Proc. Fla. State Hort. Soc. 118:80-84. 2005.

THE 10-YEAR PERFORMANCE AND SURVIVAL OF 'MARSH' GRAPEFRUIT TREES ON SUN CHU SHA MANDARIN AND VARIOUS CITRUMELO ROOTSTOCKS ON RIVIERA SAND, DEPRESSIONAL, AN ALFISOL

WILLIAM S. CASTLE[1]* AND MACE G. BAUER[2]
[1]*University of Florida, IFAS*
Horticultural Sciences Department
Citrus Research and Education Center
700 Experiment Station Road
Lake Alfred, FL 33850

[2]*University of Florida, IFAS*
Indian River Research and Education Center
2199 Rock Road
Ft. Pierce, FL 34945

Additional index words. *Citrus paradisi*, Argillic horizon, landscape position, tree decline

Abstract. **'Marsh' grapefruit (*Citrus paradisi* Macf.) trees were planted in 1991 in double-row beds formed from Riviera sand, depressional, an Alfisol with a loamy horizon at depths between 20 to 40 inches. Each bed was planted with approximately 75 trees on a single rootstock. There were two replicate blocks and in each block there was one bed of trees on each rootstock. There were eight rootstocks: six numbered citrumelos (*Citrus paradisi* × *Poncirus trifoliata* [L] Raf.), Swingle citrumelo, and Sun Chu Sha mandarin (*Citrus reticulata* Blanco). Cropping began in the 1993-94 season and was measured for all trees through the 2002-03 season. Mean cumulative yield totaled for the 10 seasons varied little among rootstocks and ranged from 28 to 40 boxes/tree. Fruit samples collected in the 1999 through 2001 seasons showed no difference in juice quality among rootstocks. Trees on Swingle and several other citrumelos were about 9.5 feet tall at age 10 years and the largest trees were 30% taller. Tree health, tree decline and ultimately tree loss, appeared to be strongly related to relative elevation, depth to the argillic horizon, and water table fluctuations. Visual symptoms of tree decline were observed first in the area of lowest elevation, but were eventually observed throughout the planting. Recorded observations of the perched water table showed that the soil was saturated to the surface for extended periods in the lowest area, and to a lesser extent in other areas. Based on longevity, Sun Chu Sha rootstock was apparently better adapted to the site conditions than the citrumelo rootstocks. However, the trees on Sun Chu Sha were also removed due to their unsatisfactory commercial performance.**

Grapefruit cultivars are an important component of Florida's fresh fruit industry, especially in the Indian River District. In recent years, Florida growers have produced 40 to 50 million boxes (1 box ~90 lbs or 41 kg) of fruit of which about 60% were processed into juice and the remainder was used for fresh sales (Fla. Agr. Stat. Serv., 2004). Much of this grapefruit is exported and the largest portion goes to Japan. The Japanese market is well-known as demanding only the best fruit in terms of size, shape, appearance, and internal quality. To achieve these requirements, suitable rootstocks are essential especially to meet or exceed minimum legal standards for Brix.

The favored rootstocks for grapefruit in the Indian River District have been Swingle citrumelo and, in recent years, Smooth Flat Seville. However, their reputations have been tarnished lately because of apparent difficulties in growing trees on Swingle in certain soils (Bauer et al., 2004; Castle et al., 2002, 2004) and disappointing to unacceptably low Brix values of fruit from trees on Smooth Flat Seville.

While continuing to evaluate new rootstocks for grapefruit, we also identified soil types and site characteristics that limit the use of Swingle citrumelo in the Indian River District (Bauer et al., 2004; Castle et al., 2002, 2004). A combination of the wrong soil series, drainage problems, position in the landscape and improper site management, can completely negate the well-known positive effects of rootstocks on tree growth, cropping, and juice quality because trees eventually decline and in most instances have to be removed. Thus, selecting a rootstock for use in the Indian River District not only involves the usual horticultural, pest and pathology criteria, but also must include a special emphasis on the suitability of soil type.

