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A Comparison of Root Distribution Patterns Among *Prunus* Rootstocks

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Abstract

Root distribution was compared among *Prunus* rootstocks budded to 'Montmorency' tart cherry (*Prunus cerasus* L.) and 'Redhaven' peach (*Prunus persica* [L.] Batsch) and grown at the Kaysville, Utah location of the multi-site NC-140 Regional Rootstock Research Project. Sampling was carried out on replicate trees with the rootstocks selected based on industry importance and to represent a wide range of tree sizes. Ten-year-old cherry trees on Mahaleb, Gisela® 5, Gisela® 6 and Weiroot 158 rootstocks, and 5-year-old peach trees on Bailey, Cadaman®, Controller 5, Krymsk® 1 and Lovell rootstocks were examined. Root distribution was determined using a soil core sampling technique. Tree roots were separated from the soil cores, assigned to one of three size classes, dried and weighed. Data were analyzed by standard analysis of variance to determine main effects and interactions of rootstock, sampling depth and location. Total root biomass distribution differed significantly among peach but not cherry rootstocks. However, differences in root mass were noted at the different sampling locations around the tree and depths in the soil profile. Most roots were located within the tree row and distribution of roots perpendicular to the tree row were primarily located within the herbicide strip. The degree of lateral root distribution of the five peach rootstocks was not proportional to trunk diameter or tree biomass. These results indicate that a relatively simple soil core sampling technique is sufficient to detect root distribution differences among rootstock cultivars.

The efficiency of tree fruit production is enhanced by the use of high-density plantings of smaller trees. Central to this approach is the use of rootstocks that impart both size control and precocity, in addition to soil-site adaptation and disease and pest resistance. Observing the effects of the rootstock cultivar on the growth of aerial portions of the tree is relatively simple. However, these observations provide no information on the differences among rootstock cultivars in root growth pattern, or how this pattern might affect the adaptability of a rootstock to different growing conditions. Visualizing and understanding root growth and distribution has long been recognized as one of the more challenging and laborious aspects of understanding plant growth and development, particularly in large perennial plants such as fruit trees.

A review of root growth studies in fruit trees provides five general approaches, including: 1) whole tree excavation, 2) various root sampling methods, 3) observation windows, 4) root activity measurements, 5) and indirect methods such as measuring tree removal force or making assumptions about root to shoot ratio (1). These various methods have been used to study the effects of orchard management practices on root growth and distribution (7, 9, 11, 12, 14), but not to compare rootstocks. One sampling method involves collecting a large number of soil cores in an array around the plant to accurately determine root distribution (2). Drost and Wilson (5) reported that a more limited soil core array could accurately detect gross differences in root distribution of a perennial herbaceous crop. Our objective was to determine whether this simplified soil core sampling technique could be used to document differences in root distribution among *Prunus* rootstock cultivars.

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Materials and Methods

Plant material. As part of the NC-140 Regional Rootstock Research Project (www.nc140.org), replicated tart cherry and peach rootstock trials were established at the Utah Agricultural Experiment Station Kaysville Research Farm in Kaysville, Utah, on a Kidman fine sandy loam soil (coarse loamy, mixed mesic Calcic Haploxerolls). The Kidman series is characterized as a well-drained, fine sandy loam to a depth of 2.0 m and is well suited for tree fruit production.

Orchards were established with full-coverage Nelson R-10 microsprinklers (Nelson Irrigation Corp., Walla Walla, WA, USA) positioned midway between trees within the tree row. These provided overlapping coverage in both the tree row and alleyways, with an approximate application rate of 5 mm/hour. Irrigation was supplied at 50 mm per week from June to August, and approximately 25 mm per week in September. These irrigation levels were sufficient to meet evapotranspirational demand of the crop. A 1.5 m weed-free herbicide strip was maintained under the trees, with the alleyways planted to a dwarf cultivar of tall fescue (*Festuca arundinacea* Schreb. 'Bonzai').

