Irrigation Scheduling for Optimum Plant Water and Nutrient uptake

Fares[1], A, H. Valenzuela[2], M. Ryder[1], V. Polyakov[1], and C. Nazario[1]

[1]Natural Resources and Environmental Management Department, University of Hawaii-Manoa

[2]Tropical Plants and Soil Science Department, University of Hawaii-Manoa

Abstract

Effective and efficient water resource management is undoubtedly one of the most important policy issues facing agriculture in Hawaii in the years ahead. A successful irrigation water management program optimizes water availability, ensures the best crop yield and quality while minimizes production costs and nutrient losses below the rootzone. The objective of the current work is to establish an irrigation scheduling program for a tomato crop to optimize plant water and nutrient uptake. A tomato variety trial was conducted at the University of Hawaii Poamoho research station on a Wahiawa silty clay soil. Irrigation setting points were determined based on root system growth and soil water release curves established from soil cores taken within and below the rootzone. Rain, irrigation and real-time soil water content were monitored throughout the soil profile. Plant water uptake and excess losses below the rootzone were calculated using a water balance approach and field data.

Introduction

Irrigated agriculture is the leading water user around the world. In Hawaii, declines in plantation agriculture resulted in a drastic reduction of agriculture water use. However, Hawaii agriculture is still required to optimize its water use for two main reasons: to optimize crop production in order to compete with the import markets and to minimize environmental impacts from erosion or nutrient leaching into aquifers.

Demands on our limited water supplies in Hawaii are increasingly competitive, especially as we experience more cycles of drought and dynamic changes in land use. Growth of a diversified agriculture in Hawaii is dependent on its ability to compete with imported products. In order to have a competitive advantage, Hawaiian agricultural production efficiency is becoming necessary for producers to maintain or increase their net returns in an increasingly global market. Increase in net returns could be realized by increasing crop yield per unit area and/or minimizing crop production costs. Several crop water production functions, describing the relationship between crop yields and evapotranspiration, have been developed for different crops under different management practices. In addition to their cost, excess water losses ensuing from poor irrigation scheduling carry with them dissolved fertilizers and pesticides beyond their targeted area resulting in substantial increases in production costs. Hence, optimum irrigation water management is critical in any effort to increase Hawaiian diversified agriculture net returns.

Yield and dry matter production of many plants are linearly related to total evapotranspiration (ET). The relationship between ET and available soil water in the rootzone is generally linear but becomes curvilinear when soil water content is close to saturation. The curved portion of the line reflects low efficiency of irrigation water use, primarily due to excessive water leaching below the rootzone. Moreover, such leaching removes nutrients and pesticides away from their intended application zones resulting in higher crop production costs and water quality impairment. Ample research findings in the literature show that efficient irrigation practices reduce production costs, improve crop yield, limits erosion and sediment-loading, and enhance environmental quality.

There are several candidate crops for irrigation studies in a new and a more diversified Hawaiian agriculture. Tomato is a good representative of an economically diversified agriculture in Hawaii. Water management of these crops is mainly based either on the growers' best judgment and experience of trial and error. To date, little information is available for the highly weathered, well-structured tropical soils that prevail in the agricultural lands of Hawaii.

The purpose of prudent irrigation scheduling is to determine when and how much to irrigate to meet crop demands. Several irrigation scheduling methods have been used for different crops. Check-books, pan evaporation and soil water monitoring devices, i.e., tensiometers and neutron probes have been successfully used as irrigation scheduling tool for several decades. However, recent electronic advances resulted in the development of real-time soil water monitoring devices such as time domain reflectometry and capacitance sensors. These devices have been used extensively for efficient irrigation and nutrient management in different crops, i.e. citrus (Fares and Alva, 2000; Fares and Alva, 1999). Since capacitance sensors monitor water content at multiple depths and at different locations in real-time; they can be used along with tensiometers to determine important soil physical properties such as soil water release curves, hydraulic conductivities and soil water holding capacities. Fares and Alva (2000, 1999) used this approach in addition to irrigation and rainfall data to calculate daily plant water use and excess water losses below the rootzone.

A sound irrigation management program requires knowledge of the soil water holding capacity, root zone depth and the ability to determine or estimate the available soil water at any time during the growing season. This information, in turn, allows for the methodical determination of the timing and amount of irrigation water to be applied (Fares et al., 2000).