An example of a soil generally unsuitable for Swingle citrumelo is the Riviera series common to St. Lucie County (Castle et al., 2002; NRCS, 1980). Riviera fine sand and Riviera sand, depressional, are Alfisols meaning they are characterized by a subsoil horizon of loamy material, a mixture of clay and sand. This argillic horizon occurs generally between 20 to 40 inches from the surface in Riviera fine sand and Riviera sand, depressional (NRCS, 1980). Alfisols occur in flats (sloughs) and depressions. This location in the landscape explains their description as "Soils of the swamps, marshes, and very wet areas that are subject to ponding or flooding" (NRCS, 1980). The combination of the argillic horizon, poor drainage, and the amount of organic material present in the A horizon apparently reduce the longevity and performance of trees on Swingle citrumelo. Whether this combination of soil and site factors has the same effect on other rootstocks is not well established. Therefore, we conducted a field study with two objectives: (1) compare the horticultural performance of trees on Swingle citrumelo with those on other rootstocks, and (2) identify site and soil features relating to tree behavior.

Materials and Methods

The site for this study was a commercial grove located NW of Ft. Pierce, Fla. The topography is flat, but the site was mapped in the NRCS Soil Survey as depressional based on elevation and native vegetation. A depressional area has a concave surface and lacks a natural outlet for surface water drainage. The soil at the site is Riviera sand, depressional, an Arenic Glossaqualf.

We thank Barney Greene for his generous contributions of land and grove care and other support of our field study. We appreciate the financial support received from the Florida Citrus Production Research Advisory Council as Grants 0110-03I and 043-05M.

*Corresponding author; e-mail: castle@crec.ifas.ufl.edu

'Marsh' grapefruit trees on eight rootstocks (Table 1) were propagated in a commercial nursery and planted at 14 × 22 ft in two blocks of double-row beds in June 1991. There were 74 or 76 trees per bed in the two blocks (Block 1 and 2). Trees of only one rootstock were planted in each bed. Rootstocks were randomly assigned to beds in each block. The trees were irrigated with microsprinklers and fertilized according to recommended practices (Tucker et al., 1995).

Yield was measured in each bed in standard containers during commercial harvest. As trees began to decline, only the remaining healthy trees in each bed were used to measure yield. Tree heights were measured on trees selected across both rows in each bed when the trees were 10 years old. The trees selected were representative of the variability within each bed. Samples of 60 fruit per bed and from two adjacent commercial blocks of trees on Swingle citrumelo were collected in the two final seasons, 1999 through 2001, and analyzed for juice quality at the CREC commercial testhouse facility.

Apparent soil electrical conductivity (EC) was measured using a Veris 3100 unit (Veris Technologies, Salina, Kans.) pulled behind a utility vehicle. The Veris 3100 measures soil conductivity by direct sensing with six spinning discs that are dragged through the soil at a depth of about 4 inches (Lund and Christy, 1998). EC was measured in the rainy season, July 2001, when the trees were 10 years old. The sensor was pulled the length of each bed at the crown position and EC recorded at one-second intervals. Each measurement point was merged with GPS location data. All spatial data were viewed in ArcView 3.1 (ESRI, Redlands, Calif.) and surface maps were created using the Interpolate Grid function of the software. Elevation data were collected using a Trimble *Ag*GPS® 214 High Accuracy Topographic Mapping System (Trimble, Inc., Sunnyvale, Calif.). The Trimble AgGPS 214 is a survey-grade system with centimeter accuracy. This system saves and displays topographic data in the format compatible with ArcView 3.1. Depth to the argillic horizon was measured by coring at 12 locations selected within Block 1 based on tree height variability. Water table fluctuations were measured using a Pressure Systems, Inc. (Hampton, Va.) model CS408 pressure transducer installed in a water table monitoring well. This is a submersible pressure transducer that measures levels of surface or ground water. The monitoring well was a 4-inch-PVC tube with well screening at the base. The base of the tube was 30 inches below the soil surface. The KPSI pressure transducer was connected to a HOBO (Onset Computer Corp., Pocasset, Mass.) datalogger. This system recorded the water level in the monitoring well at 30-min intervals. When trees began to decline, trunk water uptake was measured by a trunk injection technique (Lee et al., 1984).

