EVALUATION OF THE PAN EVAPORATION METHOD FOR SCHEDULING IRRIGATION ON AN OXISOL IN PUERTO RICO[1,2]

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ABSTRACT

The purpose of this study was to evaluate the pan evaporation method for scheduling irrigation of a sweet pepper (*Capsicum annuum*) crop grown on an Oxisol at the University of Puerto Rico Agricultural Experiment Station at Isabela, PR. Irrigation scheduling refers to a procedure in which water is applied to the field according to the water demand by the crop. Ideally, water should be applied at a rate equal to the potential evapotranspiration rate of the crop minus the effective rainfall. However, when plastic mulch is used to eliminate weed growth, as is common in vegetable production in Puerto Rico, much of the rainfall runs off and is not available to the plants. To minimize the possibility of crop water stress when plastic mulch is used, water should be applied at a rate equal to the crop evapotranspiration rate. If the contribution from rainfall is assumed to be zero, but in fact some rain enters the soil through holes in the plastic, this may produce deep percolation. Deep percolation is undesirable (except as required for salinity control) because it represents a loss of water and fertilizer, and may also contribute to groundwater contamination.

The daily pan evaporation-derived evapotranspiration (ET_{pan}) was obtained from the product of pan evaporation (E_{pan}), a pan coefficient (K_p) and the evapotranspiration crop coefficient (K_c). The contribution of water from rainfall was assumed to be zero. However, some rainfall was observed to enter through holes in the plastic mulch where the pepper plants were located. This contribution of water however, was spatially variable and difficult to quantify. Through calibration of a water balance equation, on average twenty five percent of the rainfall was found to enter the soil beds.

Evaluation of the pan method for scheduling irrigation was based on comparison of ET_{pan} with the Penman-Monteith-based evapotranspiration (ET_c), estimates of deep percolation, measured vertical hydraulic gradients, and measured soil moisture distribution. Seasonal estimates of ET_{pan} and ET_c were 350 mm and 401 mm, respectively. The estimated seasonal deep percolation was 60.9 mm. A simulated irrigation schedule using the Penman-Monteith method resulted in even greater seasonal deep percolation (127.7 mm). Vertical hydraulic gradients were observed to be downward throughout a significant portion of the season, and observed moisture content distributions below the root zone clearly indicated that deep percolation was occurring.

BACKGROUND

The pan evaporation method is widely used for irrigation scheduling. The method is popular because it is inexpensive and easy to apply. Currently in Puerto Rico, the University of Puerto Rico (UPR) Agricultural Experiment Station is promoting its use for vegetable production. Problems,

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however, may result from this approach owing to the inherent differences in water loss from an open water surface and a crop. Allen, et al. (1998) list the following factors that may cause significant differences in loss of water from a water surface and from a cropped surface:

- Reflection of solar radiation from the water surface might be different than the assumed 23% for the grass reference surface.
- Storage of heat within the pan can be appreciable and my cause significant evaporation during the night while most crops transpire only during the daytime.
- There are differences in turbulence, temperature and humidity of the air immediately above the respective surfaces; and
- Heat transfer occurring through the sides of the pan can affect the energy balance.

Another potential limitation of the method as it has been applied in Puerto Rico is that only a single value of crop coefficient is normally used, whereas, by definition, the crop coefficient varies throughout the season. Although recommended irrigation application rates by this method may maximize crop yields, the method may also result in the over-application of water early in the season, leading to the degradation of groundwater resources from leaching of agricultural chemicals. The purpose this study is to evaluate the potential for deep percolation to occur when scheduling irrigation using the pan evaporation method.

TECHNICAL APPROACH

Experimental Layout

A sweet pepper crop was planted at the UPR Experiment Station at Isabela, PR during March 2002. Figure 1 shows the experimental layout. Although the study considered treatment differences due to different lime levels and fertigation frequencies, this paper only reports the results of the soil water balance.