Materials and Methods

The study was conducted at the University of Hawaii-Manoa Poamoho research station, Waialua, Oahu, HI. This study was part of a tomato variety trial (*Lycopersicon esculentum*) grown under drip irrigation on a Wahiawa silty clay. A typical soil profile for a Wahiawa silty clay consists of Ap1 (0-6 inch), Ap2 (6-12 inch), B21 (12-16 inch), B22 (16-33 inch), B23 (33-45 inch), and B24 (45-60 inch) horizons (National Cooperative Soil Survey, 1978). Bulk densities range from 1.10 – 1.30 g/cm^3 for 0-14 inch depths, permeability ranges from 0.6-2.0 in/hr for depths of 0-2 inch and 0.2-0.6 in/hr for depths of 2-14 inch. Soil water release curve data for a typical Wahiawa silt clay loam soil as reported by Gavenda, et al. (1996) are presented in Fig. 2.

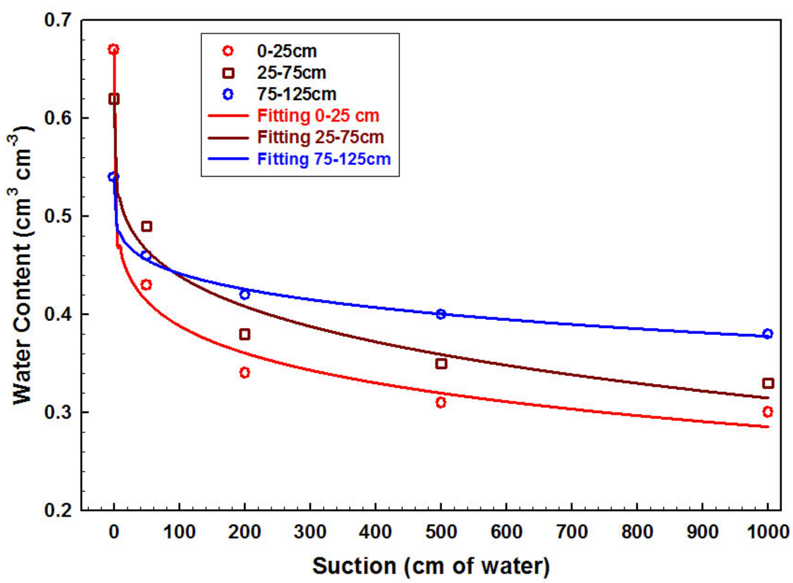

Figure 1. Soil water release curves for a Wahiawa soil (Gavenda, et al., 1996).

The mean annual rainfall is 1270 mm and mean annual temperature is 22º C, however, this year there was 1230 mm (Fig. 2) in only four months of the dry season.

Description of Field Experiment

Four tomato plants, each representing a variety (FI 68-5, HA-3816, F1 #5, and BHN555), were selected for soil water monitoring and measurements. Three ECH$_2$O® capacitance sensors (Decagon Devices, Inc.) and one EasyAg® (Sentek Sensor Technologies) capacitance sensor, one per plant, were installed to measure soil moisture content in real-time within a root zone of 0-

25cm. Sensors measured soil moisture content every 10 to 30 minutes and data were recorded using a Campbell Scientific data logger. In this paper, we are reporting the EasyAg data only. A rain gage equipped with a data logger was used to monitor both irrigation and rainfall events. Daily and cumulative rainfall during the study period are shown in Fig.2.

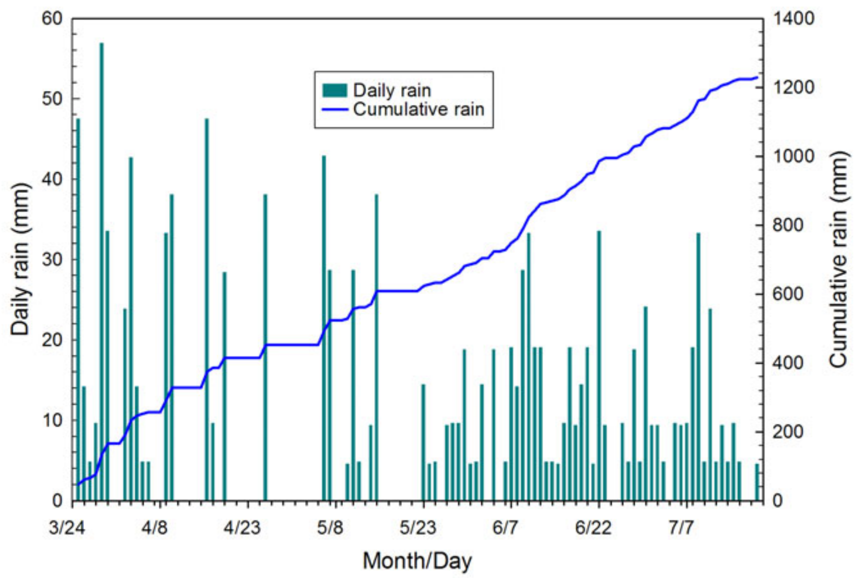

Figure 2. Daily and cumulative rain for the research site.