Cherry study. The tart cherry cultivar 'Montmorency' (*Prunus cerasus* L. 'Montmorency') budded to 13 rootstock cultivars and selections was planted at the Kaysville research farm in 1998. Eight replicate single-tree plots of each rootstock were established in a randomized complete block design at 4.5 m in-row and 6.1 m between-row spacing. Trees were trained to a modified central leader in keeping with NC-140 protocols (www.nc140.org). In fall 2008, a subset of four rootstocks (Mahaleb, Gisela® 5, Gisela® 6, and Weiroot 158) was selected for their commercial importance and for above-ground tree size. Tree size was determined by measuring trunk diameter and total above ground biomass (fresh weight) determined by destructive harvest of dormant trees. Six replicate trees of the selected rootstocks were sampled for root distribution (Table 1), except in the case of Weiroot 158 where only four healthy trees remained. After soil core samples were collected, the rootstock collar and some of the associated structural roots were removed from the ground using an excavator and allowed to air dry in the field for several weeks. After drying, soil was dislodged from the remaining roots, and the resulting stumps were weighed.

Table 1. Size of tart cherry and peach trees sampled for root distribution, and estimated root biomass, based on core sampling. Tree size was quantified by trunk cross-sectional area (TCSA) and total aerial biomass as determined by fresh weights taken during the dormant season.

Species and rootstock cultivar	TSCA (cm^2)		Aerial biomass (kg/tree)		Root biomass (g/m^3)	
Tart cherry[y]						
Mahaleb	221.3	a[z]	107.6	a	832	
Weiroot 158	158.2	b	69.6	b	1279	
Gisela® 6	145.8	b	73.7	b	815	
Gisela® 5	75.0	c	28.0	c	1096	
Peach[y]						
Cadaman®	121.4	a	60.4	a	1992	a
Lovell	92.0	b	42.9	b	1567	b
Bailey	64.0	c	28.2	c	692	e
Controller 5	43.9	d	14.9	d	1296	c
Krymsk® 1	20.8	e	3.9	e	968	d

[z] Letters denote significant difference as determined by Duncan's Multiple Range Test

[y] Replication number was six for tart cherry and five for peach except in the case of Weiroot 158 and Krymsk®1 where only four healthy trees remained.

Peach study. The peach experiment consisted of 'Redhaven' (*Prunus persica* [L.] Batsch 'Redhaven') budded on 14 *Prunus* rootstock cultivars and selections and planted in 2001. Eight replicate trees of each rootstock cultivar were planted in a randomized complete block arrangement at 5 m in-row by 6 m between-row spacing, with blocking by location in the orchard. Peach trees were trained to an open-center system and managed according to NC-140 protocols (www.nc140.org). At the end of the 2006 growing season, a subset of five peach rootstocks was sampled for root distribution. The rootstock cultivars Bailey, Cadaman®, Controller 5, Krymsk® 1 and Lovell were selected for their commercial importance, and because they represent the full range of tree vigor included in the study (Table 1). Sampling was carried out as described above on five replicate trees for each rootstock, except in the case of Krymsk®1, where only four trees remained.

Root distribution sampling. Root distribution was determined by a soil core sampling technique (4, 5), with soil cores collected in a radial array around a randomly selected quadrant of each tree trunk. Soil cores 0.9 m deep and 7.5 cm in diameter, were taken with a tractor-mounted hydraulic soil corer (Giddings Machine Company, Windsor, Colorado). Cores were bored and collected at 0.45, 0.9, and 1.35 m from the trunk parallel to, perpendicular to, and at a 45% angle from the tree row (Fig. 1). Extracted cores were divided into 0.15 m segments to a depth of 0.6 m. Roots collected from the 0.6-0.9 m depths were combined due to variability in sampling depth, a lack of roots found at these depths, and difficulty in extracting soil to the full depth of the soil cores.

Root extraction and measurements. Fibrous and larger trunk roots were removed by hand from the soil samples in the field and stored in individual plastic bags. Roots were further separated in the lab into three size classes (fine fibrous roots (<2 mm diameter); small laterals (2-4 mm) and larger trunk roots (> 4 mm). Roots were dried at 70°C for 48 h before weighing. Data were expressed as grams root dry weight per cubic meter soil volume based on the volume of the corresponding soil core segments.

