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REVIEW

Flooding Responses and Water-use Efficiency of Subtropical and Tropical Fruit Trees in an Environmentally-sensitive Wetland*

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Agriculture is often viewed as having a negative impact on natural ecosystems. However, agriculture can contribute to maintaining these ecosystems by serving as a buffer between natural and urban areas. If agriculture is to coexist with the natural environment, crop production practices must be profitable and sustainable. This often requires optimizing crop productivity while minimizing agricultural inputs. The largest wetland restoration project in history is underway in the Florida Everglades to restore the natural ecosystem by increasing water flows to re-establish the natural hydrology. This area is also agriculturally unique because it is the only region in the continental United States where several species of subtropical and tropical fruit crops are commercially grown. In agricultural areas adjacent to Biscayne and Everglades National Parks in southern Florida, studies with subtropical and tropical fruit trees are currently aimed at keeping agriculture viable whilst having no negative impact on the natural wetland ecosystem. Research has focused on determining the effects of continuous and cyclical flooding on physiology and growth of the major subtropical and tropical fruit tree species grown in south Florida. Furthermore, attempts are being made to increase crop water-use efficiency to reduce chemical leaching into the aquifer. This is being done by continuously monitoring soil water content with multi-sensor electrical capacitance probes and adjusting the soil water content to reduce drainage and leaching of agricultural chemicals below the root zone and to avoid the onset of plant water stress. Crop research methodologies used in south Florida should be applicable to other areas of the world where sustainable agriculture may be the 'best neighbour' to environmentally-sensitive natural habitats.

Key words: Fruit crops, wetlands, adaptation, flooding, water quality, leaching, sustainable agriculture tropical fruit.

INTRODUCTION

What maybe the most costly natural wetland restoration project in history is underway in southern Florida to restore the natural ecosystem of the Everglades National Park. In the past, water levels in this area have been lowered by a series of canals built to provide flood protection to adjacent urban and agricultural areas. Recent efforts by several state and federal agencies of the United States are underway to restore the natural hydrology of the Everglades by increasing the flow of water into the area. This will undoubtedly have an impact on crops growing adjacent to this wetland (Lord, 1993; Davis and Ogden, 1994).

There are approximately 25000 ha of agricultural land between the Biscayne and Everglades National Parks in south Florida, with subtropical and tropical fruit crops comprising about 5500 ha. The major fruit crops in the area are avocado (*Persea americana* Mill.), mango (*Mangifera indica* L.), Tahiti lime (*Citrus* × Tahiti) and carambola or starfruit (*Averrhoa carambola* L.). There is also limited commercial production of several other fruit species, including atemoya (*Annona squamosa* L. × *Annona cherimola* Mill.), lychee (*Litchi chinensis* Sonn.), longan [*Euphoria longan* (Lour.) Steud.], banana (*Musa* spp.) and papaya (*Carica papaya* L.) (Schaffer, 1995). Sustaining fruit tree production in areas adjacent to the protected natural wetlands maintains a commercially viable buffer zone between the rapidly expanding urban areas and the native wetlands. The alternatives to maintaining crop production in areas bordering natural wetlands are to allow urban encroachment or leave the land fallow, thus increasing the potential for invasion of exotic weed species that can threaten the native habitat.

For crop production to serve as a buffer between the urban areas and the natural wetlands, it is essential to: (1) identify crops that can tolerate a high water table during the wet season; and (2) ensure that crop production has no negative impact on the natural ecosystem through the leaching of agricultural chemicals into the aquifer. Thus, a considerable amount of agricultural research in south Florida near the Everglades and Biscayne National Parks has focused on determining responses of subtropical and tropical fruit trees to flooding and improving the water-use efficiency of these crops.

This paper reviews studies with subtropical and tropical fruit trees in south Florida aimed at improving crop sustainability in an environmentally-sensitive wetland ecosystem. The review is divided into two main sections. The

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first section discusses responses and adaptations of subtropical and tropical fruit crops to flooding stress. The second section focuses on improving water-use efficiency to reduce the potential for leaching of agricultural chemicals into the groundwater.

