



The Florida Citrus Soil Water Atmosphere Plant (SWAP) Project: Final Summary of Cumulative Yields and Tree Health

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The Florida Citrus Soil Water Atmosphere Plant (SWAP) Project was initiated by applying three soil tillage (mixing) treatments: shallow tillage (ST), deep tillage (DT), and deep tillage plus lime (DTL) to nine blocks on a Spodosol (Oldsmar fine sandy loam) at the University of Florida Indian River Research and Education Center. Each block had six subsurface plastic drain lines, three adjacent drains were submerged and three adjacent drains were open. 'Pineapple' sweet orange and 'Marsh' grapefruit scions on six rootstocks were transplanted from the nursery in November 1970. Yields were measured from 1973–74 to 1984–85 by scion, rootstock, tillage treatment, subsurface drain type, and replication. At the end of 12 harvests, cumulative yields of 'Pineapple' orange were greatest for rough lemon, Rangpur lime, and Cleopatra mandarin rootstocks, intermediate for sour orange and Carrizo citrange, and lowest for *Poncirus trifoliata* rootstocks. The last survey of tree health was conducted in November 1984. The healthiest trees were on Cleopatra mandarin rootstock. Rough lemon had the most trees with blight symptoms. Sour orange had the most trees with Tristeza. Rangpur lime and rough lemon had some foot rot. Carrizo citrange and *Poncirus trifoliata* had the most water damage symptoms. Yields were related to tree health.

Citrus production in Florida occurs mainly on two types of landscapes, upland Entosols and Ultisols of the South-Central Florida Ridge Major Land Resource Area and flatlands, mostly Spodosols, of the Southern Florida Flatwoods Major Land Resource Area, or other flatland soils of the Southern Florida Lowlands Major Land Resource Area (USDA-NRCS, 2006). Spodosols typically have seasonally-high water tables and a 20-cm thick spodic layer with low hydraulic conductivity below sandy layers of the surface horizons (Carlisle and Schoon, 1969). The Oldsmar sand at this site had the spodic layer (B2h horizon) at 86–107 cm depth (Hammond et al., 1971). The combination of soil factors and seasonal rainfall patterns require special drainage and irrigation to successfully support citrus production.

The Florida Soil-Water-Atmosphere-Plant (SWAP) project was initiated to investigate the effects of (i) three soil profile modifica-

tions, (ii) two types of subsurface drain lines, and (iii) six citrus rootstocks with two types of citrus scions, orange and grapefruit, on drainage and soil water management, as well as plant growth and yield (Knippling and Hammond, 1971). Rootstocks were (1) Carrizo citrange, *Citrus sinensis* (L.) Osb. *Poncirus trifoliata* L. (Raf.) (2) Rangpur lime, *C. limonia* Osb. (3) Cleopatra mandarin, *C. reshni* Hort. ex Tan., (4) Rough lemon, *C. jambhiri* Lush. (5) Sour orange, *C. aurantium* L., and (6) *Poncirus trifoliata*. Scions were 'Pineapple' sweet orange, *C. sinensis* (L.) Osb., and 'Marsh' grapefruit, *C. paradisi* Macfad. The three soil profile modifications were surface tilled or shallow tilled (ST, control) to a depth of 15 cm, deep tilled (DT) which was deep mixed to a depth of 107 cm, and deep tilled with a heavy application of lime (DTL), 56 Mg·ha⁻¹ (25 ton/acre) of lime mixed throughout the soil to a depth of 107 cm. The ST and DT treatments had 2.2 Mg·ha⁻¹ (1 ton/acre) of lime mixed in the top 15 cm (6 inches) of soil. The purpose of the deep tillage was to mix the clay-like spodic layer throughout the sandy upper profile materials (Knippling and Hammond, 1971).

Many attempts at installing and using subsurface drain lines in the Florida Flatwoods for rapid removal of excess soil water had encountered problems of clogging with ochre that formed when reduced iron was oxidized by aeration provided by the drain line itself during periods of low water tables (e.g., Ford, 1965, 1971, 1972, 1982). Therefore, two types of drain lines were installed: open (O, control) and submerged (S). The submerged drain lines

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were designed with an inverted water trap at the outflow end to retain water throughout the length of the drain line itself, whereas the open drain lines would allow water to drain out and air to freely enter the drain line at the outflow point. These drain lines were flexible 10-cm (4-inch) diameter, perforated, corrugated black plastic tubes, spaced laterally at 18.3 m. The drain lines were surrounded by 8–10 cm (3–4 inches) of silica gravel and covered by a 23-cm (9-inch) wide strip of polyethylene sheeting to prevent soil from entering the drain (Knipling and Hammond, 1971). The drain line trenches were back-filled with low organic matter sand.

The SWAP project system was planned and designed by a team of USDA-ARS, University of Florida, and other scientists and professionals, consisting of Soil Scientists, Horticulturalists, Plant Scientists, and Engineers (Knipling and Hammond, 1971; also see acknowledgements). The SWAP project system design was executed by contractors funded largely by USDA-ARS. The research that followed was conducted by a team of University of Florida and ARS scientists.