The study was a randomized complete-block design with two replications (Blocks). Data were analyzed by PROC GLM of the SAS software with mean separation by Least Significant Difference.

Results and Discussion

At the end of the 1999-00 season when the trees were 8 years old, there were no differences in cumulative yield among rootstocks ($p > 0.5890$) and no tree loss had occurred. In the 1999-00 and the following season, fruit juice content ranged between 57 and 61% and Brix varied from 11.1 (F80-9 and Swingle citrumelos) to 9.9 (W-2 citrumelo), but the differences were not significant among rootstocks (data not shown).

After 8 years, an obvious change occurred as trees began to decline beginning with those on Swingle citrumelo in Block 1. They continued to decline and all trees on the entire Swingle bed were removed ca. 4 years later. The change in the performance of these trees was evident in their cropping as yield dropped from nearly 5 boxes per tree in some years to <1 in 2002-03 (Table 1). Within a few years after decline started in the trees on Swingle citrumelo, trees on the other rootstocks began to decline and eventually all trees in the study were removed. The trees that generally remained in the best condition before removal were those on Sun Chu Sha mandarin. The tree decline we observed did not appear to be from classic blight because the trees absorbed water from trunk injection at normal rates by comparison with apparently healthy trees in the study and with other nearby grapefruit trees.

Tree heights measured in 2001 ranged from 12.6 ft (F80-18 citrumelo) to 9.2 ft (F80-8 citrumelo) (Table 1), but they do not adequately represent the variability in tree growth (Fig. 1) and site variability (Figs. 2 and 3). Tree growth and performance were related to elevation and depth to the argillic (clay) horizon. Bed-top elevations varied from a low of 25.9 ft above sea level to the highest spots that were >27 ft. This difference of 1.2 ft existed after the beds had been formed and planted (Fig. 2). The EC map roughly coincided with the elevation map, i.e., areas of relatively low elevation had relatively high conductivities, and vice versa. Furthermore, relatively low elevations and high conductivities corresponded to places of shallow depths to the argillic horizon (Fig. 3). The best appearing, longest surviving trees on Swingle citrumelo in

Table 1. Yield and tree height of 'Marsh' grapefruit trees on various rootstocks, Ft. Pierce. Trees were planted in double-row beds in June 1991 at 14 × 22 ft (138 trees/acre).

Rootstock	Yield, boxes/tree 93-94	94-95	95-96	96-97	97-98	98-99	99-00	00-01	01-02	02-03	Cum. Yield	Tree ht, ft[z]
F80-5 citrumelo	0.3	1.7	3.5	4.4	5.4	3.8	4.8	3.2	4.0	2.0	33.0	11.8
F80-8 citrumelo	0.7	1.7	2.3	4.9	4.9	3.9	5.4	3.3	4.0	2.5	33.7	9.2
F80-9 citrumelo	0.6	1.9	3.5	5.1	4.9	4.2	4.	5.0	3.4	3.2	35.9	9.6
F80-14 citrumelo	0.7	1.9	3.2	5.2	5.4	5.0	5.0	4.5	5.4	3.6	40.0	11.1
F80-18 citrumelo	0.3	1.7	3.8	4.5	5.8	5.3	4.1	4.0	4.1	2.9	36.3	12.6
Sun Chu Sha mandarin	0.2	1.6	2.6	4.2	4.6	3.8	5.0	3.6	4.7	2.4	32.7	10.3
Swingle citrumelo[y]	0.5	1.8	3.0	4.7	4.7	4.3	2.8	2.7	3.0	0.6	27.9	9.5
W-2 citrumelo	0.5	1.8	2.8	4.8	4.6	3.9	4.1	3.4	4.0	4.4	34.3	10.9

[z]Mean tree height based on representative variability within beds.
[y]All trees on Swingle citrumelo in Block 1 were removed this year.