RESPONSES OF SUBTROPICAL AND TROPICAL FRUIT CROPS TO FLOODING

Agricultural areas between Biscayne and Everglades National Parks in south Florida are prone to periodic flooding (Fig. 1) due to their relatively low elevation and naturally high water table. Additionally, the water table has been artificially raised in this area as a result of new water delivery and management practices in Everglades National Park (Poole, 1996). These activities have resulted in a recent increase in the severity, duration and extent of flooding in tropical fruit production areas that were previously subject to only rare and minor flooding during the rainy season. Future plans to further elevate water tables in the park will impact on fruit crop production in the adjoining areas. In order to sustain fruit crop production in these areas, it is essential to understand the impact of flooding on physiology, growth and yield of fruit crops and to identify crops and production systems that are adapted to flood-prone areas.

Plant responses and adaptations to flooding stress have been reviewed by Kozlowski (1984, 1997) and Vartapetian and Jackson (1997). Specific responses of a wide range of fruit crops to flooding have been reviewed by Rowe and Beardsell (1973) and more recently by Schaffer, Anderson and Ploetz (1992). This section focuses on flooding responses and adaptations of the major subtropical and tropical fruit trees grown in the oolitic limestone soils adjacent to Biscayne and Everglades National Parks in southern Florida.

Flooding detrimentally affects many tropical and subtropical fruit tree species cultivated in Florida, including avocado (Ploetz and Schaffer, 1987, 1989; Schaffer and Ploetz, 1989; Schaffer *et al*., 1992), mango (Larson, Davies and Schaffer, 1991*a*; Larson, Schaffer and Davies, 1991*c*, 1992, 1993; Schaffer, Whiley and Crane, 1994; Whiley and Schaffer, 1997), carambola (Joyner and Schaffer, 1989), citrus (Phung and Knipling, 1976; Syvertsen, Zablotwicz and Smith, 1983; Schaffer and Moon, 1990), and several species in the genus *Annona* (Purseglove, 1968; George, Nissen and Brown, 1987). The primary effect of flooding on these crops is a reduction in root and shoot growth due to depletion of soil oxygen (Larson, Graetz and Schaffer, 1991*b*; Schaffer *et al*., 1992). In southern Florida, the majority of subtropical and tropical fruit trees are grown in oolitic limestone soil (Krome very gravely loam; loamy-skeletal, carbonatic, hyperthermic Lithic Rendoll; Noble, Drew and Slabough, 1996). Under certain conditions, short-term flooding in these soils may actually be beneficial to subtropical and tropical fruit crops. Flooding alters the oxidation reduction status of the soil, reducing the redox potential due to chemical changes and various byproducts of soil microbes (Ponnamperuma, 1972, 1984). The rate of soil reduction is related to soil pH (Cho and Ponnamperuma, 1971; Ponnamperuma, 1984). The oolitic limestone soils of southern Florida are alkaline (pH = 7·4–8·4) (Larson *et al*., 1991*b*; Noble *et al*., 1996). Flooding decreases the pH of alkaline soils (Ponnamperuma, 1972), allowing particle-bound nutrient elements such as iron, magnesium and manganese to become more soluble (Larson *et al*., 1991*b*). Flooding of mango trees in calcareous soils resulted in a significant increase in absorption of magnesium and iron (Larson *et al*., 1992).

FIG. 1. Flooding of a mango (*Mangifera indica* L.) orchard near the Everglades National Park in southern Florida after 3 d of heavy rainfall.

Similar to other woody perennial plant species (Kozlowski, 1984, 1997; Schaffer *et al*., 1992), the earliest symptoms of flooding stress of subtropical and tropical fruit trees are reductions in net CO_2 assimilation, stomatal conductance and transpiration. Prolonged flooding usually results in a cessation of root and shoot growth, wilting, decreased nutrient uptake, and often tree death (Schaffer *et al*., 1992). Some subtropical fruit trees, such as mango and carambola can adapt to short-term flooding, although growth is often reduced (Joyner and Schaffer, 1989; Schaffer *et al*., 1994).