In 1968, after planning and design, the 20-ha site at the University of Florida's Indian River Research and Education center (lat. 27°25'42"-57" north; long. 80°24'13"-25" west) was cleared of vegetation (trees and palmetto). A perimeter ditch was dug to collect water from surface drainage. In 1969, the 1-ha (2.47-acre) blocks were prepared as ST, DT, or DTL treatments (Fig. 1). Sub-surface drains were installed and connected to concrete well-pipe

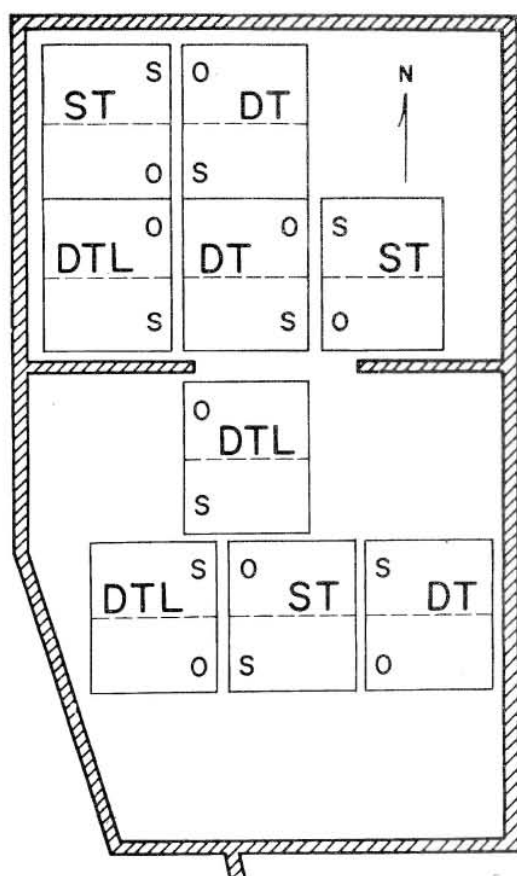


Fig. 1. Diagram of SWAP citrus field experiment at Fort Pierce showing perimeter drainage ditch and nine main plots (ST, DT, and DTL) with 18 split-plots (O and S). ST = Surface Tilled, DT = Deep Tilled, DTL = Deep Tilled + Heavy Lime. O = Open Drain and S = Submerged Drain. (Adapted from Knipling and Hammond, 1971 and Rogers et al., 1983.)

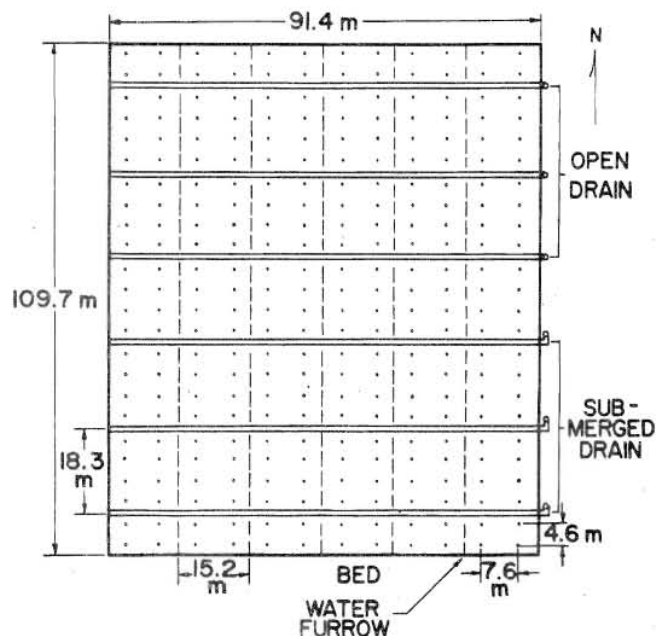


Fig. 2. Diagram of a 1-ha (2.47-acre) main plot of the SWAP citrus experiment at Fort Pierce showing north and south split plots with OPEN and SUBMERGED drains. Each dot shows the location of a tree on the two-row soil BEDS separated by a WATER FURROW. (Adapted from Knipling and Hammond, 1971 and Rogers et al., 1983.)

pits with drainage outflow measurement devices. Double-row, north-south beds were formed for surface drainage, and surface drainage outflow measurement weirs established for each half-block. Each half-block had 3 each of either open or submerged drain lines (Fig. 2). Each tillage treatment had three blocks with 12-tree-unit replications within each half-block (Alberts et al., 1971; Hammond et al., 1971; Knipling and Hammond, 1971; Stewart and Alberts, 1971). Trees were transplanted in Nov. 1970.

Within the objectives of the SWAP study, there were several hypotheses to be tested. The first hypothesis was that the deep mixing of the soil profile would provide better soil water and nutrient retention that would lead to improved water uptake and plant nutrition for the trees and, thereby, increase tree growth and fruit yields. An associated hypothesis was that deep mixing plus heavy liming would lead to even greater tree growth and higher fruit yields. The second hypothesis was that "submerged" subsurface drains would lead to less clogging by iron ochre and, thereby, also lead to better yields, especially over the long term. The third hypothesis was that rootstocks would perform differently among the various tillage and drainage treatments, and that a preferable rootstock or several preferable rootstocks, could be identified for use within these soil modification treatments.

A large factor in the economic viability of a citrus grove is the health and survivability of the trees. Therefore, the last of five citrus tree health and disease assessment conducted in Nov. 1984 will be an important part of these findings and summary. The hypothesis that yields are highly related to overall tree health will be tested.