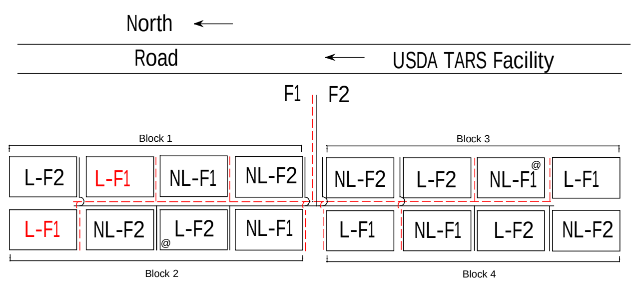

Figure 1. Experimental layout of the field study.

The soil at the Isabela Experiment Station belongs to the Coto series. It is a very fine kaolinitic, isohyperthermic Typic Eutrustox. These are very deep, well drained, moderately permeable soils formed in sediments weathered from limestone. The available water capacity is moderate, and the reaction is strongly acidic throughout the whole profile. Consistence is slightly sticky and slightly plastic in the Oxic horizons. A strong, stable granular structure provides these soils with a very rapid drainage, despite their high clay content (Keng et al, 1981).

The experimental site of 0.1 ha was divided into four blocks, each block divided into four plots, one for each treatment, for a total of sixteen plots. The plots measure 67 m^2. The treatments included two lime levels (lime and no lime) and two fertigation frequencies (F1 and F2). Each plot had four beds covered with plastic (silver side exposed) with two rows of sweet pepper plants per bed. The transplanted sweet peppers were grown in rows 91 cm apart, 30 cm apart along rows, with beds 1.83 meter on center. This gave a plant population of approximately 37,000 plants per hectare. There was an initial granular application of triple super-phosphate of 224 Kg/ha and 80 Kg/ha of 10-10-10 fertilizer. Peppers were planted from March 11th through March 13th. KNO_3 and urea were injected through the drip irrigation system throughout the season at different frequencies (weekly [F1] or bi-weekly [F2]). The total nitrogen applied during the season was 225 Kg/ha. After transplanting, soil samples were taken bi-weekly at 20 cm increments, down to an 80 cm depth from each plot to be analyzed for moisture content and nitrogen concentration. Each date in which soil samples were collected, whole plants were harvested for growth data. Periodic pesticide applications were made to control weeds and insects affecting crop growth.

Water Balance

A water balance approach was used in this study to evaluate potential percolation below the root zone. The water balance is shown in the following equation:

$$PERC = (R - RO) + IRR - ET_c + \Delta S. \qquad (1)$$

where PERC is percolation below the root zone, R is rainfall, IRR is irrigation, RO is surface runoff, ET_c is crop evapotranspiration, and $\Delta S = S_1 - S_2$, where S_1 and S_2 are the water stored in the soil profile at times 1 and 2, respectively. The units of each term in equation 1 are in mm of water per day.

Rainfall (R) was obtained from a tipping bucket-type rain gauge located on the Experiment Station property. The rain gauge was located within a weather station complex located approximately 0.4 km from the study area. The weather station consisted of a 10 meter (high wind resistant) tower with lighting protection, data logger and radio communication system, and sensors to measure the following parameters: wind direction and speed, temperature, relative humidity, barometric pressure, cumulative rainfall, and solar radiation (Zapata et al., 2001).

In this study, the implement used to form the soil beds piled the soil on the shoulders of the beds slightly higher than in the middle of the beds. Consequently, some rainfall became trapped in the interior area of the beds until it entered through holes in the plastic where the pepper plants were located or ran off the end of the bed. Because the (R – RO) term was highly variable spatially, it was necessary to derive an average value through means of a calibration process (described below).

