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Effect of Dwarfing Rootstocks on Low Temperature Tolerance of 'Golden Delicious' Apple Trees During Winter 2008-2009

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Abstract

Winter injury can significantly reduce apple production, particularly in areas subjected to dramatic freeze-thaw cycles. The responses of 'Golden Delicious' apple trees on 11 rootstocks, during freeze-thaw cycling that occurred during the winter of 2008-2009 in Georgia, were investigated in an orchard trial of apple [*Malus* × *sylvestris* (L.) var. *domestica* (Borkh.) Mansf.] dwarf rootstocks that had been established at the Georgia Mountain Research and Education Center in Blairsville, GA in 2003 with the Gibson strain of 'Golden Delicious' as the scion. It was one location of the larger 2003 NC-140 Dwarf Apple Rootstock Trial. The four rootstocks Malling 26 EMLA (M.26 EMLA), Budagovski 9 (B.9), M.9 Pajam 2, and M.9 NAKBT337 (M.9 T337) were included as industry standards. The remaining seven rootstocks in the planting were B.62396, CG.3041 [Geneva®41], CG.5935 [Geneva®935], G.16, J-T-EH, Pi Au56-83 and Pi Au51-4. Vertical splitting of the bark on the lower trunk was observed in spring 2009 after a series of freeze-thaw cycles during winter 2008-2009. There were significant rootstock effects on the incidence and severity of visible trunk injury, tree vigor during 2009 and yield in 2008 and 2009. G.16 and B.9 had a lower incidence of visible trunk injury compared to M.26 and M.9 Pajam 2. Visible trunk injury was more severe on M.9 Pajam 2 and M.9 T337 than CG.5935, G.16, and Pi Au 51-4. Surviving tree yields in 2009, expressed as a percentage of yield in the previous year (relative yield), ranged from 18% (Pi Au 56-83) to 92% (G.16). The only rootstocks to yield greater than 50% of the previous year's yield in 2009 were B.62396 (60%), J-T-EH (63%), B.9 (69%), and G.16 (92%). Tree survival was lowest in M.26 (13%) and M.9 Pajam 2 (12%) and highest in G.16 (100%).

Winter injury can limit apple production in many regions of the world. Injury may occur if trees have not become acclimated to low temperatures or as the result of premature de-hardening or de-acclimation in response to a warm period followed by freezing temperatures (i.e., freeze-thaw cycles). Apple rootstocks differ in their ability to withstand cold temperature treatments, M.9 demonstrating poor survival and regrowth compared to M.26 (6). Freeze-thaw cycles are more detrimental to apple rootstock viability than periods of constant freezing (7). De-acclimation is less likely in continental climates, but may occur relatively frequently in areas where freeze-thaw cycles can be dramatic such as the southeastern United States.

Apple rootstocks can differ in their rate of cold acclimation in the fall and the rootstock may also influence the cold hardiness of the associated scion (2). Induction of cold hardiness was reported to be slow in M.26 and MM.106, but these rootstocks retained their low temperature resistance later in the spring (11). Apple cultivars also differ in their winter hardiness, 'Golden Delicious' being considered as a winter tender cultivar (8).

This report describes the response of 'Golden Delicious' apple trees on 11 different rootstocks to a series of freeze-thaw cycles that occurred during winter 2008-2009 in the 2003 NC-140 Dwarf Apple Rootstock Trial located in northeast Georgia (5).

Materials and Methods

'Golden Delicious' (Gibson strain) apple trees on 11 dwarfing rootstocks were planted at the Georgia Mountain Research and Education Center in Blairsville, GA in spring 2003 as one of 12 locations of the 2003 NC-140

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Dwarf Apple Rootstock Trial (5). The trees were propagated at Treco Nursery, Woodburn, OR, and trained to the vertical axe system. The experimental design was a generalized randomized complete block design with four blocks and two trees of each rootstock randomly assigned within each block to provide eight trees per rootstock. Performance of the rootstocks in this planting during its initial five years to 2007 has been previously reported (5). Trunk cross-sectional area (TCA) was calculated from trunk circumference measurements taken each fall. All fruit were counted and weighed during harvest each year. The trees at this location cropped lightly in 2007 as a result of a freeze during bloom (April 15) in that year. However, in 2008 all the trees had a "snowball" bloom and produced excellent commercial crop loads after hand thinning most fruiting spurs to a single fruit but removing all the fruit from some spurs so that remaining fruit were spaced 20-25 cm apart. Neither chemical thinners nor return bloom sprays were used in 2008. All trees produced adequate bloom for a commercial crop load in 2009.