Materials and Methods

The site description, soil profile treatments, drain line systems, and rootstock-scion combinations were described in the introduction and in papers of a symposium at the 1971 meetings of the

Soil and Crop Science Society of Florida, The SWAP Project in Florida. Listed in order, these papers were: Knipling and Hammond, 1971; Hammond et al., 1971; Stewart and Alberts, 1971; Alberts et al., 1971; Rogers et al., 1971; Overman et al., 1971; Fiskell, 1971; Calvert and Phung, 1971; Phung, 1971; Ford, 1971; Mansell et al., 1971). All cultural, fertilization, irrigation, and pest control activities in the grove were essentially the same according to best methods of citriculture. The primary method of yield responses were reported as cumulative annual yields with second-degree polynomial regressions (and r^2 values) over the years 1973–74 through 1984–85 to reflect the overall yield responses to the three tillage treatments, the two drain line treatments, and six rootstocks of the ‘Pineapple’ orange scion. The annual yield data had been summarized earlier as the number of 90-lb boxes of fruit per tree averaged over the surviving trees of the 12-tree units within the six rootstocks, three tillage treatments, and two drain line treatments. Average annual yields in boxes per tree were similar to multi-year yields of equivalent aged trees for the Indian River District of the Florida Commercial Citrus Production Areas (Florida Production Statistics 2009–10, 2011). [The only ‘Marsh’ grapefruit data available currently were mean annual yields of fruit within each of the three tillage treatments for the first nine years (Rogers et al., 1983)]. Upper and lower confidence bands of regressions lines at the 95% level obtained via SigmaPlot 11.0 software were used to document differences among treatments or rootstocks. Use of cumulative annual yields gives clearer information over the span of all years rather than over any year or small group of years. Citrus tree health and disease conditions of each rootstock-scion for ST, DT, and DTL tillage treatments were assessed in Nov. 1984 (Pelosi, 1985). A two-way analysis of variance (ANOVA) of rootstock-scion and tillage treatments was conducted on each health or disease condition using SigmaPlot 11.0. Pairwise comparisons on tillage treatments used the Holm-Sidak test.

Results and Discussion

Function of the SWAP systems

Ground water recession (falling water table) and subsurface drainage of the three tillage treatments in the SWAP site was measured from its inception (Alberts et al., 1971; Stewart and Alberts, 1971). During one 16-day rain-free period, average ground water recession rates followed the order of ST > DT > DTL treatments. Initial average ground water recession rates of the DT were almost as rapid as ST, but tended to become like DTL as days elapsed. Thus, deep tillage treatments could hold more soil water for uptake by the citrus trees. Slower ground water recession and greater soil water retention led to increased evapotranspiration in the order of DTL > DT > ST based on nine years of hydrologic data analyzed by Rogers et al. (1983). Many results of nutrient and pesticide losses from the grove, as well as water balances, have been reported elsewhere (Calvert, 1975; Calvert et al., 1981; Mansell et al., 1977, 1978, 1980, 1986; Rogers et al., 1977, 1982, 1983).

Citrus yields

Citrus yields for ‘Pineapple’ orange and ‘Marsh’ grapefruit were reported for years 3 and 4 (1975–76 and 1976–77) by Calvert et al. (1977), for year 5 (1977–78) by Calvert et al. (1980), and for years 7 and 8 (1979–80 and 1980–81) by Calvert et al. (1983). Long term mean annual yields of both scions by tillage treatment (ST, DT, and DTL) were reported by Rogers et al. (1982)

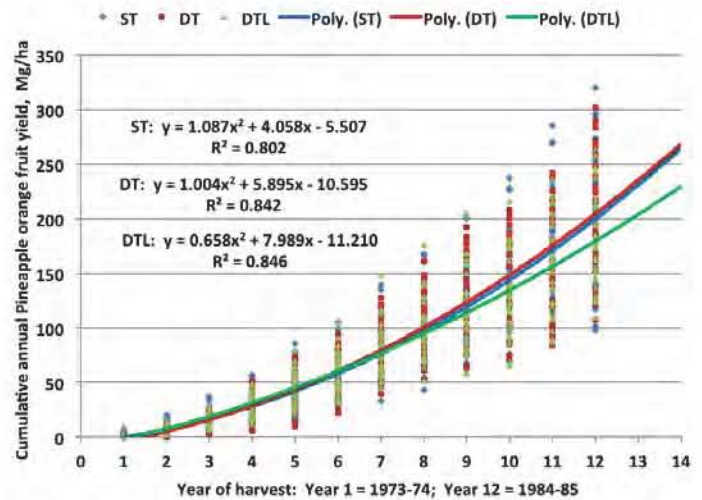


Fig. 3. Second-degree polynomial regressions of cumulative annual ‘Pineapple’ orange yields for 12 years from the SWAP site at the Indian River REC, Fort Pierce, Florida for tillage treatments of shallow tilled (ST), deep tilled (DT), and deep tilled plus heavy lime application (DTL). Calculated 95% confidence interval bands overlapped for all years except for DTL for harvest years 10, 11, and 12, and for extrapolated years 13 and 14 (data not shown). Therefore, yields in the DTL treatment began to fall behind yields in the ST and DT treatments beginning in harvest year 10.

for years 1 through 9 (1973–74 through 1981–82). However, no single publication provides data through the 12 years of records from 1973–74 through 1984–85. Therefore, data will be shown over the 12 years as cumulative annual yields that illustrate the effects of (i) ST, DT, and DTL tillage treatments averaged over all other treatments on fruit yield, (ii) open versus submerged drain lines averaged over all other treatments on fruit yield, and (iii) rootstocks averaged over all other treatments on fruit yield.

The impact of tillage treatments on cumulative annual ‘Pineapple’ orange yields is shown in Fig. 3 (based on second order polynomial regressions using Microsoft Excel). After 12 years, the cumulative annual yield regression lines were almost the same for the ST and the DT treatments, but yields from the DTL treatment were lagging. The 95% confidence interval bands for the regressions overlapped from the beginning to year 12 for the ST and DT treatments, but the confidence interval bands were separated slightly by year 12 for the DTL treatment (data not shown). Cumulative mean ‘Marsh’ grapefruit yields are shown in Fig. 4 for the 9 years of data reported by Rogers et al. (1983). (Detailed yield data for 12 years are not available for ‘Marsh’ grapefruit.) The 95% confidence interval bands for the regressions of Marsh grapefruit cumulative mean annual yields overlapped from the beginning to year 9 for all tillage treatments (data not shown). Thus there was no significant difference in cumulative yields among tillage treatments of either Pineapple orange or Marsh grapefruit. Therefore, the effort and expense of deep mixing would not appear to be warranted for citrus production on Spodosols in the Southern Florida Flatwoods Major Land Resource Area (USDA-NRCS, 2006).