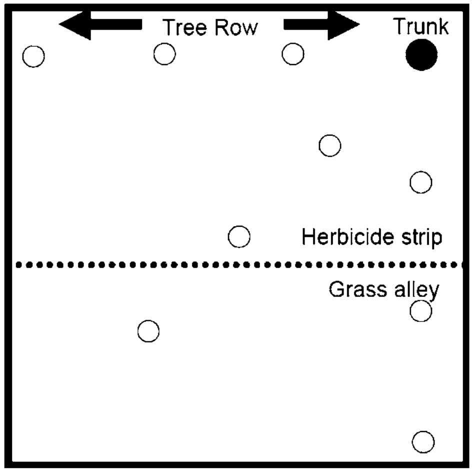

Fig. 1. Root sampling locations. Cores were collelcted 45, 90 and 135 cm from the trunk of the tree in three transects.

Root dry weights were analyzed as a split plot design with rootstock as the main plot factor and location and depth as subplot factors. Standard analysis of variance was used to test for main effects and interactions of rootstock, location and depth. The general linear model procedure (SAS Inst., Cary, NC) was used for analysis of variance. Root distribution graphs were generated from these data using a contouring program in Surfer 7 (Golden Software, Inc.; www.goldensoftware.com).

Results and Discussion

Scion growth (TCSA and biomass) was significantly affected by rootstock for both peach and tart cherry (Table 1). TCSA was a good predictor of tree size, showing similar mean separation to above ground biomass in both cherry and peach. TCSA was more closely correlated with tree size than were tree height or spread (data not shown). Mahaleb produced the largest tart cherry trees and Gisela® 5 produced the smallest. Cadaman® rootstock grew the largest peach trees while Krymsk® 1 had the smallest trunk and the least amount of aerial biomass.

Cherry study. Although total aerial biomass of 'Montmorency' tart cherry was dramatically different among rootstocks sampled (3-fold difference between Mahaleb and Gisela® 5), sampling procedures did not detect significant rootstock difference in fine (Table 2) or total (Table 3) root mass across the volume sampled. However, there were significant rootstock × sampling location and rootstock × sampling depth interactions. It is difficult to intuitively think about the meaning of significant two- and three-way interactions. Computer mapping software provides a powerful tool for visualizing these interactions. Figures 2 and 3 show the total root distribution maps for within-row (Fig. 2) and between-row (Fig. 3) transects for the four cherry rootstocks sampled. Within-row root distribution was similar for the four rootstocks and the majority of roots were located in the upper 75 cm of the soil profile. The most dramatic rootstock differences were in the degree of lateral root distribution perpendicular to the tree row (Fig. 3), where Gisela® 6 showed the least lateral root growth. This difference is particularly striking in comparison to Weiroot 158, a tree with similar aerial biomass. Gisela® 5 produced the smallest tree, and the least dense concentration of roots, but the root distribution both within and between rows was relatively uniform. This suggests that Gisela® 5 is less affected by competition from the grass cover crop.

Peach study. Total root mass collected in the sampled soil volume and the extent of root distribution differed significantly among peach rootstocks (Table 1). These differences did not correlate with TCSA or aerial biomass. Aerial biomass ranged from 3.9 kg/tree for Krymsk® 1 to 60.4 kg/tree for Cadaman® (Table 1) and