Irrigation (IRR) was applied through a drip irrigation system. The inline-type emitters produced a flow of 1.9 liters per hour per emitter at a design pressure of 10 pounds per square inch. Emitters were spaced every 30 cm. Irrigations were scheduled based on the estimated evapotranspiration rate as determined from the following equation:

$$IRR = ET_{pan} = (K_c\ K_p\ E_{pan}) \qquad (2)$$

where ET_{pan} is the pan evaporation-derived evapotranspiration, K_c is the evapotranspiration crop coefficient for sweet peppers (FAO Paper No. 56, Allen et al., 1998), which varied daily; K_p is the average annual value of the pan coefficient equal to 0.78 for Isabela, PR (Gonzales and Goyal, 1989). A cumulative water meter was used to control the gallons of irrigation water applied.

The evapotranspiration term in equation 1 was estimated from the following equation:

$$ET_c = K_c\, ET_o \qquad (3)$$

where K_c is the crop coefficient (dimensionless) and ET_o (mm/day) is the reference evapotranspiration obtained using the Penman-Monteith method. Initial values of the crop coefficient were obtained from the literature for sweet pepper for the initial, mature and end crop stages (FAO Paper No. 56). Adjustments of K_c were made during the calibration of equation 1 as described later in this section. ET_o was estimated on a daily basis using a spreadsheet program. The calculation methodology is described by Allen, et al. (1998). ET_o is a function of the average daily measured solar radiation, minimum and maximum air temperature, relative humidity, and wind speed. These data were obtained from the weather station located near the study area. Wind speeds obtained from the 10 m high tower were adjusted to the 2 m wind speed, required by the Penman-Monteith method, by means of an exponential relationship.

The values of S in equation 1 and 2 were obtained from the following general formula: $S = \theta_v * Z$, where θ_v is the vertically averaged volumetric soil moisture content over the depth Z, obtained by multiplying the moisture content, mass-basis (θ_m), by the soil bulk density and dividing by the density of water. The soil bulk densities were obtained from undisturbed soil cores.

Between sampling dates when measured values of θ_v were not available, daily values were estimated using equation 1 along with information about the moisture holding capacity of the soil. In this method, if the water added to the profile by rainfall or irrigation exceeds the soil moisture holding capacity (or field capacity), then the excess water was assumed to be equal to PERC and the moisture content was set equal to the field capacity on that day. This approach has previously been used for irrigation scheduling (Shayya and Bralts, 1994), waste landfill leachate estimation (Fenn et al., 1975) and estimation of aquifer recharge rates (Thornthwaite and Mather, 1955; Papadopulos & Associates, Inc. and MathSoft, Inc. 1994). In this study, the effective field capacity of the soil was determined in-situ by saturating the soil and obtaining the soil moisture content within 48 hours.

Equation 1 was calibrated by adjusting certain parameters, within reasonable limits, until the values of the estimated moisture content on the sampling dates were approximately equal to the measured values. The parameters adjusted were (R – RO) and K_c.

RESULTS AND DISCUSSION

Figure 2 shows a comparison of the evapotranspiration derived from pan and Penman-Monteith methods. ET_{pan} was observed to have higher variability than ET_c. For reference, Figure 2 also shows the ET_c based on long-term average climate data for Isabela, PR. The seasonal ET for the methods of pan, Penman-Monteith and Penman-Monteith based on long-term data were 350 mm, 401 mm and 451 mm, respectively.

