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Soil Moisture and Shallow Water Table Monitoring for Irrigation and Drainage Decision-Making

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ABSTRACT

Fresh water quantity and quality is increasingly more important in south Florida due to the rising demands by the environment, agricultural, industrial, and urban sectors. A soil moisture and water table monitoring study was done in a 3.5 m diameter and 0.9 m deep polyethylene tank lysimeter used to simulate an Everglades Agricultural Area muck soil (Histosols) with shallow water table. A soil moisture sensor in the soil profile, a water level sensor for water table monitoring, and a data logger can be combined with crop stress and meteorologic forecasting to optimize irrigation and drainage decisions. This paper presents over 600 days of soil moisture, soil temperature, water table, and meteorologic data (observed) and demonstrates applicability to irrigation and drainage decision-making. Results show that irrigation requirements and drainage quantities can be minimized on shallow water table irrigation and drainage systems using automated soil moisture and water table monitoring devices.

Keywords: Everglades Agricultural Area, Histosols, Lysimeter, Soil Temperature, South Florida

INTRODUCTION

Water control and management throughout south Florida have increased in importance due to issues such as wetland and ecosystem restoration (Everglades) and conservation, urban water use, agricultural water use (irrigation/drainage), soil subsidence, salt water intrusion of aquifers, and water quality (Windemuller et al., 1997). These issues stress the need for efficient water table monitoring and control. However, management of optimal water tables will be difficult in the absence of in-field monitoring devices able to discern operational conditions. The intent of water table management is to optimize irrigation and minimize drainage. Currently, agricultural best management practices are being applied to this effect in the Everglades Agricultural Area (EAA) of south Florida.

High water tables on organic soils reduce the rates of subsidence, primarily by changing redox conditions (Reddy, 1987), reducing soil temperatures (Shih and Gascho, 1979), and altering microorganism populations (Terry and Tate, 1980). Water table depth, soil moisture, and soil temperature can be monitored, and directly or indirectly can be related to the factors affecting organic soils subsidence. An EAA soil subsidence model was developed by Shih et al (1978) using water table depth, soil temperature, and carbon content. From this model, it is apparent that water table depth (drainage) is related to the rate of soil loss. The water table control in the Everglades maintained at 61 cm has historically resulted in soil losses averaging 2.5 cm per year (Allison, 1939; Clayton, 1943).

Precision irrigation scheduling has been applied for sprinkler irrigated potato in Oregon and the increased efficiency has resulted in the reduction of nitrate leaching (Shock et al., 1996). Woodhead (1996) reported from New Zealand that a spatially-averaging soil moisture sensor (Lincoln Soil Moisture Sensor[2]) can be used to automatically trigger irrigation. Smajstrla and Locascio (1996) reported success in automating drip irrigation of tomatoes using tensiometers with magnetic switching near Gainesville, Florida.

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2 Mention of a specific product does not constitute endorsement.

The purpose of this study is to demonstrate how continuous soil moisture, soil temperature, and water table monitoring devices can be used for decision-making in irrigation and drainage scheduling.. The study was done at the Everglades Nutrient Removal constructed wetland, a 1500 ha marsh designed to remove P from agricultural drainage (Abtew et al., 1995). The soil used in the study was identified as Okeechobee muck (euic, hyperthermic Hemic Medisaprists). The area had been in irrigation and drainage farming prior to being converted to wetlands.

MATERIALS and METHODS

A lysimeter system was designed and employed to measure evapotranspiration (ET) from unsaturated, saturated and ponding water conditions in the Everglades Nutrient Removal constructed wetland in south Florida (Abtew, 1996). The lysimeter system was designed to simulate a wetland which goes through cycles of ponding (saturated and unsaturated states). The water balance lysimeter has 9.8 m^2 surface area and 0.9 m depth. The unsaturated moisture content was measured indirectly with a combined electrical soil moisture and temperature sensor (AQUA-TEL, Model 29+T, Automata Inc., Grass Valley, CA). The 74 cm long sensors measure the dielectric constant of the soil. The dielectric constant was directly related to soil water content. The sensor averages moisture content of the soil and soil temperature through the soil profile. The change in water content of the saturated zone can be computed from the change in water level in the saturated zone and the soil water holding capacity. The water level in the soil and the ponding on the soil was monitored with redundant water level gauges, a pressure transducer and an SDI float mechanism (Abtew, 1996).