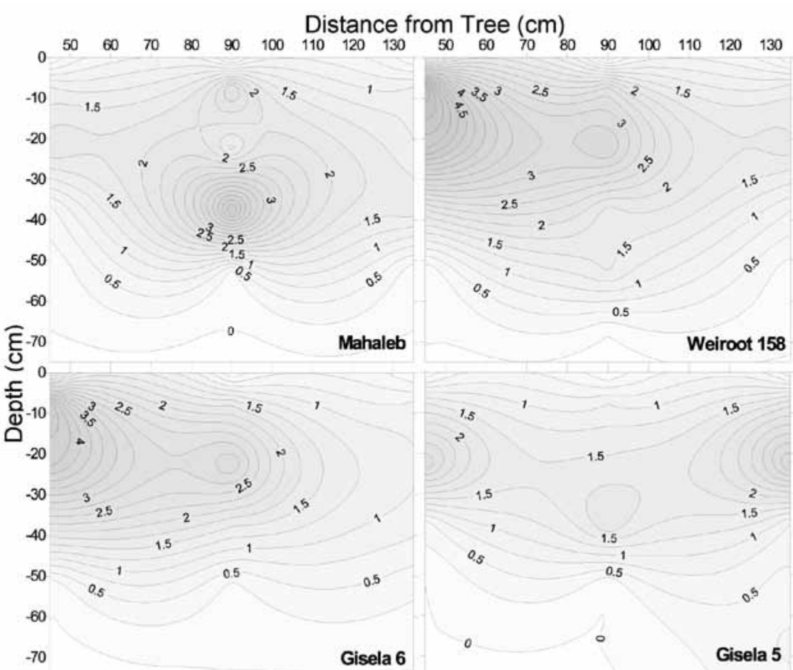

Fig. 2. Total root distribution within tree rows for four rootstocks in the 1998 NC-140 tart cherry rootstock trial. Isolines represent the change in total (sum of all root sizes) root mass (mg/cm³) over distance from the tree and depth in the soil profile.

Table 2. Analysis of variance for peach and tart-cherry fine root (<2 mm diameter) biomass.

	Tart cherry			Peach		
Source	df	MS	P	df	MS	P
Replicates	5	0.131	0.942	3	0.026	0.120
Rootstock	3	0.856	0.488	4	0.050	0.017
Error a	13	0.583		12	0.011	
Sample Location	8	1.611	0.000	8	0.436	0.000
Location*Rootstock	24	0.362	0.000	32	0.013	0.324
Error b	144	0.115		120	0.012	
Sampling Depth	4	17.727	0.000	4	1.336	0.000
Depth*Rootstock	12	0.164	0.119	16	0.014	0.122
Depth*Location	32	0.629	0.000	32	0.120	0.000
Depth*Rootstock*Location	96	0.112	0.412	128	0.009	0.619
Error c	648	0.125		540	0.010	

was closely correlated with TCSA. Rootstock collars ranged in weight from 3.17±0.56 kg per tree for Krymsk®1 to 12.33±0.37 kg per tree for Cadaman®, and were closely correlated with aerial biomass (data not shown). Peach fine and total root mass per soil volume differed significantly with sampling location and sample depth (Tables 2 & 3). In the case of fine roots (<2 mm diam) there were no significant rootstock × location or rootstock × depth interactions (Table 2). However, analysis of total root biomass (sum of three root size classes), showed a significant rootstock × location × depth interaction (Table 3). Again, root distribution maps best illustrate this 3-way interaction. Figures 4 and 5 show distribution maps of total roots for the five peach rootstocks for within-row (Fig. 4) and between row (Fig. 5) transects. Within-row root distribution was similar for the five rootstocks (Fig. 4). The majority of the roots were located in the upper 60 cm of the soil profile. As with cherry, total peach (Fig. 4) root biomass (mg dry weight/cm^3 of soil volume) was greatest near the trees, decreasing with distance from the tree regardless of sample depth. In general, few roots were located below 60 cm depth regardless of the rootstock.

Between-row root distribution was quite extensive in cherry rootstocks, though the amount of biomass was considerably less than within the rows (Fig. 2). The cherry trees sampled in this experiment were older than the peach trees and had root growth to greater depth, although root growth between rows was suppressed by grass competition. Root distribution transverse to the row direction was severely limited in peach rootstocks, as very few roots were detected except at the 45 cm sampling distance (Fig. 5). The lack of lateral root growth perpendicular to the row is likely due to the young age of the orchard (14) and competition with the grass cover growing in the alleyways (7, 10). At the sample spacing used here, only the sampling point closest to the tree row fell within the herbicide strip (Fig. 1). The core samples taken at 90 and 135 cm from the tree trunk were taken from within the grass cover crop in the alleyway. Reighard and Newall (14) monitored peach tree growth during the first 5 years after establishment with and without grass alleyways and found that tree growth was improved when orchards were clean cultivated, indicating potential competition between the grass groundcover and young peach tree roots for nutrients or water (7), or possible allelopathy. The lack of root biomass observed under the grass alleys confirms the competitive nature of tall fescue, relative to tree root growth. Some groundcovers reduce tree rooting more than others through greater direct competition or allelopathic affects. Parker and Meyer (12) showed no differences in TCSA between bare ground and nimblewill