A considerable amount of research has been conducted to investigate growth and physiological responses of avocado and mango trees to flooding. Avocado is generally considered a very flood-sensitive species (Schaffer *et al*., 1992; Whiley and Schaffer, 1994). Short periods of flooding often result in leaf abscission and inhibition of leaf expansion resulting in smaller leaves (Schaffer *et al*., 1992). Thus, flooding of avocado generally leads to a reduction in shoot growth (Stolzy *et al*., 1971; Ploetz and Schaffer, 1987). Short-term flooding of avocado has been shown to cause root necrosis (Ploetz and Schaffer, 1987, 1989; Schaffer and Ploetz, 1989) and inhibition of root growth (Stolzy *et al*., 1971). In avocado trees with a high shoot:root ratio, only a few days of flooding can result in tree mortality. Phytophthora root rot (caused by the fungal pathogen *Phytophthora cinnamomi* Rands) if left uncontrolled, is the major limitation to avocado tree growth and production (Zentmyer, 1980). However, in the oolitic limestone soils of south Florida, Phytophthora root rot causes severe damage only under flooded conditions (Ploetz and Schaffer, 1987, 1989; Schaffer and Ploetz, 1989; Schaffer *et al*., 1992).

Net CO_2 assimilation declines shortly after avocado trees are flooded (Schaffer *et al*., 1992; Whiley and Schaffer, 1994). Furthermore, there is an additive negative effect of

flooding and Phytophthora root rot on stomatal conductance and photosynthesis of avocado (Ploetz and Schaffer, 1987, 1989; Schaffer and Ploetz, 1989; Schaffer *et al*., 1992; Whiley and Schaffer, 1994). Non-flooded avocado trees with high levels of root necrosis (greater than 50 %) due to Phytophthora root rot exhibited a 65 % decrease in stomatal conductance and net CO_2 assimilation, whereas in flooded conditions as little as 20 % root necrosis resulted in almost complete inhibition of photosynthesis (Schaffer and Ploetz, 1989; Schaffer *et al*., 1992). Flood-induced reductions in net CO_2 assimilation of avocado trees could not be attributed to a reduction in CO_2 diffusion into the leaf since decreases in leaf conductance were not observed at the time of reductions in net CO_2 assimilation (Schaffer *et al*., 1992). Reductions in net CO_2 assimilation of avocado as a result of flooding were attributed to non-stomatal factors such as biochemical changes associated with photosynthetic reactions (Schaffer *et al*., 1992).

Flooding reduces the transpiration rate of avocado trees (Ploetz and Schaffer, 1987; Schaffer *et al*., 1992) and this is most likely the result of reduced stomatal conductance rather than a hydraulic effect, since flooding did not significantly decrease the xylem water potential (Schaffer *et al*., 1992). Phytophthora root rot exacerbates the effects of flooding on inhibition of transpiration (Ploetz and Schaffer, 1987; Schaffer *et al*., 1992). For avocado trees infected with Phytophthora root rot, under flooded or non-flooded conditions, reduced transpiration may be due to decreased hydraulic conductivity. This is based on observations that *Phytophthora* infection alone or in conjunction with flooding reduced xylem water potential compared to that of non-flooded or flooded, non-infected trees (Schaffer *et al*., 1992; Whiley and Schaffer, 1994). Whiley and Schaffer (1994) proposed that reduced transpiration in flooded, non-infected avocado trees is due to reduced stomatal conductance, whereas reduced transpiration of flooded, diseased plants is partly the result of decreased hydraulic conductivity.

Flood tolerance of avocado in calcareous soils has been increased by inhibiting the development of Phytophthora root rot with fungicides prior to flooding (B. Schaffer and R. C. Ploetz unpubl. res.). However, this only reduces the rate as which avocado trees succumb to flooding stress and is therefore not a long-term solution. The only practical solution for growing avocado trees in flood prone areas would be the development of flood-tolerant rootstocks.