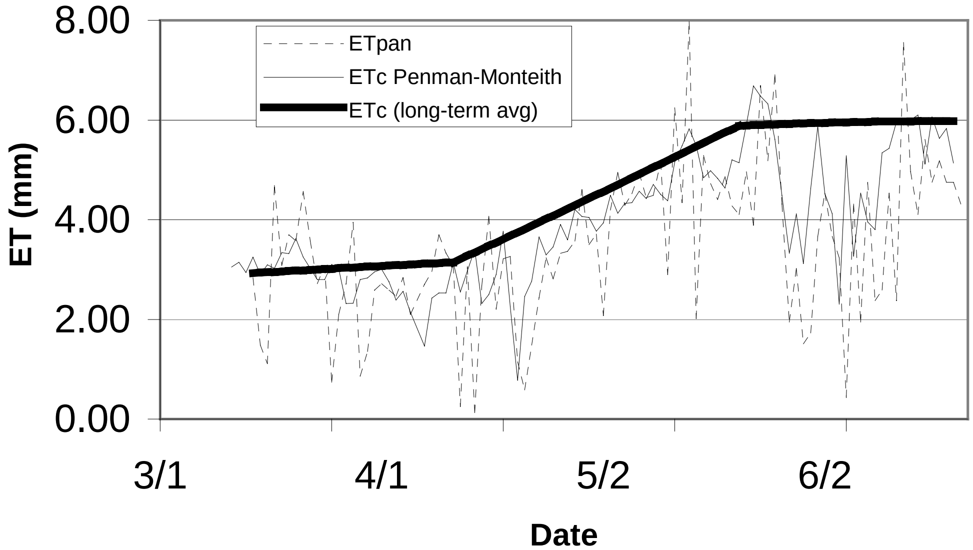

Figure 2. Daily values of evapotranspiration for a sweet pepper crop between March 11th to June 21, 2002 at Isabela, PR. Evapotranspiration was derived from the pan evaporation and Penman-Monteith methods.

The water balance equation (Equ 1) was calibrated for the site conditions. Figure 3 shows the simulated and measured average soil moisture content. The measured moisture contents shown in Figure 3 represent the vertically averaged moisture content over all sixteen plots. A comparison of the average moisture contents by treatment (not shown) indicated little variation relative to the overall mean values shown in Figure 3. To obtain the simulated results it was necessary to allow 25% of the rainfall to enter the soil bed. Furthermore the crop coefficient needed to be adjusted to account for a short period of extreme weed growth, which occurred between the beds during the period between April 10th and April 29th. We believe that during this period significant amounts of water were extracted from the soil profile below the beds by the adjacent weeds. However, by April 29th the weeds had been completely eliminated by a herbicide application. Figure 4 shows the calibrated crop coefficient curve and the unadjusted crop curve obtained from FAO Paper No. 56. A vertically averaged value of the measured field capacity equal to 0.39 was used in the analysis.

Based on equation 1, deep percolation events occurred on April 6th, 7th, 8th and 13th in the amounts of 40 mm, 1.3 mm, 8.2 mm, and 11.5 mm, respectively. The large 40 mm percolation event was associated with a 175 mm rainfall event. The total seasonal deep percolation was 60.9 mm. As a further confirmation that percolation was occurring during the season Figure 5 shows some measured vertical hydraulic gradients between approximately 50 and 80 cm depths during May and June. The hydraulic gradient represents the difference in soil pressure divided by the vertical distance between the ceramic cups of the tensiometers used to measure soil pressure. The majority of hydraulic gradients were downward (positive value), indicating that the soil water flux was in a downward direction during much of the time.