The overall effect of submerged versus open drain lines on cumulative annual yield of ‘Pineapple’ orange is shown in Fig. 5. Citrus on submerged drain lines appeared to yield slightly better throughout the 12 years. However, the 95% confidence interval bands of the regressions for the two types of drain lines overlap for most years and the prediction interval bands overlap for all years (figure not shown), which indicates no better performance

for submerged drain lines. The hypotheses that deep tillage treatments and submerged drains would increase citrus yields were not supported by the 95% confidence interval bands around the second-degree polynomial regressions of cumulative yields. If the practice of mixing is not used, then by implication, higher beds and deeper water furrows for drainage and for furrow flood irrigation would alleviate the need for subsurface drainage. However, higher beds and deeper water furrows as used commonly in the Spodosols of the Florida Flatwoods was not part of the treatments of this study.

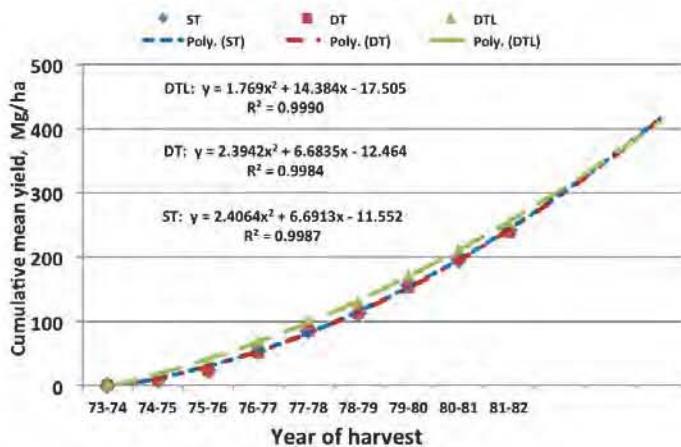


Fig. 4. Second-degree polynomial regressions of cumulative mean 'Marsh' grapefruit yields for n years from the SWAP site at the Indian River REC, Fort Pierce, Florida for tillage treatments of shallow tilled (ST), deep tilled (DT), and deep tilled plus heavy lime application (DTL). Regression lines were extrapolated from year of harvest 81-82 to 84-85. From harvest year 3 to harvest year 8, the low band of the 95% confidence interval of DTL was greater than the high band of the 95% confidence interval of either ST or DT treatments (data not shown). However, at harvest year 9, the 95% confidence interval bands overlapped. Furthermore, extrapolated 95% confidence interval bands completely overlapped by year 11.

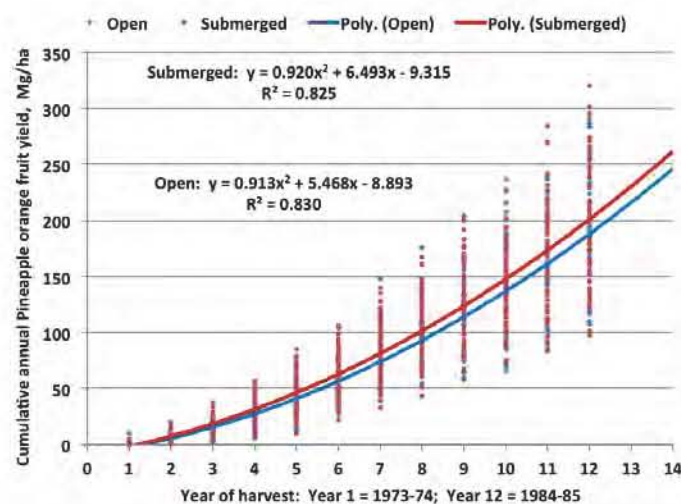


Fig. 5. Second-degree polynomial regressions of cumulative annual 'Pineapple' orange yields for 12 years from the SWAP site at the Indian River REC, Fort Pierce, Florida for drain line treatments of submerged outlet or open outlet. Calculated 95% confidence interval bands overlapped for harvest years 1 through 7, but barely did not overlap for years 8 through 12 (confidence interval bands not shown). However, extrapolated 95% confidence interval bands overlapped again for years 13 and 14.

The most interesting response of the study was the comparison of the performance (yields) of 'Pineapple' sweet orange on the six rootstocks (Fig. 6). The cumulative annual yields on the rootstocks appeared to separate into three groups. Fruit yields on Rough lemon, Rangpur lime, and Cleopatra mandarin rootstocks emerged as the highest toward the end of the 12 year period, and 95% confidence interval bands support this separation (Fig. 7). Cumulative annual yields on Sour orange and Carrizo citrange were intermediate. Yields on *Poncirus trifoliata* were lowest, and tended to be lowest from the beginning of the study. The hypothesis was that rootstocks would perform differently among the various tillage and drainage treatments, and that a preferable rootstock or several preferable rootstocks, could be identified for use within these soil modification treatments, was not really tested. However, grouping all tillage and drainage treatments, there was a clear separation of the performances of the rootstocks in this experiment based on 95% confidence interval bands around the second-degree polynomial regressions.