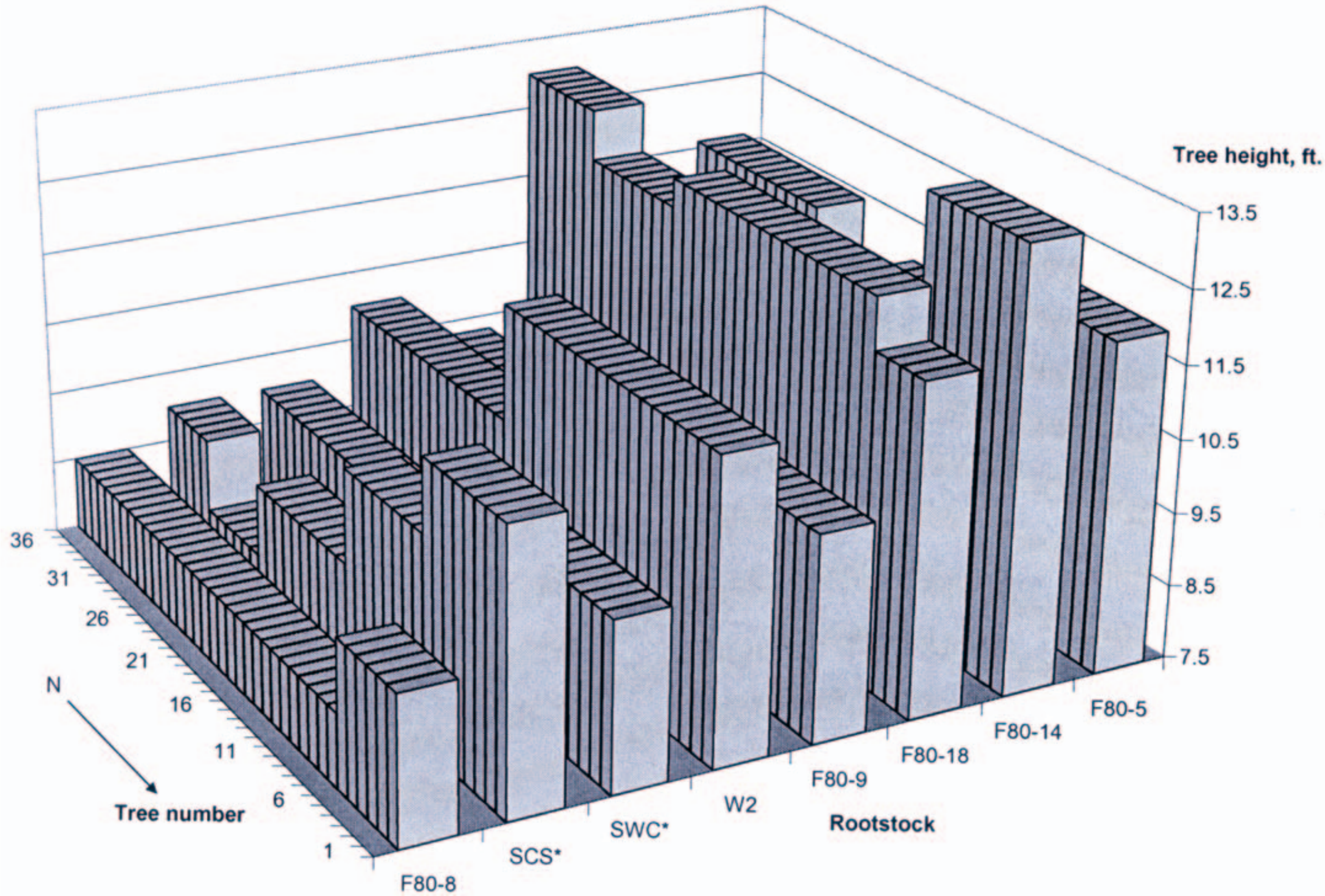

Fig. 1. Variability in heights of 10-year-old 'Marsh' grapefruit trees on various rootstocks growing in the Ft. Pierce, Florida, area in Riviera sand, depressional, an Alfisol. The rootstocks appear in the order in which they were planted in the field. The measurements were obtained from a mixture of representative trees across both rows in each double-row bed.