Mango is considered to be a moderately flood-tolerant species (Schaffer *et al*., 1994; Whiley and Schaffer, 1997). However, vegetative growth of mango trees generally declines if trees are flooded for more than 2–3 d. When containerized trees growing in limestone soil were flooded for more than 110 d there was a 94 % reduction in shoot extension growth, while flooding for approx. 10 d resulted in a 57 % reduction in shoot extension growth (Larson *et al*., 1991 *a*). In a subsequent study, stem radial growth (a more sensitive indicator of tree growth than shoot extension growth) of mango trees decreased 2 weeks after roots were submerged. Flooding for more than 14 d also significantly reduced root dry weight, resulting in an increased shoot to root ratio (Larson *et al*., 1991 *a*). These adverse effects of flooding on the growth of mango trees resulted from reduced net CO_2 assimilation rates and presumably higher root respiration rates that limited the availability of carbon-based assimilates required for growth (Whiley and Schaffer, 1997).

FIG. 2. Hypertrophied lenticels on the stem of a flooded mango (*Mangifera indica* L.) tree.

Although continuous flooding adversely effects mango trees, short-term or cyclical flooding of trees in limestone soils can result in increased micronutrient availability and improved plant nutritional status. In calcareous soils of south Florida, after removing mango trees from 10–20 d of flooding, the net CO_2 assimilation rate rose to above pre-flooding levels (Larson *et al*., 1992). This increase was correlated with improved iron and manganese uptake as a result of these elements becoming more soluble when calcareous soils were flooded (Larson *et al*., 1991 *c*, 1992).

Adventitious roots have occasionally been observed on mango trees above the water-line when container-grown trees have been flooded for long periods (Schaffer *et al*., 1994; Whiley and Schaffer, 1997). It is likely that these roots facilitate the absorption and translocation of O_2 to submerged roots (Kozlowski, 1997). Development of adventitious roots is a common morphological response of many woody plants to root anoxia. The development of these roots has not been reported for flooded, field-grown mango trees and they may only form on young plants after extended flooding periods which usually do not occur under normal production conditions.

The ability of mango trees to survive prolonged flooding appears to depend on the development of hypertrophic (swollen) stem lenticels immediately above the water line (Fig. 2). The initial stages of lenticel hypertrophy are

characterized by the development of intercellular spaces in the phellem tissue and production of additional phellem tissue by increased phellogen activity. Later stages of hypertrophy are characterized by the development of intercellular spaces in the phellem tissue and cortex (Larson *et al.*, 1991*b*). Observations vary among studies as to whether trees developed hypertrophic lenticels and how quickly they formed after flooding. These anomalies have been attributed to environmental differences at the time of root submersion (Larson *et al.*, 1991*a*). In trees that died as a result of flooding stress there was no lenticel hypertrophy; however, stem lenticels hypertrophied within 4–10 d on mango trees that survived flooding (Larson *et al.*, 1991*c*, 1993). Sealing hypertrophic lenticels of mango trees with silicone grease or petroleum jelly resulted in trees dying within 3 d of flooding, demonstrating their necessity for tree survival (Schaffer *et al.*, 1994). Similar to other woody perennial plant species, hypertrophic lenticels in mango trees probably enhance O_2 diffusion to the roots (Kozlowski, 1984). There is also evidence that hypertrophic lenticels serve as excretory sites to eliminate potentially toxic compounds such as ethanol, acetaldehyde and ethylene which result from anaerobic metabolism in the roots (Chirkova and Gutman, 1972). Larson *et al.* (1993), observed that flooded mango with little oxygen (1–2% O_2) in the floodwater exuded significantly more ethylene from the lenticels than trees in artificially oxygenated (10–20% O_2) floodwater. Recent research has focused on determining the relationship between mango genotypes and the ability to form hypertrophied lenticels under flooded conditions (B. Schaffer, unpubl. res.). Thus, lenticel hypertrophy may be a useful mechanism to screen mango cultivars for flood tolerance.

