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## MULTI-SENSOR CAPACITANCE PROBES FOR MONITORING SOIL WATER DYNAMICS IN TROPICAL FRUIT ORCHARDS IN SOUTH FLORIDA

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**Abstract.** Determination of an effective method of monitoring water movement in the hard, porous limestone soil of south Florida should improve irrigation management for tropical fruit crops in the area. The effectiveness of multi-sensor capacitance probe systems for detecting rapid changes in soil water content and for determining crop water use were evaluated in commercial avocado, lime and carambola orchards in Miami-Dade County. These systems allowed us to detect changes in soil water content with high precision and were reliable for the measurement of real-time soil water dynamics and water use. They also allowed observing penetration depth of irrigation water and rainfall through the soil profile and changes in the amount of available water in the rhizosphere. This information can be used as the basis for irrigation scheduling to avoid insufficient irrigation resulting in crop stress, or over irrigation that may result in leaching of fertilizers and other chemicals into the groundwater.

The hard, porous oolitic limestone soil used for agriculture in south Florida has very low water- and nutrient-holding capacities. Consequently, large quantities of water and nutrients have been traditionally applied to the soil to insure adequate establishment of new plantings, crop growth, and yields (Schaffer, 1995). Excessive irrigation can enhance the leaching of pesticides and nutrients into the aquifer. Leaching of agricultural chemicals into the ground water can pose a threat to public health and environmentally sensitive areas, but also is a major expense to growers. Therefore, sustainable agricul-

tural practices, which incorporate efficient use of water, must be developed for tropical fruit crops in south Florida.

Due to the lack of crop-specific information, water management decisions are based largely on studies with other types of fruit crops conducted on soils other than those found in the tropical fruit production area of south Florida. Since these other soils often have little resemblance to those of Miami-Dade County, irrigation recommendations on which they are based are often grossly inaccurate. Furthermore, most growers in the area base irrigation rates and frequency on experience and observation of crop growth and yield rather than on quantitative scientific information. This empirical approach often results in inefficient irrigation scheduling with soil water content at optimum levels only rarely during the growing season. Hence, tree growth and yield may be limited by improper water balance due to either too little or too much water.

There is a need for a reliable technique capable of continuously measuring soil water content to efficiently manage irrigation in the oolitic limestone soil of south Florida. The best way to optimize crop water-use efficiency in orchards is by continuously monitoring soil water content in the root zone and adjusting irrigation to maintain soil water content below the field capacity but above the point where plants are adversely affected by drought stress (Schaffer, 1998). Recently developed multi-sensor capacitance probe systems which are commercially available provide critical, rapid, and continuous information on soil water content which eliminates guesswork and helps make accurate decisions of when and the length of time to irrigate (Buss, 1993).

Measurement of soil moisture content with a multi-sensor capacitance probe (EnviroSCAN, Sentek Environmental Innovations, Pty, Ltd., Kent, Australia) demonstrated that this technique was highly successful and accurate in measuring real-time soil water dynamics for irrigation scheduling, resulting in reduced water use and fertilizer leaching in several fruit and vegetable crops (Buss, 1989, 1993; Fares and Alva, 1999; Moller and Buss, 1994; Paltineanu and Starr, 1997; Starr and Paltineanu, 1998; Zekri et al., 1998). Multi-sensor capacitance probes had not been previously used to monitor soil water content in tropical fruit orchards on oolitic limestone

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soil in south Florida. This study was conducted to generate information that would help tropical fruit growers in south Florida to improve their irrigation management for optimum water-use efficiency and reduced leaching of agricultural chemicals. The objectives were: 1) to investigate the effectiveness and usefulness of multi-sensor capacitance probes (the EnviroSCAN system) for monitoring rapid changes in water content of a porous limestone soil, and 2) to test the system for optimizing irrigation scheduling for commercially-grown subtropical and tropical fruit trees in south Florida.

### Materials and Methods

This study was initiated in May 1997 in separate, commercial avocado (*Persea americana* Mill.), 'Tahiti' lime [*Citrus aurantifolia* (Christm.) Swingle] and carambola (*Averhoa carambola* L.) orchards in Homestead, Florida. The average annual precipitation in the area of 1350 mm is not evenly distributed throughout the year. The calcareous soil is classified as Krome very gravelly sandy loam-limestone complex.

A multi-sensor capacitance probe system (EnviroSCAN) was installed in each orchard. Each system consisted of a solar powered, central logging facility connected by cable to eight probes at several monitoring sites. Two probes were used per tree, one 1-2 m away from the trunk and the other in-row between two trees. All probes were placed within the root zone in the area watered by the irrigation system. Each probe was fitted with 4 capacitance sensors located at 10-, 20-, 30-, and 50-cm depths. These depths were chosen based on the expectation that the primary root activity would be at the top 30 cm of soil. The monitoring system was set to log soil water content continuously at 10-minute intervals.

