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ROOT SYSTEMS OF HEALTHY AND DECLINING CITRUS TREES ON SWINGLE CITRUMELO ROOTSTOCK GROWING IN THE SOUTHERN FLORIDA FLATWOODS

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Abstract. **The variable performance of trees on Swingle citrumelo [*Citrus paradisi* Macf. × *Poncirus trifoliata* (L.) Raf] rootstock in southern flatwoods soils appeared to be related to differences in root growth and soil characteristics. We examined the root systems of trees at several locations in the Indian River and Southwest Florida production areas by trenching between adjacent trees using a small backhoe with a 16 inch wide bucket. The exposed roots were observed and the abundance and relative proportions of fibrous and secondary roots noted. The soil morphology of each profile was described and samples were collected for organic matter, pH, Ca, Mg, P, and K analyses. All trees were over 10 years old, growing in double-row beds, and were either apparently healthy or in decline. Healthy tree root systems had a shallow, flat distribution with fibrous and secondary roots present, but located mostly in the A horizon. Of the total root biomass, about two-thirds was on the crown side and one-third on the furrow side of the bed. Declining trees commonly had fewer fibrous roots than healthy trees, few or no secondary roots, and root decay was evident. Adequate soil drainage and the presence of a thick, dark surface horizon appeared to be the most important characteristics contributing to healthy root system development. There was little correlation between tree vigor and any measured soil chemical property.**

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Site and soil characteristics are well known criteria for locating citrus groves in Florida and choosing rootstocks (Ziegler and Wolfe, 1961). Florida citrus growers have accumulated considerable knowledge on these subjects based largely on years of experience and observation. When applying this knowledge, rootstocks have been selected for their combined adaptation to the soils of the region and horticultural traits. Often one "best-choice" rootstock has been planted throughout an entire grove or block of trees. Those rootstock decisions have been relatively easy to make for plantings on the Central Ridge. The soils in this region are relatively uniform, are well to moderately well drained, and do not present any serious management problems.

The soils of the Southern Florida Flatwoods are very different from those of the Central Ridge. They are poorly to very poorly drained under natural conditions. Water drains from the profile so slowly that the soil remains saturated for long periods of time thereby preventing most crops from being grown without artificial drainage usually provided by ditching, and bedding which alters the soil profile.

An axiom of the Southern Florida Flatwoods is that soils vary markedly. The soil orders (the broadest level of classification) of primary importance in Flatwoods citrus production are Alfisols and Spodosols. Alfisols are characterized by a subsurface horizon with a finer textured nearly impermeable soil horizon. Spodosols are characterized by the presence of a spodic horizon, a nearly impermeable subsurface horizon composed of aluminum and organic matter with or without iron. The presence of these horizons restricts the downward movement of water resulting in slow internal drainage. In an undisturbed state, these soils also typically have a dark colored natural surface A horizon (topsoil). For most of the Flatwoods soils, the surface horizon is gray, dark gray, or dark grayish brown sand that has higher organic matter content and cation exchange capacity than the underlying light gray horizons.

Previously, the simple answer to Flatwoods rootstock selection was sour orange because it offered many desirable horticultural traits in addition to being well-adapted to virtually all soils and site conditions. However, citrus tristeza virus susceptibility eliminated sour orange from use in new plantings and has rendered many commercial trees unproductive (Stover and Castle, 2002). As a result, trees on Swingle citrumelo were widely planted in place of sour orange using the established concept of selecting one best rootstock for a given situation. It is now clear that Swingle citrumelo is not suitable for every Flatwoods place where sour orange was previously successful. Growers are left today with questions about where Swingle citrumelo should or should not be planted and the answers appear to be related to soil factors. Furthermore, these questions have taken on added imperatives due to less favorable grower monetary returns, and the advent of precision agriculture, providing a framework for matching rootstocks and field conditions.

Swingle citrumelo is the most popular commercial rootstock in Florida. Many trees on this rootstock have been planted in the Alfisols and Spodosols of the Southern Florida Flatwoods. We have typically observed considerable variability in performance and condition among tress growing in Flatwoods soils and even within areas classified as a single soil series (Castle et al., 2002). In some instances, tree decline occurs but often not before the trees are 5 to 8 years old, which is a sufficient period of time for differences in root system development to express themselves.