Results and Discussion

The data presented in Fig. 3 show the daily rain data (C), and the water content at 10, 20 (A), 30 (B) and 50 (C) cm below the root zone. In an average year, summer months are dry; however, this year over 600 mm of rain was received during three summer months (June - August). A calibration experiment was conducted on the same site to calibrate the EasyAg to these tropical soils. Results of this work are not presented here; however the calibration equations developed for each depth were used to process the raw data collected by the capacitance sensors. Soil water content data presented here were converted using these new calibration equations and not the manufacturer default calibration equation.

The water content in the top 10 cm showed more wetting and drying cycles as compared to all the other depths. The water content at that depth varied between 0.26 and 0.40 cm^3 cm^{-3} as a result of water inputs (rain and irrigation), and water losses through soil evaporation, and plant water uptake through evapotranspiration, and excess water losses below the rootzone and occasional runoff under intense rainfall events.

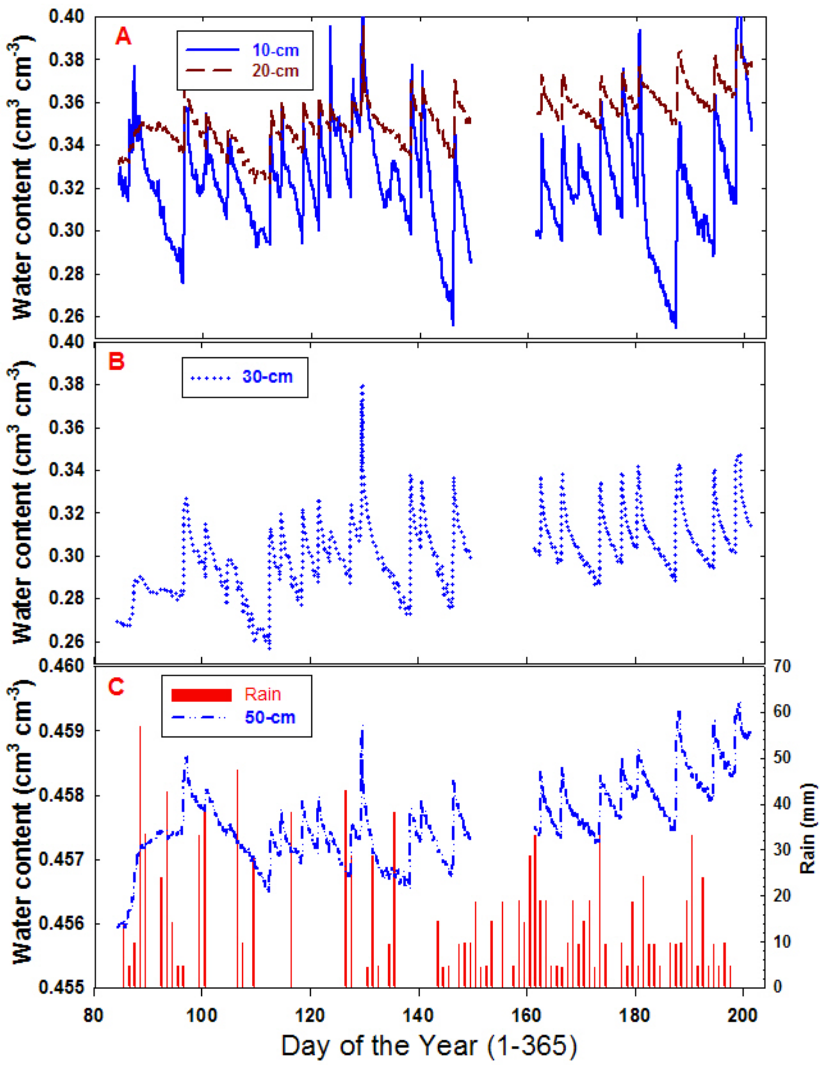

Figure 3. The daily rain (C), and the water content at 10, 20 (A), 30 (B), and 50 cm below the soil surface.