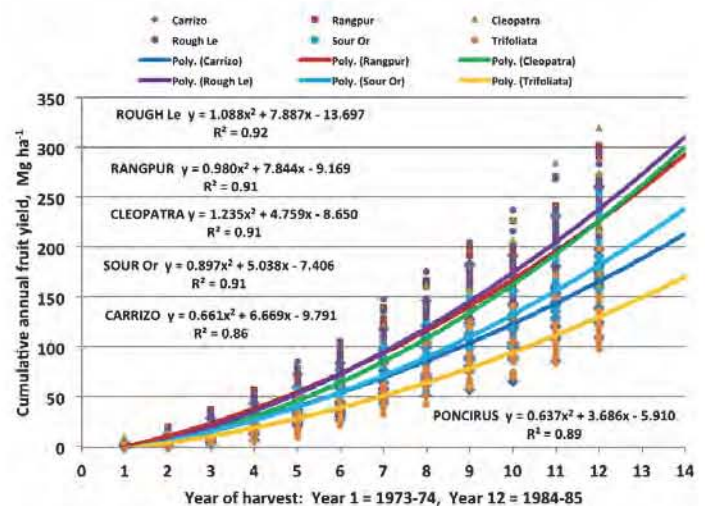


Fig. 6. Second-degree polynomial regressions of cumulative annual 'Pineapple' orange yields for 12 years for the six rootstocks from the SWAP site at the Indian River REC, Fort Pierce, Florida. (95% confidence interval bands shown in Fig. 7.)

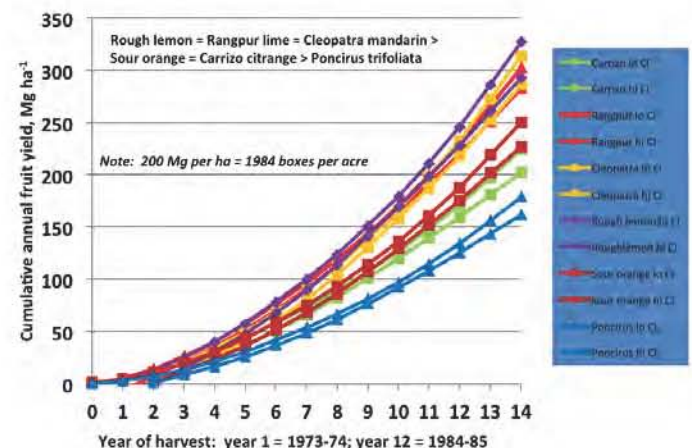


Fig. 7. The 95% confidence interval bands for second-degree polynomial regressions of cumulative annual yields of 'Pineapple' sweet orange on six rootstocks. Regression curves shown in Fig. 6.

In summary, tillage treatments had no effect on cumulative yields of either 'Pineapple' orange or 'Marsh' grapefruit. Likewise, the subsurface drain type had no effect on yields of 'Pineapple' orange. Based on absence of overlap of 95% confidence bands of second-degree polynomial regressions, after 12 years of yield measurements (Fig. 7), the cumulative annual yields for 'Pineapple' orange were significantly different among rootstocks, with cumulative annual yield rankings of Cleopatra mandarin = Rangpur lime = rough lemon > sour orange = Carrizo citrange > *Poncirus trifoliata*. In a study of the same rootstocks on a Spodosol at Indiantown, Florida, Castle et al., (2010b) found 'Valencia' orange cumulative yield rankings of rough lemon > Rangpur lime > Carrizo citrange > Cleopatra mandarin = sour orange > trifoliata orange after 12 years of harvests.

The impact of citrus health or diseases/disorders on yield of the various rootstocks, or the impact of various soil profile modification on development of citrus diseases/disorder are discussed after the results of the tree health assessment of Nov. 1984 are presented.

Tree health and disease assessment, Nov. 1984. Previous surveys of citrus tree health have been reported for 1980 (Cohen et al., 1981) and 1982 (Cohen et al., 1983). The fifth annual survey of citrus tree condition and diseases in the SWAP project was made during the week of Nov. 20, 1984 (Pelosi, 1985). Causes of tree decline were determined, if possible, for all unhealthy trees. Also, a special effort was made to look for citrus canker, but none was found. Another focus of the 1984 survey was to determine if a tree had several disease problems. Foot rot and blight had become common disease combinations on rough lemon rootstock. Likewise, water damage and blight had become common combinations on Carrizo citrange and *Poncirus trifoliata* rootstocks.

An overview of findings from the Nov. 1984 survey was as follows:

1. Average tree condition was much poorer than in previous years.
2. The number of healthy trees continued to decrease.
3. The number of trees with blight increased 30% above the number in Nov. 1983.
4. Overall incidence of blight in the DT treatment was lower than in other soil tillage treatments, but the annual rate of increase was similar.
5. A total of 47% of trees on rough lemon rootstock were in decline from blight in Nov. 1984, or were removed earlier due to blight.
6. An increase in foot rot occurred, particularly in the rough lemon rootstock.
7. By Nov. 1984, Tristeza [Citrus tristeza virus (CTV) disease (genus *Closterovirus*)] related to sour orange rootstock affected nearly twice as many trees of 'Pineapple' orange scions as 'Marsh' grapefruit scions.