Previous published information about Swingle root systems was obtained from studies conducted among trees growing in Central Ridge Entisols (Elezaby, 1989; Menocal-Barbarena, 1999). No systematic large-scale studies have been conducted of Swingle citrumelo or other citrus root systems in Flatwoods soils with high water tables. The few previous studies have yielded similar results emphasizing the limitations of the environment. The root systems of trees grown in the Flatwoods display much stronger lateral than vertical development resulting in root systems with a 'pancake' appearance and nearly 75% of the fibrous roots located within ca. 18 inches of the soil surface (Calvert et al., 1977; Reitz and Long, 1955). Strong correlations also have been shown between rooting depth and water table position (Ford, 1954; Reitz and Long, 1955). A chronic high water table or flooding can also cause loss of roots as described by Ford (1968).

Ford (1964) reported that few roots were present in the white subsurface horizons of Leon and Immokalee fine sands, two Spodosols of the Flatwoods. In experiments to verify field results, trees grown in containers with controlled irrigation and drainage also had poor fibrous root growth in white sand even though moisture, nutrients, and drainage were adequate. In general, concentrations of fibrous roots for the trees in containers were identical to those observed in field trials.

We studied relationships between soils and rootstocks and chose to focus on Swingle citrumelo since it is widely used and displays notable variability. Our hypothesis was that differences in the root system between healthy and declining trees existed and could be explained by variations in site and soil factors. Our initial findings are reported herein.

Materials and Methods

Nine citrus groves were located in which grapefruit and orange trees, all over 10 years old, were growing at a similar spacing on double-row beds. Each grove had unique environmental and management history. The observed trees varied in size and condition from large and healthy to small and healthy to different stages of general decline with thinning canopies, shoot dieback, and reduced yield with small fruit. The trees in each grove were selected based on their visual appearance. We did not test the declining trees for citrus blight; however, water uptake was rapid when we conducted trunk water flow tests with declining trees in other studies of the overall project indicating that blight was not the cause of decline.

Tree root system distribution was studied by trenching perpendicular to the tree row between adjacent trees using a small backhoe with a 16-inch wide bucket. The trench began near the bottom of the water furrow and continued toward the middle of the bed. The exposed roots were observed and the relative proportions of fibrous and secondary roots noted. It was not our intention to conduct a precise, quantitative study, but only to note any clearly visible and obvious differences in soils and root system characteristics. Soil horizon depths and thicknesses, soil color (by Munsell chart), and soil texture (by field technique) were recorded. The presence of $CaCO_3$ was checked on-site by applying 0.5M hydrochloric acid and noting any effervescence. Soil samples were collected from the trench wall at the tree-row position in five citrus groves at 0-3, 3-6, 6-12, 12-18, and 18-24 inch depths and tested for organic matter, pH, Ca, Mg, P, K. Organic matter determination was by loss-on-ignition at 400 °C, pH was measured in a 1:2 soil-to-water ratio, and the soil macronutrients were extracted with a Mehlich-1 solution.

Results and Discussion

Typical root distribution of a healthy tree. We observed four readily apparent and consistent characteristics of the Swingle citrumelo root systems; (1) a broad, shallow distribution; (2) a lateral distribution of one-third on the water furrow side, and two-thirds on the crown side of the bed with few roots extending much beyond the canopy dripline. In some cases, roots of older trees had grown to the crown of the bed; (3) in most sites, a root system located entirely in the topsoil (A horizon); and, (4) a consistent proportion of fibrous and secondary roots (Fig. 1). The trees usually had a dense mat of fibrous roots growing immediately below the soil surface under the entire tree canopy. Secondary roots of various sizes ranging from 0.25 inch to 0.75 inch diameter were commonly observed at the trench wall, but roots larger than 0.75 inch diameter were rare. This general description is based on observations made primarily in Alfisols, mostly the Riviera series, and applies across grapefruit and sweet orange scion cultivars. Root characteristics were similar in the Spodosols studied, but at one site with Wabasso sand, roots had penetrated into the spodic horizon located at a depth of ca. 30 inches (Castle et al., 2002).

Root distribution and the A horizon. The roots of most trees were located in the surface A horizon which was more darkly colored than underlying horizons in most profiles. Healthy roots were rarely observed growing deeper than the lower boundary of the A horizon despite the absence of any obvious restrictive layers or adverse soil chemical properties among those measured that explained those observations. One explanation may be that the A horizon is the one least affected by perched water tables. However, in one site where the water table was monitored, roots were exclusively in the A horizon even though the water table level was not inundating the horizon below. Ford (1962) also observed that the roots of trees on rough lemon did not grow into the white subsurface horizon of an Immokalee fine sand even in field conditions where the water table did not compromise such growth.