The water content in the 20-cm depth showed similar variation as of that in the 10-cm depth; however, the amplitude of this variability was lower, it varied between 0.33 and 0.38 cm^3 cm^{-3}.

The water content in the 30-cm depth showed similar dynamics as the water content in the top two levels. The range of this variability is more similar to that in the 10-cm depth than to that in the 20-cm depth. It varied between 0.26 – 0.34 $cm^3 cm^{-3}$. The water content at the 50-cm depth showed less than 1% variability over the entire period (Fig. 3 C). At the finer scale, the water content variations are similar to those shown in upper sensors.

The water content data at the four depths, 10, 20, 30 and 40 cm were used to calculate the water content in the rootzone and below it. It was assumed that the majority of the tomato roots are in the top 45 cm; thus the water content data from the top three sensors were multiplied by 15, 10 and 20 cm, respectively, to determine the total water stored in the rootzone (Fig. 4 A). The "Full Point" and "Wilting Point" were defined as the water storage in the rootzone, top 45 cm, corresponding to field capacity and permanent wilting point, respectively. Optimum irrigation management practices should ensure that the storage water in the rootzone should vary between those upper and lower boundaries. The sensor at the 50-cm depth was used to represent the water content below the rootzone in the zone between 45 and 55 cm below the rootzone. Data for this sensor are plotted in Fig. 4 B. These data show that excess water reached the 50-cm depth as a result of the rainfall events shown in Fig. 2.

The stored water below the rootzone followed a similar pattern as that in the rootzone; however, the amplitudes of the variation of the latter were relatively small; this could be attributed to the low hydraulic conductivity of this soil. The variations of the stored water in the rootzone are the results of water input from the rain and occasional irrigation and water output that include evapotranspiration through the soil surface and plant transpiration, excess water losses below the rootzone and potential surface runoff.

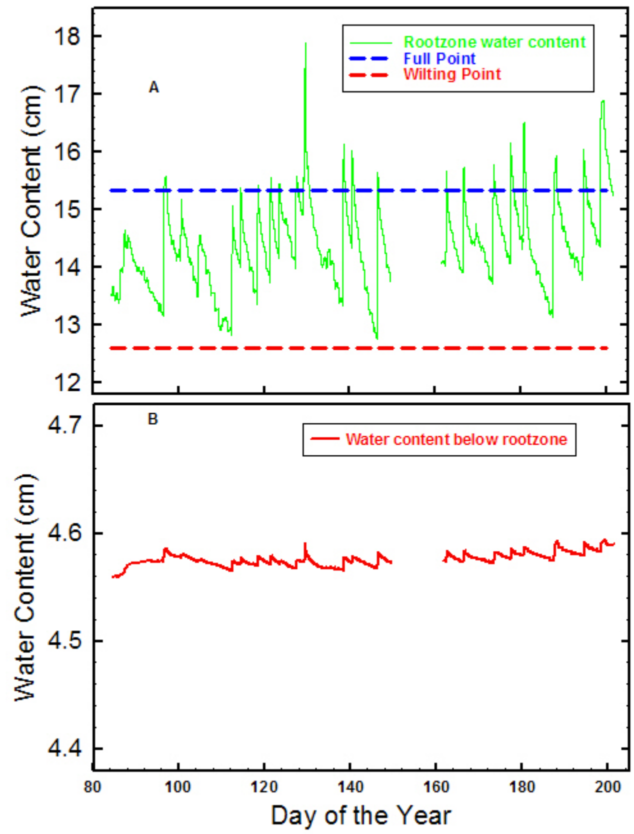

Figure 4. cumulative water in the rootzone (A) and blow it (B) with the upper and lower limits.

Summary and conclusions

As a major water user, irrigated agriculture is expected to make substantial changes to optimize its water use. Optimum water management should be based on understanding soil water holding capacity and crop water use through the growing season. Water content within and below the rootzone in a tomato trial was monitored for several months. Soil samples were taken for a laboratory determination of soil water release curve at four different depths, 10, 20, 30 and 40 cm. Real-time soil water content monitoring within and below the rootzone showed substantial variations as a result of water input through irrigation and rainfall and also the as a result of water output through evapotranspiration and deep percolations. Future field work should include at least three soil moisture sensors per treatment, on site weather data collection and field determination of soil physical properties. These data will be necessary to determine the different water budget components for a tomato crop grown under Hawaii leeward conditions.

References

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