In response to a series of freeze-thaw cycles during winter 2008-2009 the trees suffered varying degrees of trunk splitting. The severity of splitting was rated in spring 2009 using a four point system where 0 = no trunk splitting; 1 = slight damage (a single split shorter than 10 cm in length); 2 = moderate damage (single split 10-20 cm in length); 3 = severe damage (one or more splits >20 cm in length). Tree vigor was rated by the same individuals at bloom (May 14) and at harvest (Aug. 25) in 2009 using a four point rating system where 0 = dead; 1 = weak shoot growth and yellow leaves; 2 = slight leaf yellowing but good shoot growth; 3 = good shoot growth and no leaf yellowing. Yield (kg/tree) was recorded for 2008 and 2009 and yield efficiency and crop density in 2008 were calculated by dividing the annual yield and fruit number, respectively, by TCA in 2008. In order to investigate the yield response to freeze injury independently of an effect of rootstock on yield, the 2009 yield was also expressed as relative yield (percent of the yield in the previous, normal cropping year). The number of surviving trees was recorded at the end of the 2010 season and survival was calculated as the percent of trees that were alive at the end of 2007. Chilling unit accumulation during winter 2008-2009 was calculated using a model developed for apples grown under the wide range of temperatures and elevations typical of the southeastern United States (10). Briefly, compared to the Utah model (9), it uses a broader range of effective temperatures and incorporates a greater negative effect when temperatures exceed 21°C.

Statistical analyses were performed with the SAS Mixed and Glimmix Procedures (SAS Institute, Cary, N.C.) where block was specified as a random effect and rootstock as a fixed effect in the model. Adjusted least squares means of response variables were compared with Tukey's test using an estimated error rate of 0.1. Tree survival data were analyzed using a logit link function in the generalized linear mixed model analysis. Tree survival data for G.16 were not included in the model since there was no variation for this rootstock (100% survival). Vigor rating data were analyzed using a cumulative probit link function in the generalized linear mixed model procedure.

Results and Discussion

Winter temperatures in 2008-2009. Beginning in mid-December 2008, several freeze-thaw cycles occurred at the Georgia Mountain Research and Education Center in Blairsville, GA (Fig. 1). The most severe of these cycles occurred between 1 Jan. and 16 Jan. when daily minimum temperatures rose from -9°C to 12°C for several days before falling rapidly to -16°C. At the time of the low temperature extreme on 16 Jan., 960 hr of chill units had accumulated according to the model developed by Shaltout and Unrath (10). Using this method for calculating chilling, 'Golden Delicious' was found to require 1050 h of chill units (3). Thus, the low temperature extreme during winter 2008-2009 occurred just before

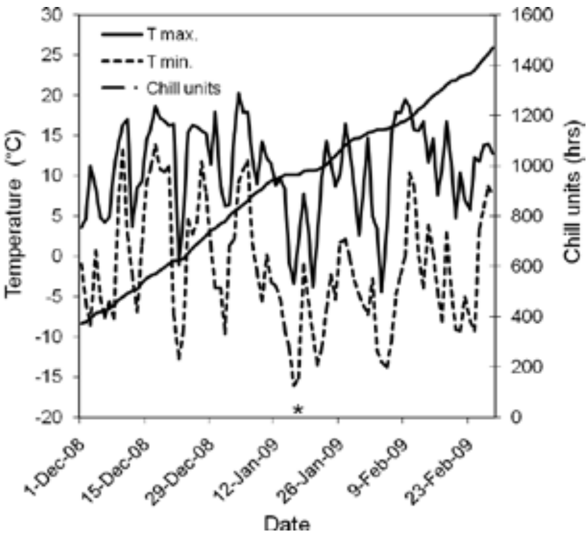

Fig. 1. Daily maximum and minimum temperatures and accumulated chill units at the Georgia Mountain Research and Education Center in Blairsville, GA during December 2008 and February 2009. Chill units were calculated according to the method of Shaltout and Unrath (10). Asterisk denotes most likely injury event (-16.1°C on Jan. 16).

the chilling requirement for the cultivar was met, assuming that there was no effect of rootstock on induction of cold hardiness in the previous fall. The visible injury to the trunks of many trees in the planting that was observed in spring 2009 is believed to have occurred on 16 Jan., 2009 (Mr. Joe Garner, superintendent at the Georgia Mountain Research and Extension Center, pers. comm.).