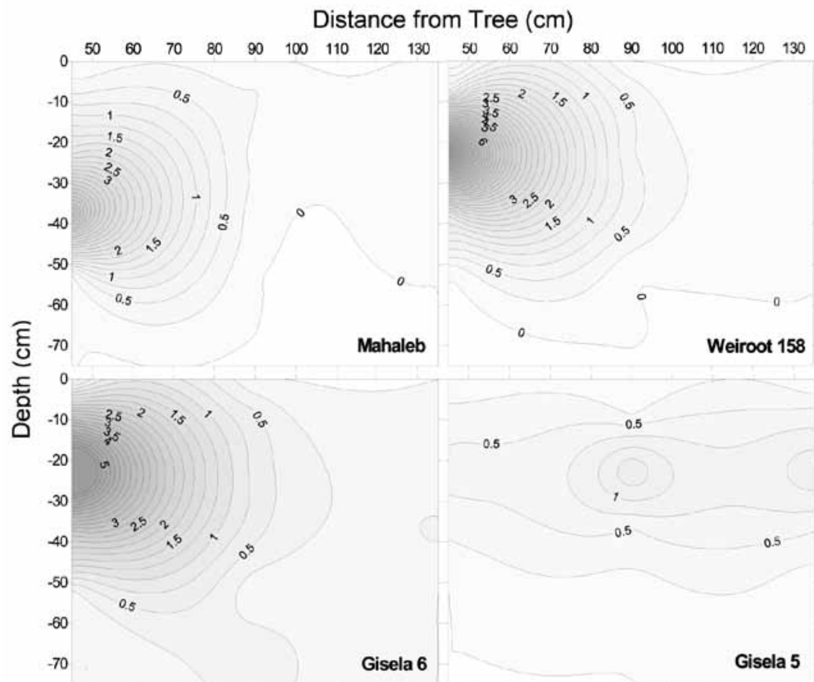

Fig. 3. Total root distribution between tree rows for four rootstocks in the 1998 NC-140 tart cherry rootstock trial. Isolines represent the change in total (sum of all root sizes) root mass (mg/cm^3) over distance from the tree and depth in the soil profile.

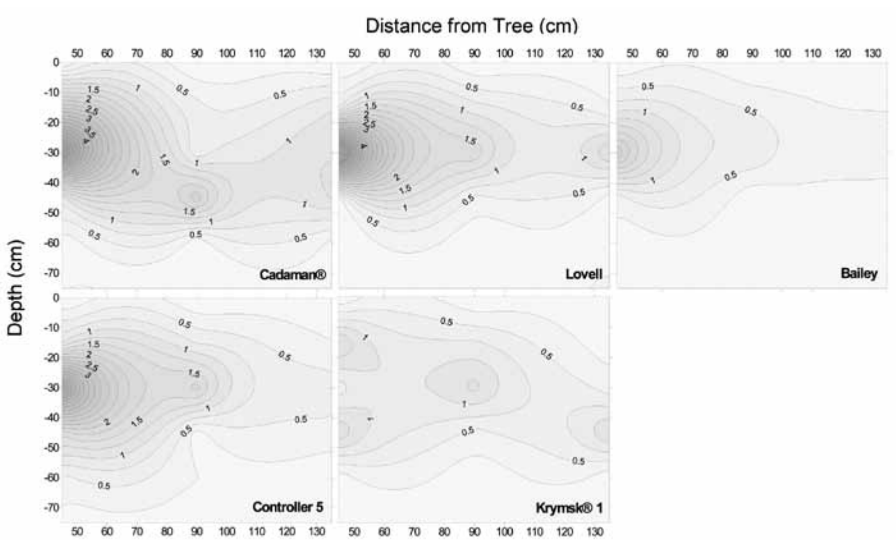

Fig. 4. Total root distribution within tree rows for five rootstocks in the 2001 NC-140 peach rootstock trial. Isolines represent the change in total (sum of all root sizes) root mass (mg/cm^3) over distance from the tree and depth in the soil profile.