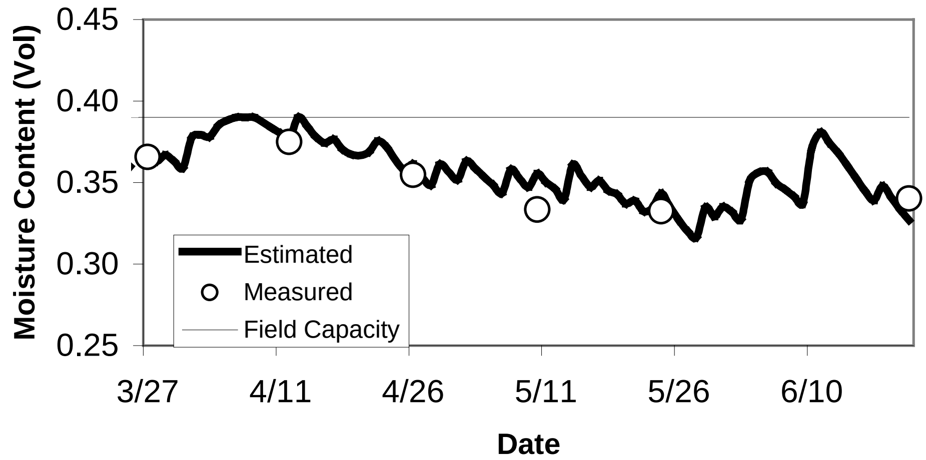

Figure 3. Estimated and measured volumetric soil moisture content.

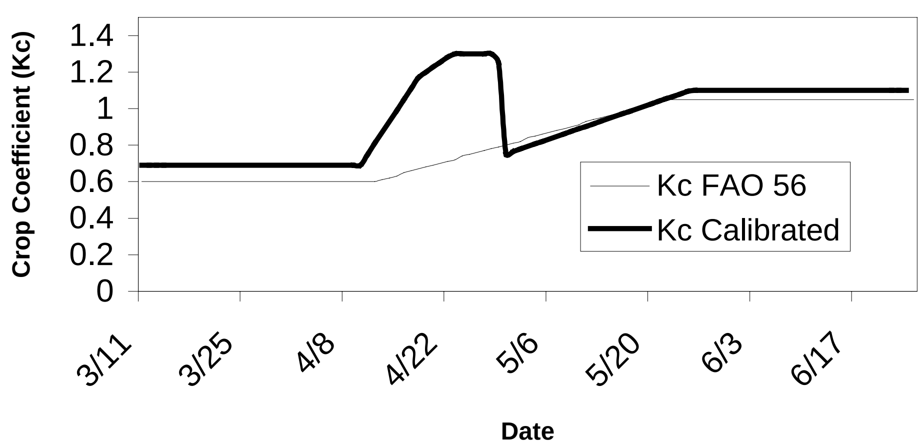

Figure 4. Crop coefficients used in this study.

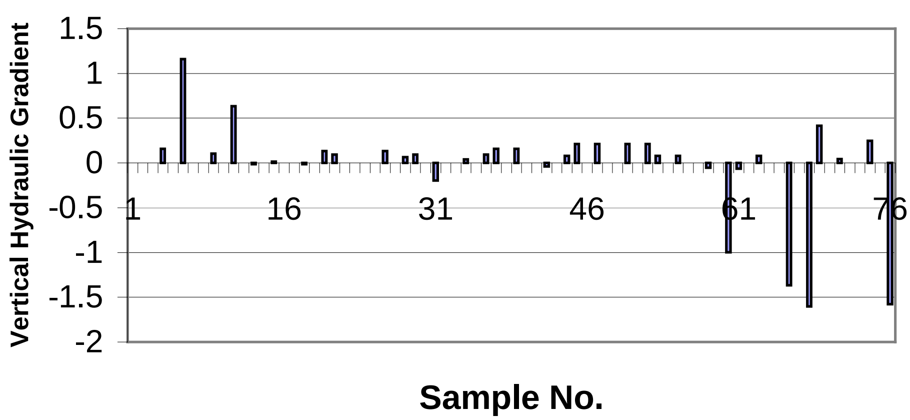

Figure 5. Vertical hydraulic gradients between approximately 50 and 80 cm depths. A positive value represents a downward gradient. Soil pressures were measured using tensiometers.

Soil moisture content distribution also supported the occurrence of percolation. Figure 6 shows the soil moisture distribution with depth and time. The soil moisture data is the average soil moisture over the sixteen plots. Percolation is indicated whenever the moisture content at the lowest depth (760 cm) increased. This occurred between March 27th and April 12th, and again between May 10th and May 25th. It should be noted that percolation was not predicted from Equation 1 during May as was indicated by the vertical hydraulic gradients and soil moisture data. This suggests that the estimate of seasonal percolation of 60.9 mm from equation 1 may be an underestimate.