Visible trunk injury. Visible trunk injury was observed in spring 2009 as vertical splitting of the bark. The trees had been painted with white latex paint in fall of 2008 between the soil line and a point 20 cm above the graft union to protect the trunks against southwest injury. Bark splitting was typically centered immediately above the painted area and extended downwards into the painted area and upwards into the area where the lower scaffold limbs originated from the trunk (Fig. 2). There was a significant effect of rootstock on both the incidence and the severity of visible trunk injury observed in spring 2009 (Table 1). G.16, and B.9 had the lowest incidence of visible trunk injury (≤28%) whereas M.26, and M.9 Pajam 2 had the highest incidence of visible trunk injury (100%). However, statistical differences reflect the high variability within each rootstock. The severity ratings of visible trunk injury were generally related to the incidence: rootstocks with a high incidence of injury also had a high severity rating. Since the injury presumably occurred just before the chilling requirement for this cultivar was met, it is speculated that rootstocks with a lower incidence of visible trunk injury in spring 2009 (B.9, G.16, Pi Au 56-83 and Pi Au 51-4) may not have de-acclimated in response to the freeze-thaw cycles to the same extent compared to those with a higher incidence of injury (B.62396, M.26, M.9 Pajam 2 and M.9T337).

Tree vigor. The proportion of trees with normal vigor on 14 May, 2009 was highest for Pi Au 51-4 (1.0), G.16 (0.97) and CG.5935 (0.88) and lowest for M.9 Pajam 2 (0.20), B.9 (0.23) and M26 (0.25) (Table 1). The proportion of trees with normal vigor generally declined during 2009 for all rootstocks except G.16, B.9, and J-T-EH. Thus, although Pi Au 51-4 and Pi Au 56-83 were among the

Fig. 2. Visible trunk injury to trunks of 'Golden Delicious' apple trees after repeated freeze/thaw cycles during winter 2008-2009. Photograph was taken on March 5, 2009.

Table 1. Effects of rootstock on the incidence and severity of visible trunk injury, estimated probability of the scion in each vigor level at two dates in 2009, and on tree survival in 2010, following freeze-thaw cycing in January 2008.

Stock	Trunk injury		Vigor rating[x]								Tree survival[w]
	Incidence (%)	Severity[y]	14 May, 2009 (Proportion of population)				25 August, 2009 (Proportion of population)				(%)
			0	1	2	3	0	1	2	3	
G.16	25 a[z]	0.5 de	0.00	0.03	0.00	0.97	0.00	0.00	0.00	1.00	100
B.9	28 ab	0.9 bcde	0.00	0.38	0.39	0.23	0.00	0.31	0.00	0.69	31
Pi Au 51-4	33 abc	0.3 de	0.00	0.00	0.00	1.00	0.00	0.11	0.43	0.46	69
Pi Au 56-83	38 abc	0.6 bcde	0.00	0.00	0.33	0.67	0.00	0.19	0.48	0.33	63
CG.5935	50 abc	0.5 de	0.00	0.00	0.12	0.88	0.00	0.00	0.34	0.66	75
CG.3041	57 abc	1.1 abcde	0.00	0.00	0.37	0.63	0.00	0.08	0.39	0.53	42
J-T-EH	63 abc	1.5 abcde	0.00	0.28	0.41	0.31	0.00	0.14	0.46	0.40	63
M.9T337	84 abc	2.3 ab	0.00	0.22	0.39	0.39	0.00	0.48	0.42	0.10	31
B.62396	86 abc	2.1 abcd	0.02	0.00	0.69	0.29	0.03	0.20	0.49	0.28	50
M.26	100 c	2.3 abc	0.00	0.33	0.40	0.25	0.31	0.42	0.24	0.03	13
M.9 Pajam 2	100 c	2.6 a	0.00	0.41.	0.39	0.20	0.16	0.38	0.38	0.07	12
P-value	0.003	<0.0001	0.07[v]				0.02[v]				0.27