Table 3. Analysis of variance of total peach and tart cherry root biomass (dry weight).

	Tart cherry			Peach		
Source	df	MS	*P*	df	MS	*P*
Replicates	5	8.32	0.826	3	0.420	0.619
Rootstock	3	13.84	0.568	4	2.322	0.045
Error a	13	19.73		12	0.684	
Sample Location	8	36.50	0.000	8	10.727	0.000
Location*Rootstock	24	13.68	0.005	32	0.702	0.126
Error b	144	6.65		120	0.520	
Sampling Depth	4	218.28	0.000	4	15.143	0.000
Depth*Rootstock	12	16.02	0.013	16	1.881	0.001
Depth*Location	32	16.28	0.000	32	2.370	0.000
Depth*Rootstock*Location	96	6.59	0.772	128	1.371	0.000
Error c	648	7.46		540	0.623	

grass (*Muhlenbergia schreberi* J.F. Gmel) while weeds, centipedegrass (*Eremochloa ophiuroides* (Munro) Hack) and bahiagrass (*Paspalum notatum* Flugge) significantly reduced tree growth. Parker et al. (11) showed greater root density in peach trees grown with Kentucky bluegrass (*Poa pratensis* L.) or alfalfa (*Medicago sativa* L.) compared to tall fescue. Glenn and Welker (8) showed that irrigation may minimize competition effects if an adequate vegetation-free root zone is available to facilitate intra-root water transfer. Establishing the sod alleyways only after the trees are mature may minimize negative competition effects in peach trees (9).

In contrast to the published literature on the effects of groundcover on peach root growth, Sanchez et al. (15) reported no effect

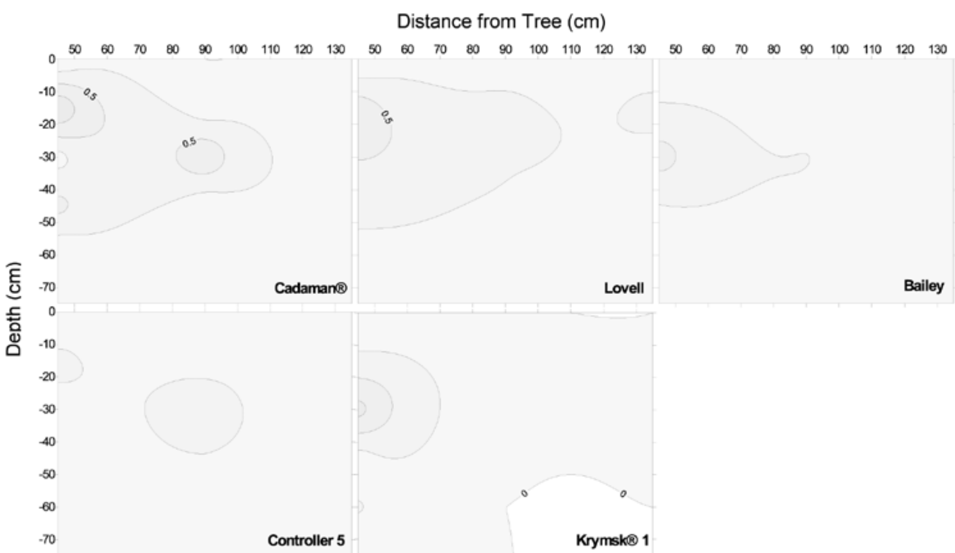

Fig. 5. Total root distribution between tree rows for five rootstocks in the 2001 NC-140 peach rootstock trial. Isolines represent the change in total (sum of all root sizes) root mass (mg/cm³) over distance from the tree and depth in the soil profile.

of groundcover on yields of tart cherry, raising the possibility that cherry may be less sensitive to sod competition than peach.