Block 1 were those where the depth to the argillic horizon was ≥25 inches; the poorest trees were located where the argillic horizon was ≤20 inches.

The area in Block 1 to the west of the F80-9 citrumelo bed (Fig. 1) was where the tallest and longest surviving trees were located. In this western part of the block, conductivities were relatively low, elevations were higher, and depths to clay were generally >30 inches. It is likely that their performance was also a site effect, not a rootstock difference. As evidence for this conclusion, 'Hamlin' tree heights were similar among rootstocks in another study with some of the same rootstocks as in our study (Youtsey and Lee, 1995).

Site factors in this study limited root volume and root health as influenced by water table fluctuations and soil water content. Citrus trees growing in flatwoods soils have stronger lateral than vertical root development with few roots below 18 inches (Calvert et al., 1977; Reitz and Long, 1955). Often few roots occur in any part of the profile except the A horizon (Bauer et al., 2004). As part of a broader investigation of Swingle citrumelo adaptation to soil, we conducted some root excavations in Block 1 (Bauer et al., 2004). The poorer appearing trees on Swingle citrumelo were those growing at low elevations with high EC and shallow depth to clay. Their root systems were sparse as compared with those of the healthier-appearing trees elsewhere in the Swingle citrumelo bed in Block 1. The soil profiles at these locations also had a lighter color and more impoverished appearance in the subsoil horizons than where the trees were taller. These observations were consistent regardless of rootstock.

It is well documented that the rooting depth of citrus trees increases as water table depth increases (Ford, 1963, 1968, 1972; Reitz and Long, 1955). A high water table limits root growth and can also cause loss of roots from flooding (Ford, 1968). The seemingly small differences in elevations and depth to clay in Block 1 had a meaningful effect on the water status of the soil profile (Fig. 4). At the low elevation location among the trees on Swingle, the depth to the argillic horizon was about 18 inches and rooting depth was <10 inches. The argillic layer impeded internal drainage, a typical situation among soils of the Alfisol order in the Indian River District and elsewhere in Florida (Boman, 1987; Obreza and Admire, 1985). As a result, the water table in the tree row was normally within 12 inches of the soil surface creating chronically wet soil conditions that apparently prevented root development and periodically damaged any roots that managed to grow into that zone during relatively dry times. At the higher elevation location among the trees in the F80-14 citrumelo bed, the depth to the argillic horizon was >30 inches and the observed rooting depth was from >12 inches to 20 inches or twice the depth at the lower elevation location. The data