ORIGINAL TREES HEALTHY IN 1984. (Fig. 8 and blue bars in Fig. 9). The SWAP citrus experiment originally contained 2592 trees. In Nov. 1984, 1490 or 57% of the original trees remained healthy. This is a decrease of 12% of healthy trees from the Nov. 1983 survey. 'Marsh' grapefruit on *Poncirus trifoliata* rootstock in all three soil treatments had the fewest healthy trees (Fig. 8). 'Pineapple' orange on Carrizo citrange rootstock had the poorest health for orange trees. For this scion-rootstock combination, only 18% of trees in DTL and 26% of trees DT treatments were healthy, whereas in the ST treatment 54% were healthy. Trees of

both scions on the Cleopatra mandarin rootstock remained the healthiest throughout the SWAP treatments, since 95% of the original trees on Cleopatra mandarin rootstocks were healthy, productive trees (Fig. 8). The two-way ANOVA showed significance (each $P < 0.001$) for tillage, rootstock-scion, and tillage X rootstock-scion. Pairwise tillage comparisons ST vs. DTL and ST vs. DT were significant ($P < 0.001$), but DT vs. DTL was not significant.

ORIGINAL TREES DEAD, MISSING, OR REPLANTED. (Green bars in Fig. 9). No large changes occurred in this category since the Nov. 1983 survey. Thirty-seven trees died or were removed in 1984. Two trees died from lightning and several died from foot rot (caused by *Phytophthora* spp.). Approximately 30 trees in severe decline were removed and replanted. The total number of trees dead, missing, or replanted was 305 in Nov. 1984. Sixty-two trees of 'Marsh' grapefruit on Rangpur lime rootstock constituted the largest rootstock-scion in this category. The next largest group with tree loss was rough lemon (40 or more of both scions). Tristeza claimed a number of trees on sour orange rootstock of both scions. Losses on *Poncirus trifoliata* rootstock have not been

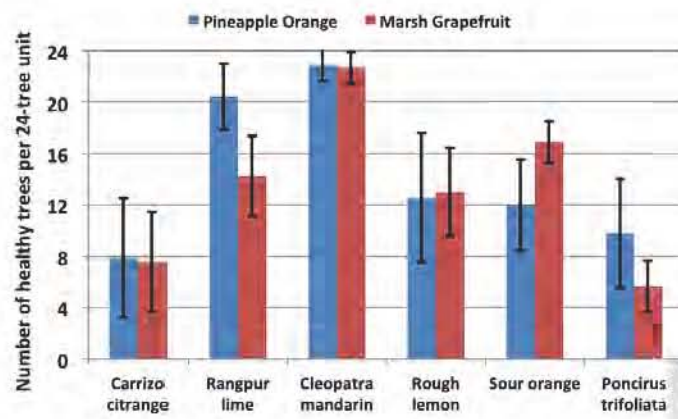


Fig. 8. Original SWAP citrus trees that were healthy in Nov. 1984. Means and standard deviations of nine 24-tree units across the three tillage treatments, ST, DT, and DTL. Error bars represent one standard deviation.

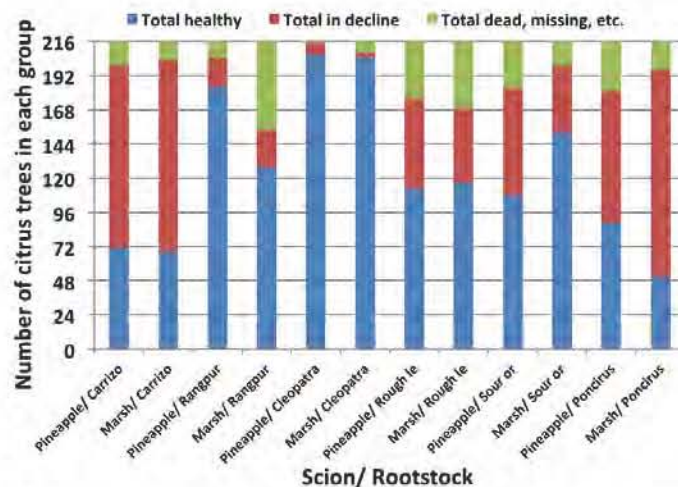


Fig. 9. SWAP citrus tree conditions in Nov. 1984. Total healthy, total in decline, and total dead missing, etc. for each scion/rootstock combination. Both scions on the Cleopatra mandarin rootstock had the highest percentage of trees in healthy condition.

as specific, but blight, water damage, and failure of growth in the ST plots claimed a total of 55 trees for both scions. The two-way ANOVA showed significance (each $P < 0.001$) for rootstock-scion and tillage X rootstock-scion but tillage differences were not significant. Pairwise tillage comparisons were all not significant.

TOTAL TREES IN DECLINE. (Red bars in Fig. 9). A total of 797 trees were in decline in Nov. 1994, an increase of 214 trees in decline from 1983. The largest increases were for those trees on Carrizo citrange and *Poncirus trifoliata* rootstocks affected by water damage. The breakdown in the underground drainage system for Blocks 6 through 9 had an effect, but that was not totally responsible as large increases also occurred in Blocks 1 through 5. Foot rot, blight, and tristeza also contributed to an increase in decline. The compound effect of two problems affecting the same tree made diagnosing cause of decline difficult. The two-way ANOVA showed significance for tillage and rootstock-scion (each $P < 0.001$) and tillage X rootstock-scion ($P = 0.009$). Pairwise tillage comparisons ST vs. DTL and ST vs. DT were significant ($P < 0.001$), but DT vs. DTL was not significant.

OVERALL TREE CONDITION. Using the 0-3 rating system (0 = healthy, 3 = nearly dead; data not shown), it was easy to assess the overall conditions of each rootstock/scion combination and the effect of the soil treatments on overall tree condition. Trees on Cleopatra mandarin rootstock appear in the best overall condition and had the best ranking throughout the SWAP project in the 1984 survey. Carrizo mandarin rootstock had the worst combined tree condition rating for both scions on all three soil treatments. 'Marsh' grapefruit on *Poncirus trifoliata* rootstock and 'Pineapple' orange on rough lemon rootstock follow with poor overall tree condition ratings. The average overall tree condition rating decreased from 0.194 in Nov. 1983 to 0.337 in Nov. 1984.