In soils without obvious drainage problems, the root size and abundance appeared to be related primarily to the color of the A horizon soil. Where the moist color of the A horizon was dark gray (10YR 4/1 on the Munsell Color Chart), dark grayish brown (10YR 4/2) or very dark gray (10YR 3/1), tree performance was satisfactory and root systems displayed characteristics as described for typical healthy trees. Soils without an identifiable A horizon or those with a light gray (10YR 7/1) or gray color (10YR 6/1 or 10YR 5/1) had a visibly lower roots abundance, lacked secondary roots larger than 0.25 inch diameter, or had no secondary roots visible along the trench wall (Fig. 2). However, the root systems in these lightly colored A horizons usually had a large amount of apparently healthy fibrous roots; also, there were no indications that the root systems had been exposed to any chronic adverse conditions nor was any soil of questionable origin observed in the beds.

Fig. 1. Root system of a large, healthy 'Flame' grapefruit tree on Swingle citrumelo planted in 1993 and observed from the furrow.

Fig. 2. Surface soil profile and root decay of a declining 'Marsh' grapefruit tree on Swingle citrumelo planted in 1991 in a landscape depression. Note the organic layer (arrow) at the base of the root zone where roots decayed.

Soil chemical properties, including organic matter (Fig. 3), were not significantly correlated with tree condition. The color of the A horizon soil was not correlated with organic matter content and there were no differences in organic matter among healthy and declining areas (Table 1). Soil profiles with a light-colored A horizon are common in many of the Alfisols and Spodosols of the Southern Flatwoods. We observed light-colored soil profiles among several soil series including Basinger, Immokalee, Malabar, and Riviera that were associated with declining trees on Swingle citrumelo rootstock.

Root distribution and chronically wet conditions. The soil in many of our study sites was Riviera sand, an Alfisol in which the argillic horizon or loamy soil layer begins between 20-40 inches from the soil surface. Low elevation areas (depressions) were commonplace at these sites as they are throughout the Indian River Flatwoods. These are places in the landscape where the depth to the top of the argillic horizon was relatively shallow, generally within 20-24 inches of the soil surface and apparently perched water in the root zone for extended periods of time.

Trees growing in these depressional areas were invariably small with shallower, less dense root systems, and prone to decline. In one typical site, 'Marsh' grapefruit trees on Swingle citrumelo rootstock had been planted in 1991 on Riviera series soil. Tree decline began in 2001. Root pruning and decay were evident at the bottom of the root zone where the perched water table led to root damage (Fig. 4). Healthy roots were found only in the top 6 inches of the surface soil horizon. The root damage probably preceded decline and eventually led to tree loss. The timing of the onset of decline and the appearance of the root system suggested that the root system was tolerant of the site conditions until 2001.

Root systems in citrus groves where trees were declining on Riviera soils in landscape depressions usually had a water-damaged appearance. One striking contrast with nearby healthy trees was the virtual absence of secondary roots among the declining trees. Root sizes at the trench position were usually less than 0.25 inch diameter and the outer sheath of many roots sloughed off easily. Roots were typically dark brown or dark gray and there was decaying root material in the root zone. We also observed tree decline on Boca and Winder soils in landscape depressions that were apparently inundated with water. Boca and Winder series are also Alfisols often found in landscape depressions.