Two soil moisture and temperature sensors (AQUA-TEL-29+T, 74 cm long sensor with 8 m cable) were placed at different depths of the unsaturated soil profile to integrate unsaturated moisture volume in the soil. One moisture and temperature sensor is placed at an angle across the tank covering 30 cm of the upper soil depth (shallow). The second sensor is placed across the tank covering 60 cm of soil depth from the surface. The shallow sensor averages soil moisture content and temperature along the upper section of the soil. The deep sensor averages soil moisture and temperature along the whole soil profile. The two sets of data provide information on the state of soil moisture and temperature at the upper and the lower sections of the soil profile. This arrangement was selected for easy withdrawal of the soil moisture sensors for maintenance purposes without disturbing the soil.

Additional temperature sensors (Senwal Electronics UUT51J1 thermistor) were placed at 2.54, 30, and 58 cm from the surface of the soil to measure point soil temperature at different levels of the soil profile. The temperature sensors that are a part of the soil moisture sensor give average temperature readings through the length of the sensor. By having multiple sensors, the temperature sensors were checked against each other and a comparison was made between point soil temperature measurement and profile averaged soil temperature. All the sensors were connected to a CR10 data logger and a radio transmitter powered by a 12 volt battery recharged with a 5.2 watt solar panel. The power source for the pumps was a 12 volt marine battery (80 ampere hour rating) recharged with an 18 watt solar panel. Rainfall was measured with a tipping bucket rain gauge at the site. Wind speed was measured at 4 m height from the rim of the tank.

The tank was filled with sand and gravel 15 cm from the bottom. The gravel and sand covered the drainage and inflow pipe network to reduce clogging of the filter cloth. Disturbed soil from the site was filled over the gravel and sand to a total depth of 75 cm from the bottom. The tank was fully saturated and left for the soil to resettle and later some more soil was added to bring the soil surface back to the desired level.

A pump-in and pump-out test was run to evaluate the storage capacity of the soil under falling and rising water table conditions (Figure 1). The soil moisture sensor output range was 0 to 1 mA. The output was changed to mV (0 to 2500) using a 2.5 kohm shunting resistor. Since muck soil is not given in the calibration curves of the moisture sensors, it was essential that sensor output versus percent moisture calibration curve for the soil in the lysimeter be developed. Seven soil samples were taken to the lab for gravimetric soil moisture content analysis for the purpose of developing a calibration curve. Due to compaction during sampling, it was not possible to determine the correct *in situ* volume of the

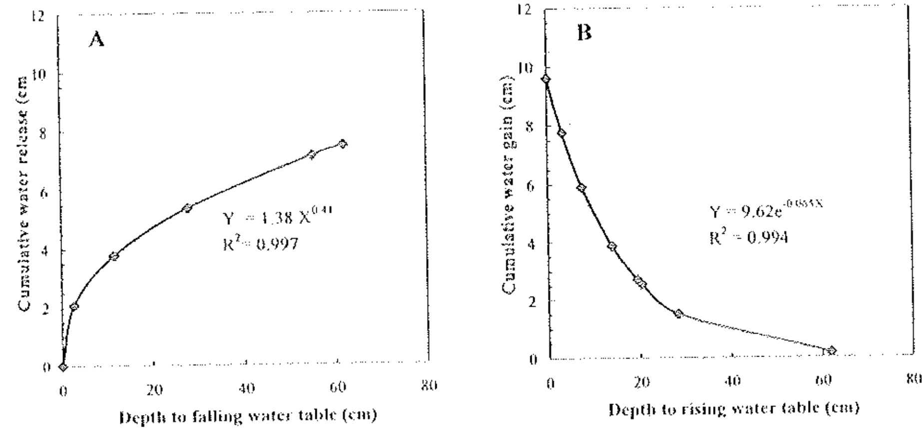

Figure 1. Water release (a) and gain (b) curves.

soil sample. Soil moisture output (mV) is a relative reading of soil moisture content (% v:v or w:w) following a non-linear relationship which is highly site specific.

RESULTS AND DISCUSSION

The lysimeter was operated from January 25, 1995 to September 26, 1996. The pump-in and pump-out test was developed on February 28, 1995 (Figure 1). Water level from the bottom of the lysimeter and soil moisture signal was recorded every 15 min. Figure 2 depicts the daily average water table, soil moisture signal (0 to 60 cm profile), and daily rainfall. No pumping was conducted after February 28, 1995; therefore, all the water table and soil moisture fluctuations are due to rainfall and evapotranspiration. The data in Figure 2 provides an objective status of soil moisture and water table. Based on a farm operator knowledge of the crop's allowable stress (dry or wet) and short term meteorologic forecasts, optimum pumping decisions can be made to irrigate or drain.