BLIGHT. (Red bars in Fig. 10). Blight continued to be a major citrus disease in the Ft. Pierce SWAP project. The number of trees with blight in Nov. 1984 was 152, an increase of 50 trees since Nov. 1983. Blight usually affects orange scions more than grapefruit scions, but in this experiment the cases were similar. Seventy-nine 'Marsh' grapefruit trees and 73 'Pineapple' orange trees had succumbed to blight. The DTL, ST, and DT treatments had 63, 52, and 36 trees with blight, respectively. Trees on rough lemon rootstock were the most severely affected (Fig. 10). Rough lemon rootstock had 47% of the original trees in decline or removed. The total of 101 trees with blight on rough lemon rootstock was divided almost equally between the two scions, 50 on 'Pineapple' orange and 51 on 'Marsh' grapefruit. The two-way ANOVA showed significance ($P < 0.001$) for rootstock-scion but tillage and tillage X rootstock-scion were not significant.

WATER DAMAGE. (Blue bars in Fig. 10). Water damage was assessed in two categories: "recent water damage" and "chronic water damage." However, these data are combined in Fig. 10. The year of 1984 was relatively dry with only 1138 mm (44.8 inches) of rainfall recorded. A decrease in water damage would be expected, but this was not the case. The Nov. 1984 data showed an increase of 199 trees with water damage compared to Nov. 1983. Water damage symptoms may not be predictable simply from total rainfall. The placement pattern of damaged trees was interesting. Trees with "recent water damage" were characterized with chlorotic leaf symptoms and a recent dieback, indicating a sudden unfavorable soil water situation had been imposed upon them after a period of good growing conditions. "Chronic water damage" trees were characterized as those usually stunted with dieback and darker green leaves, a condition assumed to occur because the top of the tree reached a new equilibrium with the root

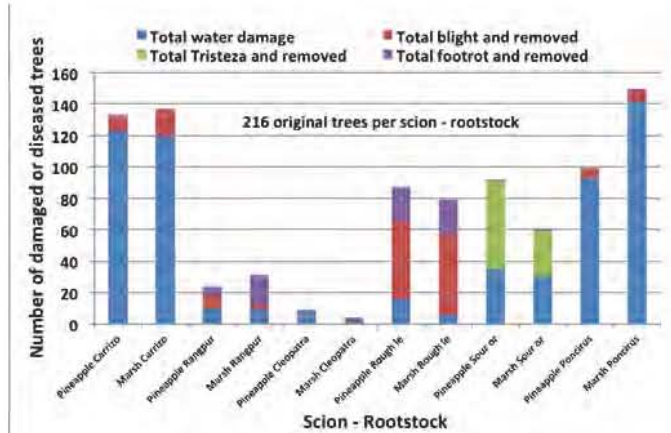


Fig. 10. Number of SWAP citrus trees of each scion-rootstock in Nov. 1984 that were either (1) water-damaged, (2) diseased with blight or removed earlier due to blight, (3) diseased with Tristeza or removed earlier due to Tristeza, or (4) diseased with foot rot from *Phytophthora* spp. or removed earlier due to foot rot.

system. Water damaged trees can vary between the two categories as wet conditions upset the root-top balance and the trees decline further, and then undergo some recovery. The malfunction of the drainage system that impaired proper drainage of Blocks 6 through 9 had a large effect on the condition of trees within these blocks. Block 6 had the most water damage in Nov. 1984 and almost doubled the Nov. 1983 total of water damaged trees, from 51 to 97 water-damaged trees. The largest percentage increase was in Block 8 where the number of water damaged trees increased from 11 in Nov. 1983 to 40 in Nov. 1984. Carrizo citrange and *Poncirus trifoliata* rootstocks appeared to be affected the most by water damage. Their performance on DT and DTL vs. ST suggests that these two rootstocks need a deeper, well-drained soil without a fluctuating water table. Trees that were evaluated with "chronic water damage" decreased in Nov. 1984 compared to Nov. 1983 since many of them shifted to symptoms of "recent water damage". The number of trees in both water damage categories totaled 592 in Nov. 1984, an increase of 199 trees from Nov. 1983 (but only 43 trees more than were recorded in Nov. 1982). This shift in the number of trees judged to show "recent water damage" and "chronic water damage" demonstrates the variability and recovery that is commonly observed with this water damage malady. The two-way ANOVA showed significance (each $P < 0.001$) for tillage, rootstock-scion, and tillage X rootstock-scion. Pairwise tillage comparisons ST vs. DTL and ST vs. DT were significant ($P < 0.001$), but DT vs. DTL was not significant.

TRISTEZA. (Green bars in Fig. 10). Tristeza affected trees only on sour orange rootstock. Tristeza in Nov. 1984 changed considerably compared with previous years. In previous years, 'Pineapple' orange and 'Marsh' grapefruit on sour orange were affected almost equally. This previous observation was unusual since orange trees were historically more susceptible than grapefruit trees. By Nov. 1984 the disease occurrence changed to a more expected situation; 56 'Pineapple' orange scions on sour orange rootstock (26% of the susceptible total) had declined from tristeza compared to 29 'Marsh' grapefruit scions on sour orange rootstock (13% of the susceptible total). Possibly mild strains of the *Closterovirus* had affected the 'Marsh' grapefruit trees on sour orange rootstock, giving them some measure of protection that they did not have earlier. Indexing for the disease several years previously showed healthy 'Marsh' grapefruit were free of any tristeza while those

in decline had a very severe strain. The 'Pineapple' orange trees from the beginning all had a mild strain of virus with the declining trees also containing a severe strain. The two-way ANOVA showed significance ($P < 0.001$) for rootstock-scion but tillage and tillage X rootstock-scion were not significant.