Averrhoa carambola (starfruit) has the potential to be cultivated in areas subjected to periodic flooding. In two independent studies, continuous flooding of starfruit trees (for 14 or 35 d) resulted in decreased net CO_2 assimilation, transpiration and stomatal conductance rates. However, when these trees were removed from flooded conditions, net CO_2 assimilation, transpiration and stomatal conductance returned to pre-flood rates (Joyner and Schaffer, 1989; Ismail and Noor, 1996). There appear to be differences in flood-tolerance among starfruit cultivars. Seedlings of the cultivar 'Golden Star' were able to recover from up to 35 d of continuous flooding (Joyner and Schaffer, 1989), whereas trees of the cultivar 'B17', grafted onto the cultivar 'B2', did not survive 25 d of continuous flooding (Ismail and Noor, 1996). Flood tolerance of grafted fruit trees is mainly determined by the rootstock and not the scion (Rowe and Beardsell, 1973; Schaffer *et al.*, 1992). For example, flood tolerance of Tahiti lime (*Citrus* × Tahiti) scions, determined by measuring leaf gas exchange rates, varied considerably among trees grafted on different rootstocks (Schaffer and Moon, 1990). Thus, the potential exists to identify flood-tolerant starfruit cultivars or rootstocks for flood-prone areas.

Starfruit, cultivar 'Golden Star', trees were able to recover from intermittent flooding (repeatedly flooded for 21 d, unflooded for 21 d or flooded for 21 d unflooded for 42 d) as indicated by recovery of net CO_2 assimilation, transpiration and stomatal conductance rates to near pre-flood levels after each flooding period. Although continuous (Joyner and Schaffer, 1989; Ismail and Noor, 1996) and intermittent (Joyner and Schaffer, 1989) flooding decreased shoot and root dry weights, flooding increased the floral initiation and the number of fruit per tree (Joyner and Schaffer, 1989; Ismail and Noor, 1996). Fruit crops grown in the south Florida Everglades are often subjected to cyclical flooding depending on the amount and length of each rainfall. Their tolerance to, and increased fruit production in, flooded soils may make some starfruit cultivars ideal for cultivation in the area. Further research is warranted to assess horticultural characteristics of various starfruit cultivars and scion/rootstock combinations under conditions of intermittent flooding in the Everglades before a flood-tolerant cultivar can be recommended for the area.

FIG. 3. A pond apple (*Annona glabra* L.) tree growing in water in Everglades National Park, Florida.

Commercial fruit crops in the Annonaceae family such as cherimoya (*Annona cherimola* Mill.), ilama (*Annona diversifolia* Saff.), sugar apple (*Annona squamosa* L.) and atemoya (*Annona squamosa* × *Annona cherimola*) are considered susceptible to waterlogging (Morton, 1987; Popenoe, 1920). Flooding of commercial *Annona* spp., even for short periods, reduces growth, may cause defoliation, and severely reduces flowering and fruit set (Marler *et al.*, 1994). Pond apple (*Annona glabra* L.), a species of *Annona* with no commercial value (Popenoe, 1920), is native to the tropical Americas, including south Florida. *Annona glabra* is extremely flood tolerant (Popenoe, 1920; Zotz, Tyree and Patiño, 1997), and has been commonly referred to as 'swamp loving' (Popenoe, 1920) (Fig. 3).

Varieties of *Annona* spp. used for fruit production are generally grown as seedlings or on seedling rootstocks of *A. squamosa* or *A. squamosa* × *A. cherimola*. Graft compatibility of commercial *Annona* spp. onto *A. glabra* rootstock is generally good (George *et al.*, 1987) and incompatibility can usually be overcome by the use of compatible interstocks (G. Zill, Zill's High Performance Plants Nursery, Florida, pers. comm.). Recent studies suggest that grafting commercial *Annona* species and cultivars onto *A. glabra* rootstock may increase flood tolerance. Atemoya trees, cultivar '49-11' (a hybrid of *Annona* spp. hybrid × *Annona reticulata* L.), grafted on *A. glabra* rootstock had significantly higher net CO_2 assimilation rates after flooding