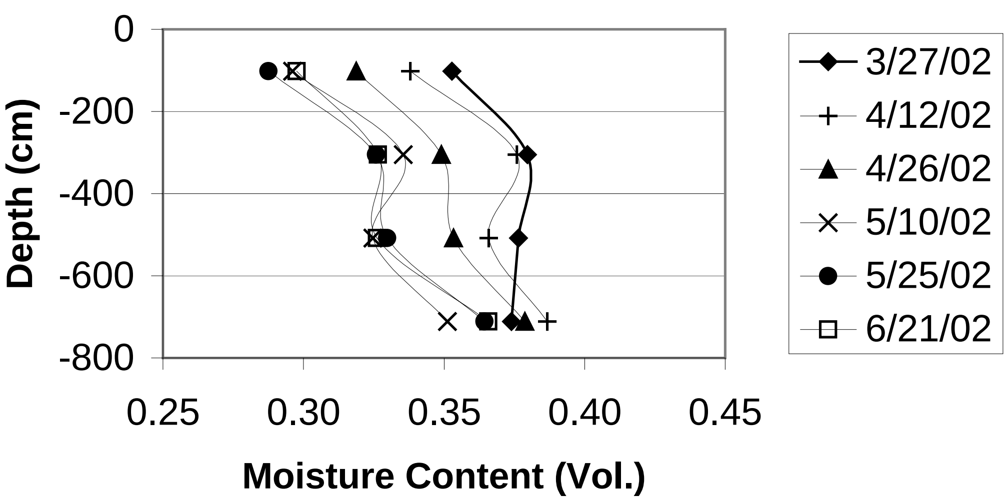

Figure 6. average soil moisture content by depth and time.

For comparison, a simulation was conducted in which the ET derived from the Penman-Monteith method was used for scheduling the irrigation. As in the case of scheduling with the pan evaporation method, the contribution to the crop water requirement was assumed to be zero. Figure7 shows the simulated percolation. The total seasonal percolation was 127.7 mm.

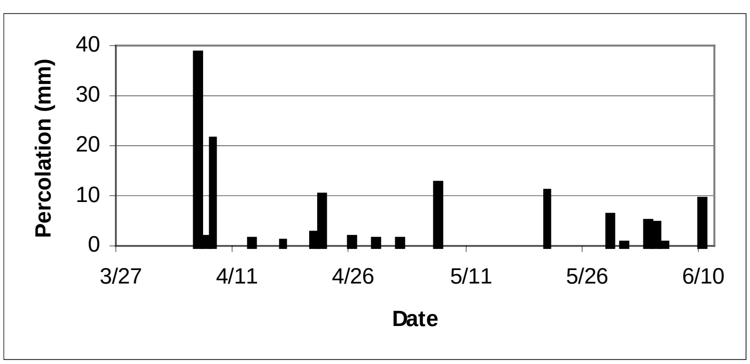

Figure 7. Estimated percolation when irrigation was scheduled using the Penman-Monteith Method

SUMMARY AND CONCLUSIONS

In this study, the pan evaporation method for scheduling irrigation resulted in deep percolation in the amount of 60.9 mm during the sweet pepper season. Measured vertical hydraulic gradient and soil moisture data suggest that the value of seasonal deep percolation may be even greater. Simulated percolation based on irrigation scheduled with the Penman-Monteith method resulted in a seasonal percolation of 127.7 mm. This result indicates a greater potential for percolation exists using the latter method if rainfall is able to enter the soil bed. The contribution of rainwater to the plastic covered beds was determined to be 25% of rainfall on average. The fact that rainfall entered the soil beds in a non-uniform fashion has important implications relative to microirrigation uniformity distribution. A study is needed to better understand the contribution of rainfall when plastic mulch is used.

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