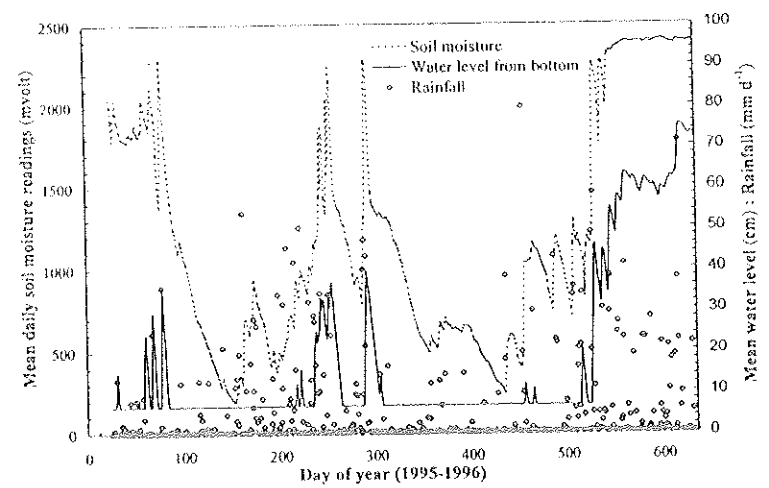

Figure 2. Average soil moisture, water level, and daily rainfall.

Soil moisture and storage characteristics studies of a Everglades peaty muck of 90 cm showed that percent water content (v:v) can be as high as 80% to 97 % at different soil layers (Weaver and Speir, 1960). The cumulative gain of water in a rising water table under saturated conditions was 10.5 cm and the drainable amount was 7.8 cm for a 60 cm soil profile (Figure 1). The fraction of soil volume drained was 0.13, comparable to 0.14 reported by Weaver and Speir (1960). Gravimetric analysis of two saturated soil samples from the site produced an average of 451% moisture (w:w). In a study done in sugarcane farm in the Everglades Agricultural Area, Andreis (1976) reported a 412% moisture content (w:w) for a soil profile 15 cm to 45 cm in depth when the water table was at 44 cm. These organic soils have a large capacity to store water. The cumulative distribution of daily rainfall, estimated potential evapotranspiration (Abtew, 1996), and water table fluctuation are shown in Fig. 3. During the study period, all excess water (rainfall > ET) was stored in the soil profile, and soil water stored was reduced when ET exceeded rainfall (Fig. 2). The water table never reached the surface until the last days of the study period (Fig. 3).

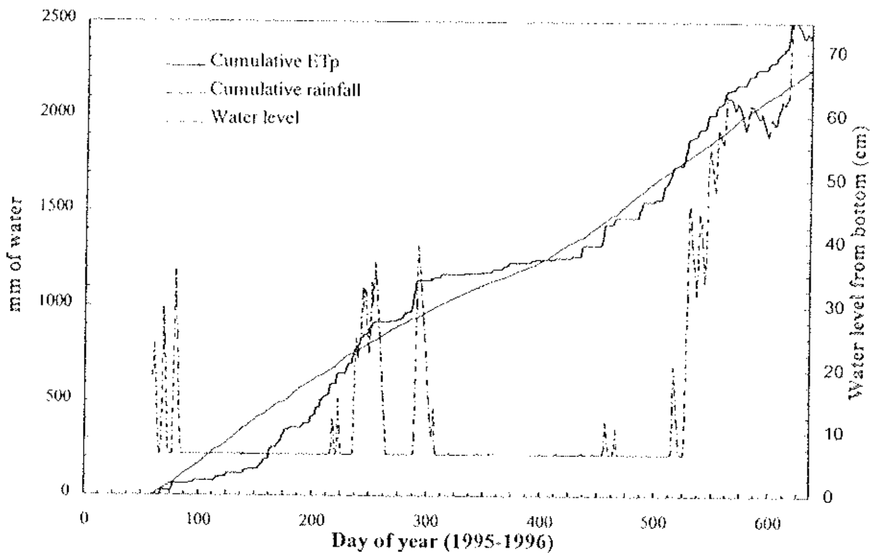

Figure 3. Cumulative Et_p, rainfall, and water level fluctuation across the study period.