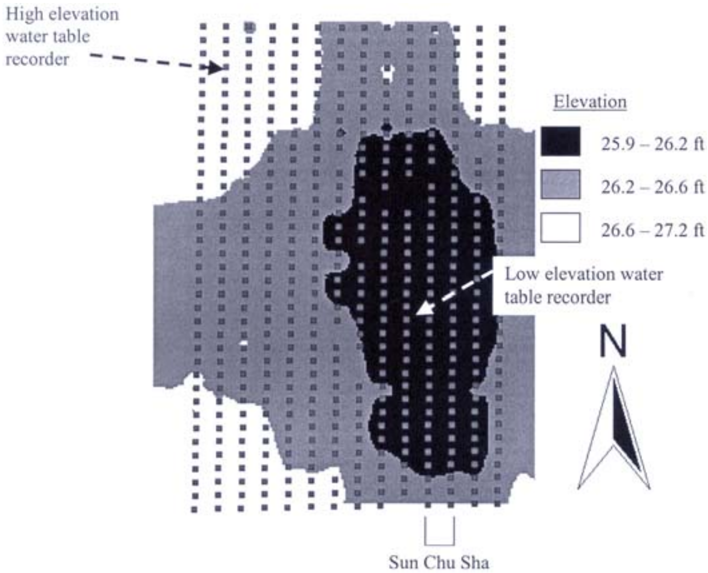

Fig. 2. Block 1 elevation map. Each pair of rows is a double-row bed as shown for the trees on Sun Chu Sha mandarin. The first bed of trees (F80-8) is not included.

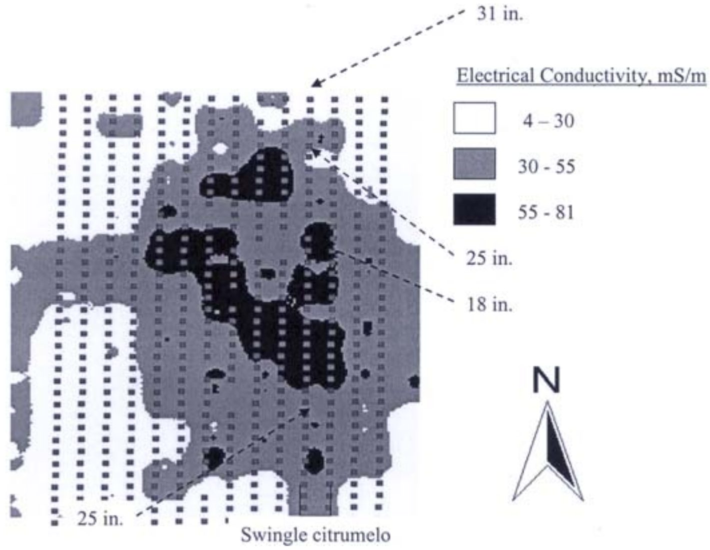

Fig. 3. Block 1 electrical conductivity map (measured in July 2001) and depth to the argillic horizon in the Swingle citrumelo bed.