compared to the same plants grafted on *Annona reticulata* rootstock. Trees of '49-11' on *A. glabra* rootstock survived prolonged flooding (50 d) whereas '49-11' trees on *A. reticulata* rootstock did not (Nuñez-Elisea *et al*., 1997). *Annona muricata* L. (soursop) has also been identified as flood-tolerant based on its ability to grow in flooded soil despite reduced net CO_2 assimilation and stomatal conductance rates when roots are exposed to anaerobic conditions (Nuñez-Elisea *et al*., 1997). Additional *Annona* scion/rootstock and scion/interstock/rootstock combinations are currently being tested to determine their relative flood tolerance. Horticultural characteristics of these scion-rootstock combinations are currently being evaluated in the field (R. Nuñez-Elisea, B. Schaffer and J. H. Crane, unpubl. res.). Thus, the use of *A. glabra* and possibly *A. muricata* as *Annona* rootstocks has the potential to improve flood tolerance of these important tropical fruit species for cultivation near natural wetlands such as the south Florida Everglades.

OPTIMIZING WATER-USE EFFICIENCY

For agriculture to be sustained near environmentally-sensitive natural ecosystems, it is essential to optimize water-use efficiency to reduce the potential for leaching of agricultural chemicals into the groundwater. The south Florida Everglades are a good example of such a system, where the water table is 1–3·5 m below the soil surface and the porous surface and subsurface strata provide little impediment to lateral movement of water (and contaminants) from agricultural to natural areas (Noble *et al*., 1996). The majority of subtropical and tropical fruit orchards between Biscayne and Everglades National Parks are irrigated at rates and frequencies based on experience and observations of crop growth and yield rather than on quantitative scientific information. This empirical approach suggests that irrigation rates may be excessive and could thus lead to leaching of nutrients and pesticides into the groundwater. There are few scientific recommendations with respect to appropriate irrigation timing and rates for subtropical and tropical fruit crops grown in the oolitic limestone soils of south Florida. This is partially because there has not been an effective method of continuously monitoring water content in these soils. Recently, the use of multi-sensor electrical capacitance probes connected to a central data logger (EnviroScan™, Sentek Environmental Innovations, Pty., Kent, Australia) has enabled the continuous monitoring of soil water content at several depths within the soil profile (Buss, 1993). The sensors use the principle of electrical capacitance and allow data to be logged for periodic downloading into a personal computer (Buss, 1989; Paltineanu and Starr, 1997). Sensors capable of measuring volumetric soil water content (ranging from oven dry to total saturation with a resolution of $\pm 0{\cdot}1\,\%$) are housed at various depths in tubular PVC probes. Each probe, which can contain multiple sensors, is placed at several locations within the field. Soil water data from the sensors are transmitted to a solar powered central logging facility which can record data at intervals as short as 1 min (Buss, 1989). The capacitance field generated between the two metal plates of each sensor extends beyond the PVC access tube into the surrounding soil. The capacitance field is affected by the dielectric constant of the material the field passes through. The dielectric constant of soil is 3 to 6, while that of air is 1 and water is 80 (Dean, Bell and Baty, 1987; Whalley, Dean and Izzard, 1992; Buss, 1993). Data are periodically downloaded from the data logger to a personal computer and sensor readings are converted to volumetric soil water content using calibration equations. Soil water content is monitored by measuring the change in the ratio of air to water at each sensor depth in the soil profile. This changes with irrigation, rainfall, drainage, evaporation and crop water use. The sensor readings are highly correlated with volumetric soil water content (Holdaway, Dillon and Dighton, 1993; Mead, Ayrs and Liv, 1995; Paltineanu and Starr, 1997).

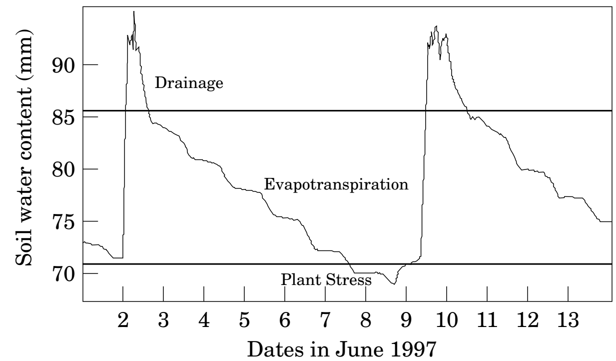

FIG. 4. Soil water content, determined with multi-sensor capacitance probes, in oolitic limestone soil in southern Florida planted with starfruit (*Averrhoa carambola* L.) trees. The orchard was irrigated on 2 Jun. 1997.