Soil temperature is an indicator of biological activity. Microbial reaction rates are optimal between 25 and 35 C, and most biological activity occurs between 17 and 48 C (Paul and Clark, 1989). Since some soil moisture sensors have soil temperature readings, the data can be used to manage soil and water. Figure 4 shows average monthly soil temperature from the five sensors and air temperature measured at 2 m height. Generally all the three point soil temperature measurements (2.54, 30 and 54 cm depths) differ from average air, upper (0 to 30 cm) soil profile, and whole (0 to 60 cm) soil profile average temperatures. The cumulative sum of degree-days (EC x days) was lowest for the upper soil profile (0 to 30 cm profile) averaged temperature followed by whole soil profile (0 to 60 cm profile), air temperature, 54 cm depth, 2.54 cm depth, and 30 cm depth point temperature readings. Based on 611 days of observation, the following relationships were developed to estimate average daily soil temperature (T) from air temperature (T_{air}) and day-of-the-year (day). All soil temperatures can be reasonably estimated from the daily mean air temperature and the day-of-the-year (equations 1-5). From these relationships, application of soil temperature and water table information can be quickly applied to subsidence algorithms (Shih et al., 1978).

$$T_{(0\ to\ 30\ cm\ profile)} = 4.70 + 0.63\ T_{air} + 0.029\ day - 0.000084\ day^2 + 0.00034\ (T_{air} \times day) \quad [R^2=0.97] \qquad (Eq.\ 1)$$

$$T_{(0\ to\ 60\ cm\ profile)} = 5.50 + 0.58\ T_{air} + 0.035\ day - 0.000104\ day^2 + 0.00044\ (T_{air} \times day) \quad [R^2=0.96] \qquad (Eq.\ 2)$$

$$T_{(2.54\ cm\ depth)} = 19.59 - 0.40\ T_{air} + 0.011\ T_{air}^2 + 0.073\ day - 0.00018\ day^2 + 0.00054\ (T_{air} \times day) \quad [R^2=0.92] \qquad (Eq.\ 3)$$

$$T_{(30\ cm\ depth)} = 15.23 + 0.0030\ T_{air}^2 + 0.073\ day - 0.00019\ day^2 + 0.00054(T_{air} \times day) \quad [R^2=0.91] \qquad (Eq.\ 4)$$

$$T_{(54\ cm\ depth)} = 7.18 + 0.55\ T_{air} + 0.036\ day - 0.00011\ day^2 + 0.00043\ (T_{air} \times day) \quad [R^2=0.96] \qquad (Eq.\ 5)$$

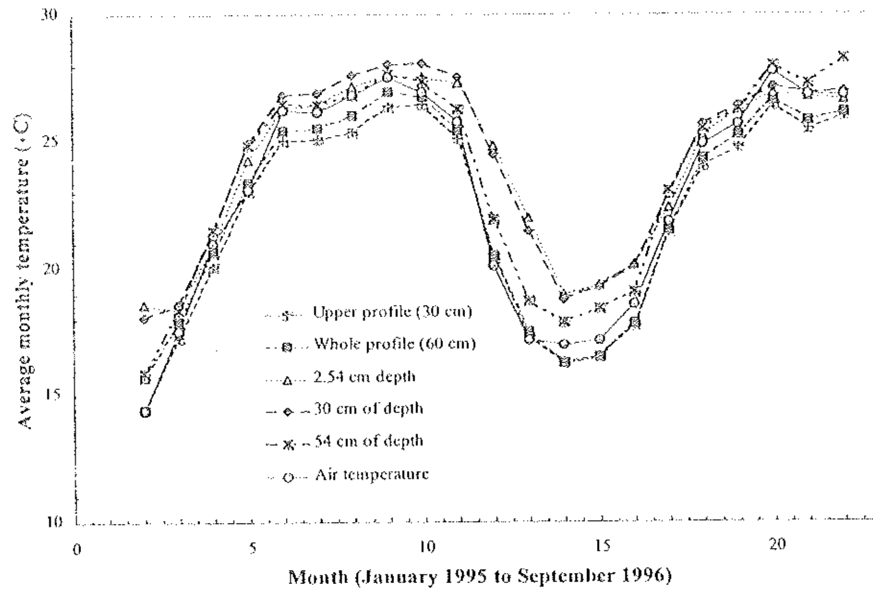

Figure 4. Average monthly air and soil temperature fluctuations over the study period.

SUMMARY

Continuous observations of soil moisture and water table can be used to implement precision irrigation and drainage. Dual observations of soil moisture content and water level provides objective water status for the farm operator. Short period of local meteorologic forecast, knowledge of the area and crop characteristics will form the basis of optimum soil and water management decision-making.

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