The techniques for hardiness evaluation following controlled freezing have been previously described (14). Root hardiness determinations of 'M 26' and 'MR 5' were made at weekly intervals in the fall of 1967 starting Nov. 1 and continuing until the soil was frozen on Dec. 19. In 1968 root hardiness determinations were made 3 times in the fall. Root moisture content was determined at each hardiness sampling date.

Soil temp were continuously recorded at a 15 cm depth. Precipitation data were taken from U. S. Weather Bureau Summaries (11) from the nearby Minneapolis-St. Paul airport.

*Results.* Roots were found to be capable of hardening and dehardening (Fig. 1). During the winter of 1967-68 all rootstock combinations increased an average of 3.3°C in hardiness between Nov. 7 and Dec. 5 and 'MR 5' was 2.2°C harder than 'M 26'. In the spring 'MR 5' roots lost their hardiness faster than 'M 26' roots. Both rootstocks, while still relatively hardy on April 22, rapidly lost their hardiness by May 28. The development of hardiness was somewhat similar in 1968-69 except that 'M 26' and 'MR 5' were equally hardy in the fall and the roots were between 3.3°C and 5.6°C less hardy than in 1967-68. By April there was no difference.

Stem and root hardiness patterns were examined to determine similarities or differences (Fig. 1). Stems were always more hardy than roots and stems hardened and dehardened faster and to a greater extent than roots. Stems continued to increase rapidly in hardiness in Oct. and early Nov. while the root hardiness of 'M 26' remained about the same or increased slightly (Fig. 1A, C, D). In the case of 'Haralson/M 26' (Fig. 1B) root hardiness

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*Fig. 1.* Changes in stem ('Delicious' and 'Haralson') and root ('M 26' and 'MR 5') killing temp in 1967-68 and 1968-69.
decreased as shoot hardness increased. In 1968-69 no correlation was found between the patterns of root and shoot hardness, while in 1967-68 the patterns of hardening were correlated at the 5% level of significance in 3 of the 4 rootstock combinations (‘Delicious/M 26’ showing no correlation). While there are gross similarities in the hardness patterns of apple roots and shoots it seems likely that each develops hardness independently of the other. More frequent evaluations might establish more clearly the relationship between root and shoot hardness patterns.

Changes in root hardness appeared to be related to soil temp. Weekly changes in root hardness followed soil temp changes rather closely (Fig. 2). Both soil temp and root hardness declined about 3.3°C during the week of Nov. 1, leveled off between Nov. 7 and Nov. 28, declined during the week of Nov. 28 and increased slightly during the week of Dec. 5. Correlation coefficients between hardness of 1- and 2-year old ‘MR 5’ roots and soil temp were .91 and .92 (significant at the 1% level) and .77 and .79 for ‘M 26’ (significant at the 5% level). Soil temp seems to be important in the development of root hardness. It is interesting to speculate how much roots harden in the soil in mid-winter in response to low soil temp. Due to frozen soil, digging and obtaining root samples for accurate laboratory root hardness evaluation is difficult in mid-winter. Previous hardness comparisons of different rootstock clones (13) revealed that roots of ‘M 26’ and ‘MR 5’ survived a brief exposure of -17.8°C in the soil. ‘MR 5’ roots survived -15.0°C in controlled laboratory tests on Dec. 5, 1967 (Fig. 2), before the coldest winter soil temp occurred.

Comparison of the fall root hardness data for the 2 years illustrates that roots were considerably more hardy in 1967 than in 1968 even though soil temp from Sept. to Dec. were actually slightly warmer in 1967 (Table 1). Since the roots were sampled from the same area, explanation for this apparent inconsistency may be due to soil moisture and root hydration differences between the 2 years. Precipitation during 1967 was 8.59 cm below normal during the Sept. to Dec. period while in 1968 precipitation was 20.96 cm above normal (Table 1). This difference was reflected in root moisture content which was from 3 to 4% lower in 1967 than in 1968 (Table 2). The observation that roots were harder and less hydrated in 1967 generally agrees with other workers observations that excessive irrigation, excessive precipitation, and high root moisture content contribute to winter root injury (1, 7, 9).

<table>
<thead>
<tr>
<th>Month</th>
<th>Precipitation (cm)</th>
<th>Avg soil temp (C°)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>1967</td>
<td>1968</td>
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<tr>
<td>Sept.</td>
<td>1.60</td>
<td>15.65</td>
</tr>
<tr>
<td>Oct.</td>
<td>4.39</td>
<td>14.27</td>
</tr>
<tr>
<td>Nov.</td>
<td>0.23</td>
<td>1.37</td>
</tr>
<tr>
<td>Dec.</td>
<td>1.14</td>
<td>5.61</td>
</tr>
<tr>
<td>Total</td>
<td>7.36</td>
<td>36.90</td>
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It seems likely that both soil temp and soil moisture play important roles in the development of root hardness in apple.

**Table 1. Precipitation and average soil temp from Sept. to Dec., 1967 and 1968.**

<table>
<thead>
<tr>
<th>Rootstock</th>
<th>1-year-old roots</th>
<th>2-year-old roots</th>
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<tbody>
<tr>
<td>M 26</td>
<td>50.6</td>
<td>54.9</td>
</tr>
<tr>
<td>MR 5</td>
<td>50.6</td>
<td>54.9</td>
</tr>
<tr>
<td>Avg</td>
<td>50.6</td>
<td>54.9</td>
</tr>
</tbody>
</table>

**Table 2. Average root hydration levels (% moisture) in 1- and 2-year-old roots of ‘M 26’ and ‘MR 5’ rootstocks during Sept., to Dec., 1967 and 1968.**

**Fig. 2. Changes in ‘M 26’ and ‘MR 5’ root hardness and average weekly soil temps in the fall of 1967.**

**Literature Cited**