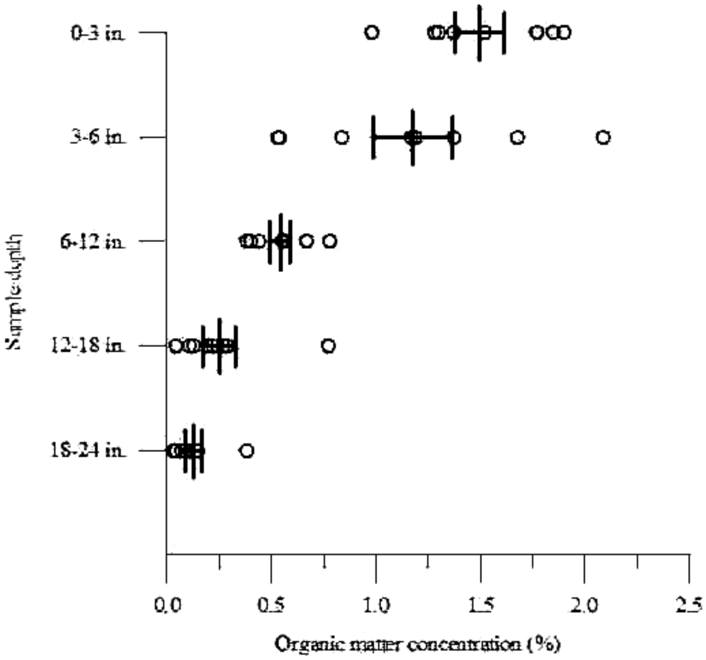

Fig. 3. Mean organic matter concentration among eight locations and sample depths in a citrus grove planted on Basinger soil, St. Lucie County, Florida. Bars indicate sample means and standard error of means.

Table 1. Mean organic matter concentration[z] of soil samples collected in areas of apparently healthy and declining 'Flame' grapefruit on Swingle citrumelo rootstock planted in 1991 on a Basinger soil in St. Lucie County, Florida.

	Organic matter concentration (%)	
Sample depth	Large healthy trees	Declining trees
0-3 inches	1.6	1.6
3-6 inches	1.0	1.3
6-12 inches	0.6	0.5
12-18 inches	0.4	0.1
18-24 inches	0.2	0.1

[z]Organic matter concentration determined by loss-on-ignition at 400 °C.

Atypical observations. We encountered several sites where soil profile and site characteristics appeared unrelated to tree decline. For example, there was a pattern of tree decline at one location, but no evidence of soil or landscape variability. In another instance, we examined declining 11-year old 'Flame' grapefruit trees on Swingle citrumelo in Riviera soil and found a near absence of fibrous roots, but a well developed system of secondary roots (Fig. 5). The site was one where trees on Swingle normally grow well; however, a recent event may have damaged the root system and initiated tree decline. A review of grove records indicated that 36 inches of rain fell in the

Fig. 4. Apparently healthy fibrous roots of a declining 'Flame' grapefruit on Swingle citrumelo planted in 1993. No roots were observed in the trench larger than 0.25 inch diameter. The 11-year-old trees began to decline in March 2004.