The sensors utilize electrical capacitance to measure the complex dielectric constant of the soil and water medium. The changing ratio of air and water at each soil depth can be measured very quickly and accurately. The sensor readings are converted to volumetric soil water content using calibration equations. Soil water content data are downloaded to a computer and displayed in easy to read graphs that directly reflect crop water use and irrigation needs. Volumetric soil water content at each sensor is expressed as either a percentage or a depth of water in mm H<sub>2</sub>O per 10 cm of soil. The software provided with the EnviroSCAN system enables viewing the data by depth for a selected individual probe or cumulatively for several depths and/or probes.

Irrigation was provided either by a high volume sprinkler or microsprinkler system. Irrigation uniformity was evaluated by the Mobile Irrigation Laboratory (South Dade Soil and Water Conservation District). Suggestions and recommendations to improve efficiency of the irrigation systems were made to the growers. Incorporation of the Mobile Irrigation Laboratories suggestions resulted in improving emission uniformity, a measurement of how evenly the water is delivered to the crop in the irrigated area, to an average rate of 98%. In several orchards, a LI-1000 datalogger (LI-COR, Inc., Lincoln, NE, USA) with an automatic rain gauge and temperature sensors were installed to collect rain and soil and air temperature data at one-hour intervals.

### Results and Discussion

Figure 1 shows soil water dynamics at four depths for two probes during November 19-28 in a carambola orchard. Probes and sensor depths are shown on the y-axis. At the

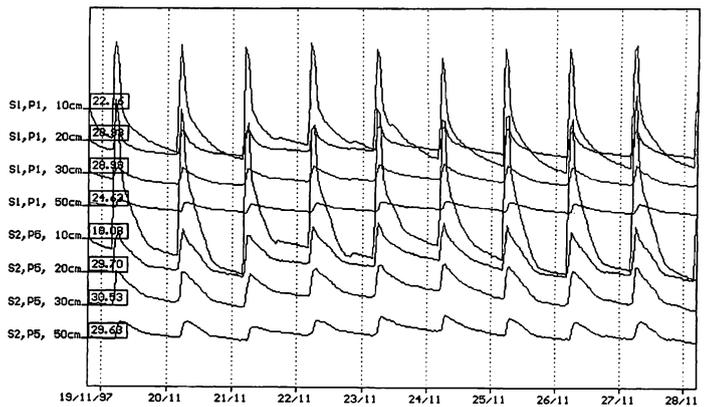


Figure 1. Soil water content at four depths for two probes in a carambola orchard during November 19-28.

point of intersection of each graph with the y-axis, soil water content values in percent volume for each depth are shown. Irrigation events were automatically controlled with a timer to occur daily. The sharp peaks in the soil water graphs for the 10-cm depth indicate a rapid and significant increase in soil water content, followed by rapid drainage of water following irrigation events. The highest fluctuations in soil water content occurred in the topsoil due to more soil water depletion as a result of drainage, soil evaporation and root uptake. The slight peaks at the 50-cm depth indicated that at each irrigation event, water reached that depth.

Figure 2 shows the changes in soil water content recorded at 4 depths on one probe in a carambola orchard. From the soil moisture data it is possible to determine when irrigation was initiated and ended and when irrigation water reached the 10-, 20-, 30-, and 50-cm depths. The increase in soil water content at a specific depth is a signal that irrigation penetrated to that depth. Irrigation was scheduled for 2 hours from 4:30 am through 6:30 am. Irrigation water reached the 10-, 20-, 30-, and 50-cm depths approximately at 4:45, 5:15, 5:45, and 6:35 am, respectively, which is illustrated by the initial increase in soil water content at those depths. From the graphs, the infiltration rate of water through the soil profile can be calculated. The data show that the water infiltration rate in the soil was relatively fast. It only took 2 hours for the water to penetrate to a depth of 50 cm. A plateau in soil water content can also be seen at 10, 20, and 30 cm, illustrating the period

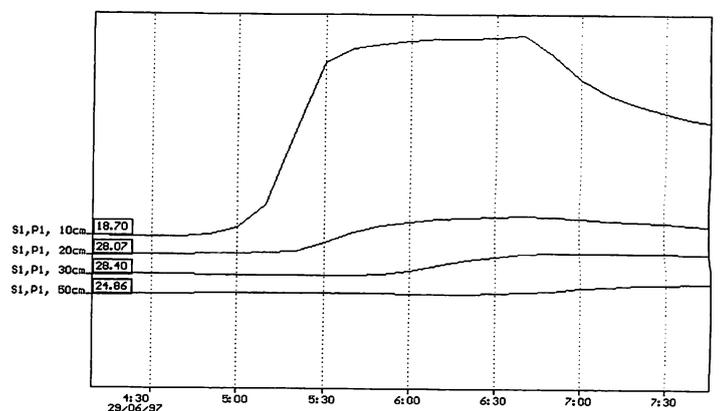


Figure 2. Soil water content at four depths on one probe in a carambola orchard.

for which the soil was saturated. These data show the degree to which multi-sensor capacitance probes can be used to adjust the exact amount of irrigation water to be applied with minimum leaching below the crop root zone.