Significant differences in root distribution and pattern have been noted for a range of plant species (4-7, 10, 12, 17). However, variability in root distribution through the soil profile, specifically differences in between-row compared to within-row root growth, and plant-to-plant variability all contribute to the variability associated with any sampling technique. Bohm (2) recommended a larger number of cores be taken per tree to more accurately assess root distribution. However, our primary objective was to rapidly assess root distribution while maintaining the ability to make comparisons among rootstocks. Atkinson (1) reviewed the known literature related to root distribution and effectiveness in temperate fruit tree species, but reported little information comparing root distribution among rootstocks. Our data show that a structured sampling grid was capable of identifying root distribution patterns and noting significant differences in root growth among rootstocks.

Researchers have used a variety of methods (cores, bags, excavation) to collect and study plant roots (3, 5, 10, 13, 16). Studies of root biomass have used soil-coring techniques, water extraction techniques, or complete tree excavation. These techniques all represent significant time and labor, though few papers report the time and effort invested in collecting and processing the data (5). Manpower requirements for our study included a tractor operator, an operator for the soil coring equipment, and two to three individuals to separate the roots from the extracted soil cores. On average, it required less than 30 seconds to extract a core and approximately 3-5 minutes to separate the roots from each core. For those cores taken in the grass alleyways, significantly less time was required due to the lack of tree root growth in this area. Roots were easily distinguishable from the grass roots by color and texture, making them easy to collect (10). Trees were cut down just prior to root sampling, which facilitated movement of soil coring equipment. More care would be required to extract roots from a growing orchard where complete destructive sampling was not possible. However, this rapid soil coring and digital mapping technique detected root distribution differences among rootstocks and could be used to determine the effects of orchard floor management on root distribution.

Acknowledgements

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'UFOne' Peach

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Abstract

'UFOne' peach {*Prunus persica* (L.) Batsch] is released for grower trials in central and north central Florida by the University of Florida Agricultural Experiment Station. Trees of 'UFOne' produce an attractive, sweet tasting, yellow and non-melting flesh, cling stone fruit intended for the fresh fruit market.

'UFOne' originated in Gainesville on the University of Florida fruit breeding facility, from a 1994 open pollination (out-crossed to an unknown peach) of Fla. 90-50cn (7), and was selected and propagated in 1997 as Fla. 97-30c (Fig. 1). Standards and methods used in this program to evaluate selections have been described (1, 2). Trees of 'UFOne' are estimated to require 150 chill units (6). This is based on full bloom occurring up to 3 days before 'UFBeauty' peach (200 chill hours) at Gainesville where full bloom occurs most seasons in late January (Table 1). 'UFOne' has fruited well where the coldest month averages 17 to 18º C (5) and in colder locations in the absence of spring frosts. Thus, we expect this new peach to be adapted in areas where 'UFBeauty' has been grown successfully. Fruits ripen just after the first week in May at Gainesville, about 95 days after full bloom (Table 1) and about 8 days after 'UFBeauty' (Table 2). Cropping at Gainesville has ranged from 70% to 90% of a commercial crop (Table 1) due to early bloom and spring frost injury. Trees have set a partial crop at the South West Florida Research and Education Center, Immokalee, Florida where 'UFBeauty' sets no crop due to night temperatures above 14°C during bloom. Observations relative to established cultivars such as 'Flordaprince' or 'UFO' that are growing in the same block indicate that 'UFOne' trees are vigorous, semi-spreading, productive and have not demonstrated alternate bearing. Observation of 4 trees propagated on 'Flordaguard' rootstock in each of 3 locations indicates that trees set a high number of flower buds, have few blind nodes (3), and exhibit little bud drop prior to bloom (8). Fruit thinning is required in areas lacking spring frost in order to maximize fruit size and prevent limb breakage. Leaves have globose glands. Flowers are showy and pink. Anthers are light red and pollen is bright yellow abundant, and fertile. Leaves have shown no bacterial spot [*Xanthomonas campestris* pv. *pruni* (Sm.) Dye] in test plantings where

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