Recent efforts to maximize water-use efficiency of subtropical and tropical fruit trees in southern Florida have focused on managing irrigation to maintain soil water content between the leaching point and the onset of plant water stress. This is done by monitoring volumetric soil water content with multi-sensor electrical capacitance probes and adjusting the rate of irrigation based on the rate of soil water depletion (Fig. 4). When the soil is saturated, the rapid rate of soil water depletion is primarily due to drainage and results in leaching of water and chemicals into the aquifer (Buss, 1989). When soil moisture is below saturation, the decrease in soil water content during the day is primarily due to evapotranspiration. When soil water content falls below a drained lower limit, trees experience soil water deficit-induced stress (Buss, 1989). Evaluating crop water use by monitoring soil water depletion rates provides an advantage over physiological plant stress determinations, such as measurement of xylem water potentials. Once the soil water content at which crop stress occurs is determined, soil water content can be kept above this level to avoid the onset of plant stress (Buss, 1989). Efforts are currently underway with tropical fruit trees in south Florida to correlate physiological indicators of stress, such as plant hydraulic conductivity, transpiration and xylem water potential, with soil water depletion rates. This will allow the determination of the total water balance budget for each of these crops. In addition to monitoring

soil water dynamics, groundwater monitoring wells have been installed in several subtropical and tropical fruit orchards in south Florida. Since fruit crops in southern Florida are heavily fertilized, concentrations of selected applied compounds such as nitrates are being monitored in the groundwater. Attempts are being made to minimize fertilizer leaching by improving irrigation management based on the soil water dynamics during different stages of tree growth.

CONCLUSIONS AND FUTURE OUTLOOK

During the past decade, there has been a concerted effort to restore and protect natural wetlands such as the south Florida Everglades from urban pressures. Agriculture can contribute to restoring and maintaining these ecosystems by serving as a buffer between natural and urban areas. This requires the identification of crop species that are adapted to the wetland environment and development of crop management practices that do not have a negative impact on the natural wetlands. In southern Florida, the potential exists to grow subtropical and tropical fruit trees that tolerate the seasonal, cyclical flooding, which occurs naturally in the Everglades. Studies on physiological and growth responses of subtropical and tropical fruit trees to flooding have helped to determine the relative flood-tolerance of several commercial species. Promising flood-tolerant rootstocks have been identified for some of the commercial fruit tree species in the area. Additionally, conventional breeding or the use of biotechnology should allow for the development of subtropical and tropical fruit tree species tolerant of cyclical flooding in wetland areas.

To successfully sustain fruit crop production in an environmentally-sensitive wetland, it is essential to optimize water-use efficiency so that there is no run-off of agricultural chemicals such as fertilizers and pesticides into the adjacent natural ecosystem. Probably 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 leaching point (below field capacity) but above the point where plants are adversely affected by drought stress. Multi-sensor, electrical capacitance probes are being used in subtropical and tropical fruit orchards in south Florida to continuously monitor soil water content. Based on the dynamics of the soil water content, irrigation timing and rates are adjusted to avoid the onset of plant water stress and to ensure that leaching of water (and concomitant leaching of fertilizers and pesticides) into the aquifer is minimized. In addition, groundwater monitoring wells have been installed in orchards and water samples are routinely checked for contamination by agro-chemicals. Irrigation and fertilization practices can thus be adjusted to reduce leaching of chemicals into the groundwater. Research methodologies used in south Florida to identify crop species adapted to the wetland environment and make fruit crop production sustainable in an environmentally-sensitive wetland should be applicable to other areas of the world where sustainable agriculture may be the 'best neighbour' to environmentally-sensitive natural habitats.

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