FOOT ROT. (Purple bars in Fig. 10). *Phytophthora*-induced foot rot appeared again in Nov. 1984. This disease was a very severe young tree problem much earlier in the experiment. Originally it attacked trees on Rangpur lime rootstock and an occasional tree on rough lemon rootstock. The incidence of foot rot tripled from 26 cases in Nov. 1983 to 76 cases in Nov. 1984. Rough lemon registered the largest increase rising from 17 to 43 trees. Rangpur lime rootstock trees accounted for 25 more while the remaining rootstocks had 1 to 3 affected trees. The two-way ANOVA showed significance (each $P < 0.001$) for rootstock-scion but tillage and tillage X rootstock-scion were not significant.

PROJECTIONS BASED ON TREE HEALTH. Fruit yields of 'Pineapple' orange on each rootstock for harvest year 12 were plotted as a second-degree polynomial with intercept (0,0) versus percentage of healthy trees in 1984 (not shown). The regression equation was:

$$y = -0.0021 x^2 + 0.588 x \text{ with } r^2 = 0.56,$$

where y = yield (Mg per ha) at 12 years and x = percentage of healthy trees at 12 years. Yield of *Poncirus trifoliata* was much lower than the regression line. Without this outlier, the yield regression was:

$$y = -0.0031 x^2 + 0.688 x \text{ with } r^2 = 0.86.$$

Poncirus trifoliata rootstock tends to be a low producer (Castle et al., 2010b and Fig 6). Except for this rootstock, percentage of healthy trees in Nov. 1984 was a good predictor of yield for that year. Thus, the hypothesis that yield is related to tree health is supported based on r -squared values of regression.

Although cumulative annual yields are limited to only 12 years, some precautions regarding longer term yields among the rootstocks seem likely from tree health conditions (Fig. 8 and Fig. 9). On the basis of this study at this location, yields of trees on rootstocks of *Poncirus trifoliata* and Carrizo citrange would likely fall behind due to water damage. Blight would likely decrease tree survival and yield on rough lemon rootstock. Although sour orange has been a highly used rootstock, tristeza disease could become a problem. Based on disease assessments in Nov. 1984, Cleopatra mandarin would seem to be the best choice. Unfortunately, the SWAP experiment ended before many of the expectation and cautions could be confirmed.

COMPARISONS WITH OTHER ROOTSTOCK STUDIES. Although Cleopatra mandarin rootstocks showed no blight at the SWAP site 14 years after transplanting, a recent study showed development of the disease after about 10 years on 'Valencia', a different sweet orange scion (Castle et al., 2010b). Furthermore, trees on Cleopatra mandarin rootstock showed a percent survival below 30% after 27 years at this coastal Flatwoods site at Indiantown, Florida, as did Rangpur lime and rough lemon rootstocks. However, Carrizo citrange and *Poncirus trifoliata* rootstocks had a survival of about 50% and trees on sour orange rootstock had a survival of 95%. Possibly calcareous soils at the Indiantown site might have contributed to these outcomes. In another experiment on a Flatwoods site (Myakka spodosol at St Cloud, FL) Castle et al. (2010a), reported that 'Hamlin' sweet orange trees on Cleopatra mandarin rootstock had an 89% survival after 11 years, whereas Carrizo citrange had only a 40% survival. These findings were more similar to the tree health conditions in the SWAP experiment

after 14 years where the Cleopatra mandarin rootstock had about 95% healthy trees with well over 95% survival. Furthermore, only about 1/3 of the trees on Carrizo citrange rootstock were healthy although survival was still above 90% at 14 years. In the SWAP experiment, the Cleopatra mandarin rootstock tended to be lower yielding in early years. Wheaton et al. (1991) also found this rootstock to be generally low yielding during early years of tree growth.

CONCLUSIONS. Disease incidence in citrus trees increased each year on the SWAP project. Except for trees on Cleopatra mandarin rootstock, the trees succumbed rapidly to the diseases or maladies that affect tree productivity and survival. In this study, none of the other rootstocks came close to the Cleopatra mandarin record of tree survival and health. Rootstocks are often judged by their average yield performance per tree but this can be misleading. A better gauge of performance would be to consider survival and project an overall yield based on average yield per tree multiplied by the number of productive trees for each rootstock-scion. Usually the Cleopatra mandarin rootstock ranks in the midrange for yield until trees are about 12 years old. In other rootstock experiments at Fort Pierce (e.g., Cohen and Reitz, 1964), yields on Cleopatra mandarin continued to increase after other rootstocks leveled off (Pelosi and Cohen, 1986). Yields on rough lemon rootstocks, an early leader, declined because of citrus blight, and yields on sour orange rootstock declined from tristeza disease (Pelosi and Cohen, 1986). The increase of yield over time coupled with high tree survival makes Cleopatra mandarin a good rootstock choice for a long term investment.

Among various rootstock studies (e.g., Castle et al., 2010a, 2010b; Davies and Zalman, 2001; Stover et al., 2004; Wutscher and Bowman, 1999; Wheaton et al., 1991; this study), there seemed to be a somewhat inconsistent range of productivity and survivability outcomes. These ranges of responses are likely to be related to site and soil conditions, rainfall and other climate conditions, fertilizer and water management, and current disease or insect problems, not to mention specific rootstock/scion sources and care of the transplants before, during, and after transplanting. Sour orange has remained a favored rootstock among growers in the Florida Indian River region (Stover and Castle, 2002) but HBL disease and new rootstock research and development might change this choice.

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