Figure 3 shows soil water dynamics at 10-, 20-, 30-, and 50-cm depths from June 24 through July 7 in a lime orchard. Two rainfall events occurred on June 24 as indicated by the two peaks on the line representing the 10-cm probe. Water from the first rainfall event reached the 20- and 30-cm depths, but had no effect on soil water content at the 50-cm depth. On the other hand, the water added during the second rainfall event was able to push the waterfront further down the soil profile to reach the 50-cm depth, which is illustrated by an increase in soil water content at that depth. The depth of water penetration with each rainfall or irrigation event is directly related to the internal soil water content and the quantity and intensity of water applied (Starr and Paltineanu, 1998). Since no rainfall or irrigation events occurred from June 25 through July 7, soil water content changes were attributed solely to drainage and crop water use or evapotranspiration. During that dry period, soil water content at the 50-cm depth was not significantly affected. However, daily water use was significant at the top 20-cm of soil as characterized by the steep slopes of the lines representing the soil water content at the 10- and 20-cm depths.

The development of step-like diurnal changes in soil water storage indicates daily water removal primarily by plant uptake with little nighttime losses by drainage. The horizontal segments of the steps or stairs correspond to the minimal night water losses and the oblique segments of the steps indicate the drastic change in soil water content due to evapotranspiration during the day. When most available water was depleted at the top 20-cm of soil and the roots within that zone were unable to extract more water (represented by reduced water use and small changes in water content at the 10- and 20-cm depths), deeper roots at the 30 cm layer became more active in absorbing water to satisfy the crop need. This is illustrated by the stair-like water-use pattern beginning on June 29 at the 30-cm depth. At this point, the crop may have suffered from water stress, due to the inability of the majority of the root system near the surface to satisfy the water needs of the crop. At this point, an irrigation event would have been useful. The flat curve for the 50-cm depth demonstrates that no active roots were present at that depth. This figure clearly shows the depth of active roots. With regards to irrigation

management, increasing soil water content at the 50-cm depth was wasted because it was below the root zone.

A large-scale plot of the data collected from an avocado orchard provides a close-up view for 24-hour crop water use on August 13 (Fig. 4). The summed graph represents the data collected from the top 3 (10-, 20- and 30-cm depth) sensors of all 8 probes. Soil water content in the top 30 cm of soil was reduced from 59 mm at midnight on August 12 to about 54 mm at midnight on August 13. Evapotranspiration can be estimated to be 5 mm for August 13. The multi-sensor capacitance probe system allows the grower to accurately measure the exact amount of water being used by the crop at any interval of time and replenish that same amount to optimize irrigation scheduling.

Soil water content data plotted as cumulative soil water content of the 10-, 20-, and 30-cm depths show water dynamics in the soil profile for a 2-week period in a lime orchard (Fig. 5). The full point (field capacity) and refill point (irrigation point) were at 72 and 65 mm, respectively. The full point is defined as the highest water content that the soil comprising the crop root zone can hold after drainage has been substantially reduced. The "onset of stress" point is the driest the soil can be before evapotranspiration is significantly reduced. The refill point should be set to irrigate the crop approximately one-day before the onset of stress. After it rained on June 24, which brought the soil water content above the full point, the soil profile lost most of its available water in 5 days and the soil water content reached the onset of stress point in 6 days. To avoid the onset of stress, this block should not have been kept without irrigation for more than 5 days. With no rain, an irrigation event should have been scheduled before the end of June. The irrigation regime must be manipulated so that the soil water content in the root zone is within the optimum range causing no waterlogging conditions or water stress.

Optimal irrigation scheduling is achieved by irrigating only as frequently as needed to prevent yield-reducing drought and flooding stresses so that the economic return is maximized. The aim of the grower should be to maintain soil water content between the full and the onset of stress points. This is illustrated in Figure 6 where the soil water content in the lime orchard was kept above the onset of stress, and between the full point and the refill point. The summed graph represents the data collected from the sensors at the 10- 20- and 30-cm depths of all 8 probes from December 31 through January 23. The multi-sensor capacitance probe system pro-

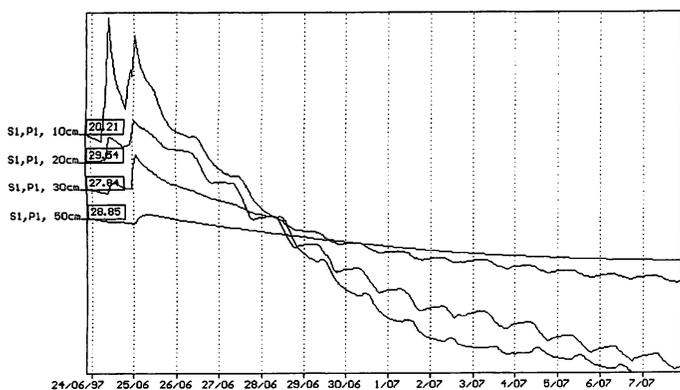


Figure 3. Soil water content at four depths in a lime orchard from June 24 through July 7.