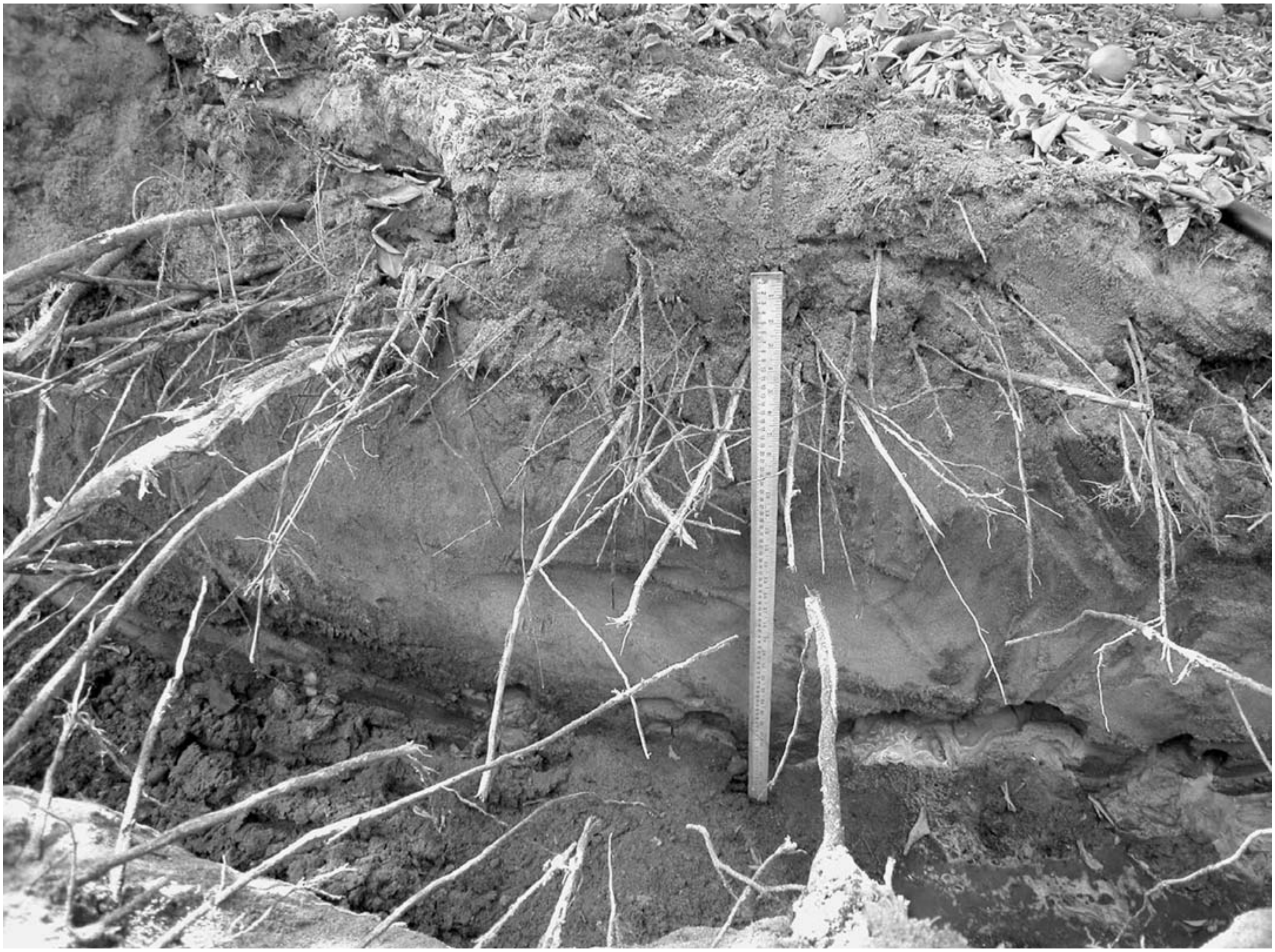

Fig. 5. Root system of a declining 'Flame' grapefruit on Swingle citrumelo planted in 1992. The trees began to decline in October 2003. No small fibrous roots were observed in the trench.

months of July, August, and September 2003, a time when a nearby water control gate was left closed. Those circumstances apparently resulted in the inundation of the soil profile near the ditch and created an abnormally high water table. That period was followed by only 0.3 inches of rainfall in October 2003, at which time the decline symptoms were first observed. The incidence of tree decline was high around the perimeter of the block on both sides adjacent to the blocked ditch. The decline of trees at this site supports the contention that Swingle citrumelo rootstock is sensitive to excessive wetness. Furthermore, it is evidence that tree decline may be attributable in some instances to soil and/or site unsuitability, an individual event, or some combination of these factors.

Summary and Conclusions

We described the root system of healthy, mature trees on Swingle citrumelo rootstock growing in Flatwoods soils. Our study showed the root systems were essentially the same as those of trees on other rootstocks (Calvert et al., 1977; Ford, 1954, 1962, and 1964; Reitz and Long, 1955). In double-row beds, Swingle citrumelo root systems were shallow, rarely developing deeper than 12 inches from the soil surface, and usually extended laterally from near the water furrow to near the crown of the bed. They consisted of a dense mat of fibrous roots mixed with secondary roots that ranged in diameter from straw size to about 0.75 inches. Furthermore, we compared the root systems of healthy and declining trees on Swingle and related the differences to measurable soil properties. We were unable to establish any direct links to soil pH, organic matter, or nutrient concentration; however, we conclude from our observations that the root systems of trees on Swingle citrumelo were modified by site and soil characteristics, and those factors were related to tree decline.

We examined the root systems of trees in soils of the Spodosol, Alfisol, Mollisol, and Entisol orders. The soil A horizon was where roots occurred in both healthy and declining trees with few exceptions. The extent of root development in this part of the profile was defined largely by the thickness of the A horizon and its color. Darker colored A horizons were more favorable for the performance of trees on Swingle citrumelo and the development of their root systems. Therefore, growers should pay particular attention to A horizon management (preservation and movement) when bedding or rebedding soils for citrus.

Declining trees on Swingle citrumelo were frequently located in depressional areas, and areas with an argillic layer close to the soil surface. Those conditions created problems with chronic wetness from a perched water table. Fibrous root abundance was lower in declining trees, root system development was restricted, and roots were decaying in sites where the trees appeared well adapted when young, but apparently became less tolerant as the trees aged. The long-term effect of chronic wetness was obvious in the types of roots. Declining trees had virtually no secondary roots.

We conclude that when selecting Swingle citrumelo as a rootstock for the Southern Florida Flatwoods, growers should determine the soils present at the planting site, give careful consideration to the "quality" and management of the A horizon, and avoid wet conditions.

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