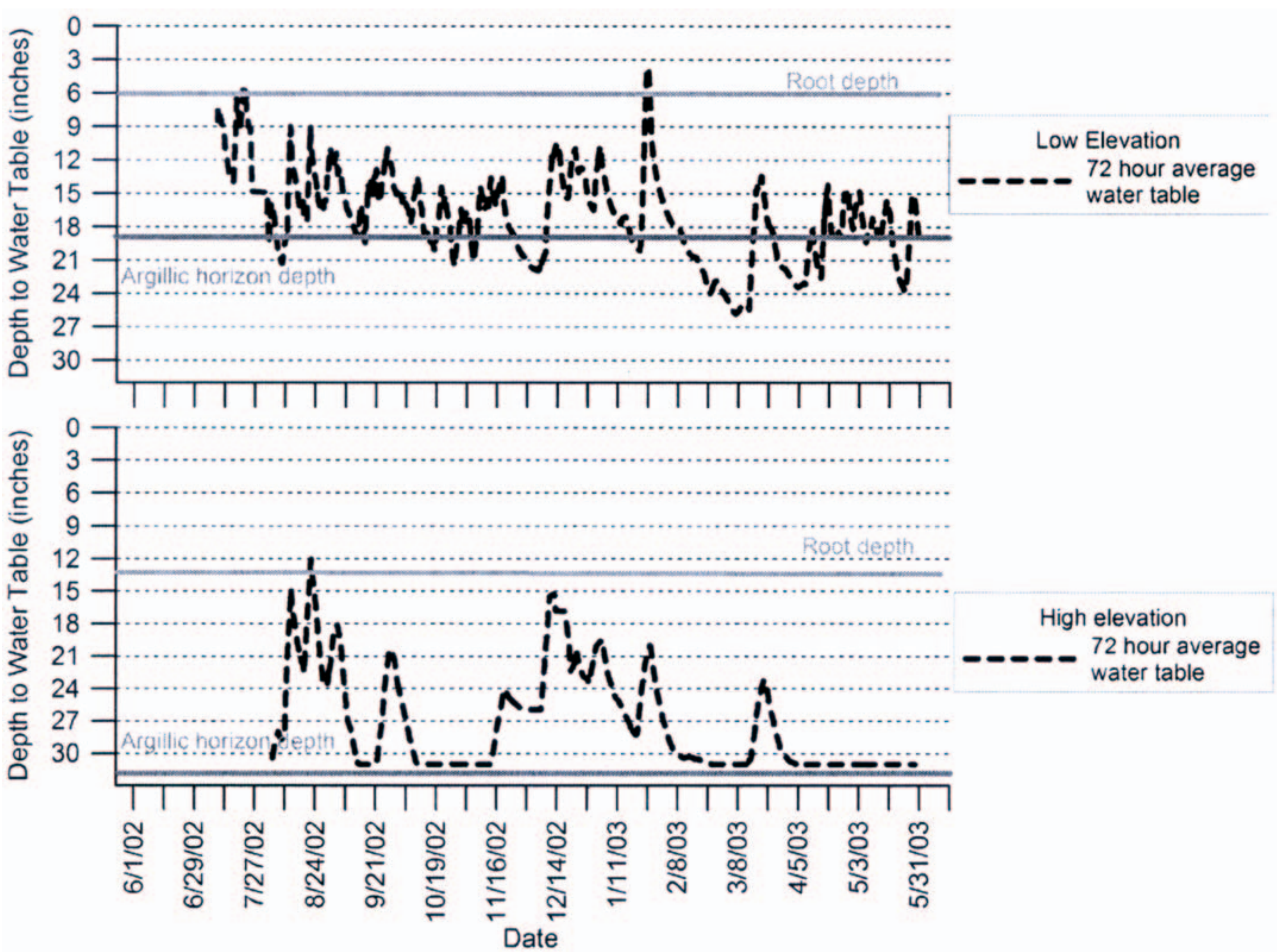

Fig. 4. Block 1 water table fluctuations. Recorders were located in the low elevation area of the bed with trees on Swingle citrumelo and a relatively high elevation area in the bed of trees on F80-14. The original data were condensed into 72-h increments for plotting in this graph.

points in Fig. 4 are 72-h summary increments of the recorded water table position. The original data (not presented) show that there were many periods when the water table at the lower elevation was within 3 to 6 inches of the surface.

Our results raise two questions: (1) If Swingle and other citrumelos are not acceptable choices for Riviera sand, depressional, are there other rootstock options available? The answer is not clear. In our study, the adjacent trees on Swingle citrumelo and Sun Chu Sha mandarin were relatively small in the poor areas of their respective beds and had correspondingly low yields. However, the trees on Sun Chu Sha survived longer in the better conditions, suggesting better adaptation to the site factors. Our other observations indicated that some rootstocks like sour orange, Smooth Flat Seville, Kinkoji, and perhaps mandarins, were better suited for soils of the Riviera series if their horticultural limitations were not restrictive (Castle and Tucker, 1998); (2) Can the limitations of Riviera sand, depressional sites for citrus be reduced? Yes, mostly through site assessment and water management. The potential impacts of depth to the argillic horizon, organic matter content in the A horizon, and elevation indicate that efforts to evaluate these components at a site in advance of planting would be beneficial (Bauer et al. 2004; Castle et al., 2002, 2004). Optimum water management contingent on monitoring depth to water table and soil water content would also provide benefits in these challenging soils.

Conclusions

A site classified in the local NRCS Soil Survey as Riviera sand, depressional, an Alfisol, was not suitable for the long-term production of citrus when the rootstocks were Swingle and other citrumelos, or Sun Chu Sha mandarin. All trees eventually declined despite site variability in elevation and depth to an argillic horizon.

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