[z] Least squares means within columns were compared using Tukey's test at the 10% level of significance.
[y] Severity rating: 0, no visible trunk damage; 1, slight damage; 2, moderate damage; 3, severe damage.
[x] Tree vigor rating in 2009: 0, dead; 1, low vigor and yellow leaves; 2, normal vigor but slight yellowing of leaves; 3, normal vigor and leaf color. Vigor rating data were analyzed using a cumulative probit link function in the SAS Glimmix procedure.
[w] Tree survival was recorded at the end of the 2010 growing season. Survival data were analyzed using a logit link function in the SAS Glimmix procedure. Data for G.16 were not included in the model since there was no variation for this rootstock (100% survival).
[v] Type III test of fixed effects due to rootstock (Pr > F).

rootstocks with the lowest incidence of visible trunk injury and severity, the scions on these rootstocks generally declined in vigor 2009, indicating that trees on these rootstocks may have suffered injury to the vascular system that was not expressed as visible trunk splitting. In contrast, while 25% of the trees on G.16 exhibited some visible trunk injury in spring 2009, the trees on this rootstock exhibited normal vigor on 25 Aug., and 100% survival in 2010, indicating that the trees recovered from any trunk injury that had occurred.

Yield, yield efficiency, crop density and relative yield. Fruit yield per tree in 2008 was the highest since the trees were planted in 2003, and in fact was higher than the cumulative

Table 2. Effect of rootstock on yield (kg) of surviving 'Golden Delicious' trees in 2008 and 2009, and 2009 yield expressed as a percent of 2008 yield (relative yield) after a winter freeze-thaw event in Jan. 2008[z].

Stock	Yield (kg)		2008 Yield efficiency	2008 Crop density	Relative yield
	2008	2009	(kg.cm^{-2})	(fruit no.cm^{-2})	(2009 vs. 2008, %)
G.16	26.6 cde	26.6 a	0.74 bc	6.3 ab	92 a
B.9	13.4 e	9.9 bcd	0.81 abc	6.3 ab	69 ab
Pi Au 51-4	59.4 a	20.4 ab	0.74 bc	5.1 ab	34 bcde
Pi Au 56-83	51.6 ab	9.0 bcd	0.71 c	5.2 ab	18 e
CG.5935	42.8 abc	13.0 bcd	1.12 a	8.9 c	32 bcde
CG.3041	28.4 cde	6.4 d	1.05 ab	8.1 bc	25 cde
J-T-EH	31.9 cd	17.3 abc	0.90 abc	6.6 b	63 abc
M.9T337	18.7 de	8.5 bcd	0.90 abc	6.3 ab	45 bcde
B.62396	28.4 cde	14.1 bcd	0.75 bc	6.2 ab	60 abcd
M.26	21.8 de	8.6 bcd	0.57 c	4.1 a	48 abcde
M.9 Pajam 2	18.6 de	6.4 d	0.70 c	5.7 ab	29 bcde
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

[z] Least squares means within columns were compared using Tukey's test at the 10% level of significance.

yields to 2007 (5). The high yields in 2008 followed light crops in 2007 due to a spring freeze in that year and a snowball bloom in spring 2008. Lowest yields in 2008 were recorded for trees on B.9, consistent with previously published yield data from this study (5). Whereas it had previously been reported that CG.5935 produced the highest cumulative yields in this group of rootstocks, PiAu 51-4 and Pi Au 56-83 generally produced the highest yields in 2008, although the yields on these rootstocks in 2008 were not statistically different. However, relative yields on these two rootstocks declined in the following year, and the 2009 yield was only 18% (Pi Au 56-83) or 34% (Pi Au 51-4) of the yield in the previous year (Table 2). Crop density values in 2008 were within the normally acceptable range for apple (4). Trees on CG.5935 had higher crop density values compared to all other rootstocks except CG.3041. The decline in yields on Pi Au 51-4 and Pi Au 56-83 rootstocks between 2008 and 2009 is probably attributable to a combination of winter injury and a biennial bearing trend. These two rootstocks produced the most vigorous trees, as determined by TCA, tree height, and canopy spread measurements (5). Because of the excessive vigor imparted by these two rootstocks, the trees are more sensitive to an imbalance between vigor and fruiting, and this imbalance may trigger biennial bearing (1).