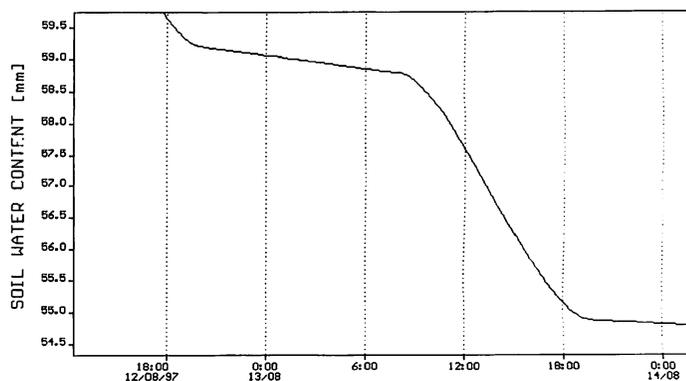


Figure 4. Soil water content in an avocado orchard indicating 24-hour crop water use on August 13.

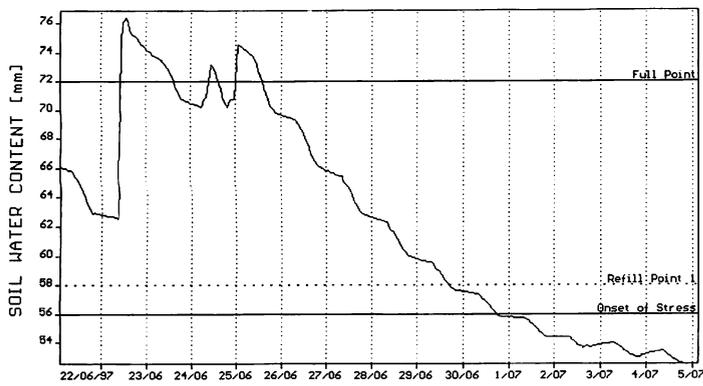


Figure 5. Cumulative soil water content at four depths in a lime orchard during a 2-week period.

vided the grower with very useful information, which allowed the examination of the water status in the soil profile to prevent over-watering or crop stress.

### Conclusions

The use of multi-sensor capacitance probes can provide a continuous record of soil water content, allowing tropical fruit growers to fine-tune their irrigation management strategy. Monitoring water use in different areas of the root zone showed that the root system was most active in the top 30 cm

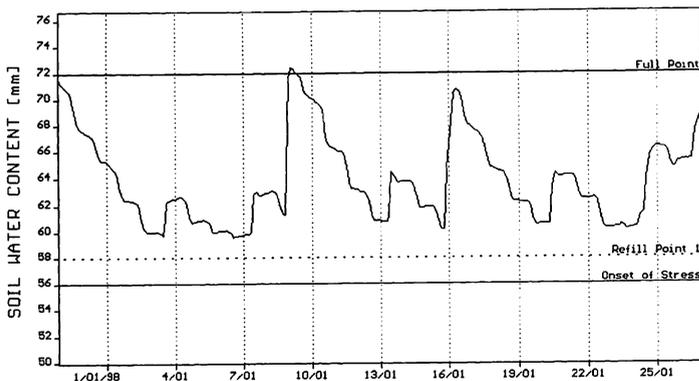


Figure 6. Soil water content at the 10- 20- and 30-cm depths in a lime orchard from December 31 through January 25.

of the soil profile. This critical information can be used to target fertilizer application within the active root zone by only applying enough water to wet the top 30-cm of soil. Placing water in the top 30 cm of the root zone would prevent leaching, resulting in the majority of fertilizer being taken up efficiently by the crop. The multi-sensor capacitance probe system indicated exactly the penetration of the rainfall and the bearing that rainfall had on available soil moisture.

The multi-sensor capacitance probe system was a very sensitive and effective tool in monitoring soil water dynamics in the porous oolitic limestone soil of south Florida. The data generated by the system was useful for quantifying evapotranspiration and monitoring root activity, and therefore can be used as the basis for accurate irrigation management decisions. With the aid of multi-sensor capacitance probe systems, it is possible to make daily adjustments to the amount of water required and the timing of application according to the crop changing needs during the year, resulting in optimum irrigation scheduling for tree growth, increased yield, and improved crop quality.

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