The yield efficiency of trees on CG.5935 in 2008 was significantly higher than many of the other rootstocks, including Pi Au 51-4, Pi Au 56-83, B.62396, G.16, M.26, and M.9 Pajam 2 (Table 2). In fact, the yield efficiency of CG.5935 in 2008 (1.12 kg·cm^{-2}) was higher than the cumulative yield efficiency of this rootstock during the first five years after planting at this location (5). The productivity of CG.5935 in 2008 is consistent with previous research showing that this rootstock had higher yield efficiency than M.26 EMLA and M.9 NAKBT337 (5).

Tree yields in 2009 were expressed as a

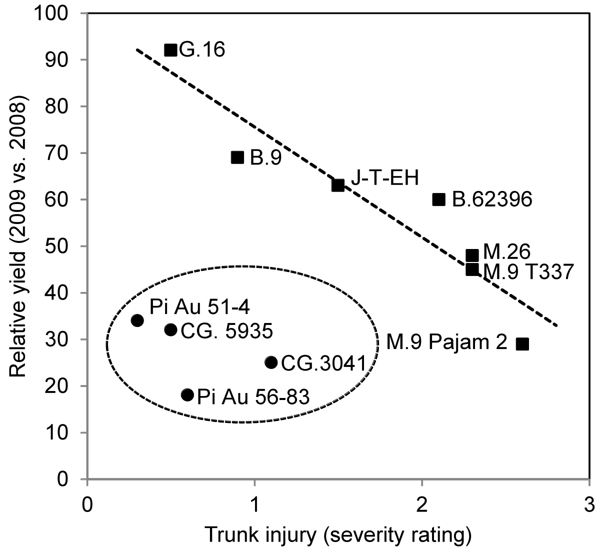

Fig. 3. Relationship between trunk injury (severity rating; 0 = no injury, 3 = severe injury) in 2009 and relative yield in 2009 (yield in 2009 expressed as a percent of yield in 2008) of 'Golden Delicious' as influenced by rootstock. Linear relationship is shown for seven of the eleven rootstocks in the study (relative yield = -23.6 (trunk injury severity) + 99.2; R^2=0.88).

percent of yields in the previous "normal" cropping year in order to investigate the cropping response of the different rootstocks to winter injury independently of any direct effect of rootstock on yield. Rootstock had a significant effect on tree yields in 2009 expressed as a percent of yield in the previous year. Trees on G.16, which had the lowest incidence of trunk injury and the highest proportion of trees with normal vigor, had significantly higher relative yields (92% of the previous years yield) than trees on M.9T337 (45%), Pi Au 51-4 (34%), CG.5935 (32%), M.9 Pajam 2 (29%), CG.3041 (25%) and Pi Au 56-83 (18%). There was a negative linear relationship between trunk injury and relative yield for seven of the eleven rootstocks (Fig. 3). However, a group of four rootstocks (Pi Au 51-4, Pi-Au 56-83, CG.5935 and CG.3041) had relatively low trunk injury severity ratings but also produced low relative yields in 2009. Of these four, Pi Au 51-4 and Pi Au 56-83 produced very high yields in 2008 but also exhibited a slight reduction in vigor during 2009 (Table 1). Thus the low relative yield of Pi Au 51-4 and Pi Au 56-83 may have been due to a combination of a biennial bearing pattern and slight damage to the vascular system resulting from the freeze-thaw cycles in January 2008. CG. 5935 and CG. 3041 produced the highest yield efficiencies in 2008 but also had high vigor ratings in 2009, indicating that the low relative yields of these two rootstocks was likely due to a biennial bearing trend alone.

Tree survival. Although there were no statistically significant effects of rootstock on tree survival, there were some trends in the survival data. Survival was lowest for M.9 Pajam 2 (12%) and M.26 (13%) and highest for G.16 (100%). It is interesting to note that while the incidence and severity of winter injury were relatively low on B.9, trees on this rootstock exhibited low vigor during 2009 and a relatively low survival rate in 2010 (31%). These responses indicate that while B.9 did not show obvious signs of trunk injury in spring 2008 the freeze thaw cycles during the previous winter may have resulted in damage the vascular system, resulting in death of almost two-thirds of the trees.

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