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THE SURFACE ENERGY AND WATER BALANCE SYSTEM (SEWBS): A COMPUTER-ASSISTED APPROACH TO IRRIGATION SCHEDULING

Bhawan Singh[1], Jean Boivin[2], Glenn Kirkpatrick[3], Benoit Houle[4] and Barry Hum[3]

1.0 INTRODUCTION

As a result of increasing competition for water by industrial, domestic and resource sectors, there is an increasing need to optimize water use. Furthermore, recent shifts in climate and rainfall patterns have increased the incidence of drought in certain regions. The need to rationlize water use therefore becomes very important.

Proper irrigation scheduling is required in environments where water use, for agricultural and horticultural production, and productivity need to be optimized. Very frequently, water for use in irrigation is a limiting factor as is the case in Trinidad and Tobago. This limitation is imposed by climate and competition among user sectors. During the dry season, which usually lasts for about six months, precipitation is low and this causes a water deficit. At the same time water for irrigation purposes has to compete with other sectors, notably industrial, commercial and residential use. For these reasons, the application of irrigation technology to agriculture has to be judiciously planned so as to optimize water use by considering factors such as consumptive use and yield, and the cost of water and irrigation technology. Yield maximization is usually the goal of farmers. However economic considerations geared towards profit maximization intervene so as to influence irrigation use and technology.

This research is of great significance for the Caribbean region where irrigation agriculture, using traditional methods such as the cycle method and furrow irrigation, is widely practised.

2.0 METHODS

2.1 *Irrigation scheduling*

Irrigation scheduling systems usually deal with two basic questions: 1) when to irrigate, and 2) how much to irrigate.

The question of when to irrigate is approached in several ways. However, these methods can be broadly classified under the following headings: 1) plant indicators, 2) soil indicators, and 3) water balance techniques (Phene *et al*, 1990).

Plant indicator methods include appearance and growth (Haise and Hagen, 1967), leaf temperature (Gates, 1968; Idso *et al*, 1977; Jackson *et al*, 1977), leaf water potential (Gardner, 1965;Scholander 1965; Barrs, 1968; Cary and Wright 1970; Ritchie and Hinckley, 1975; Stegman *et al*, 1976) and stomatal resistance (Gates, 1968; Kanemasu *et al*; 1969; Clark and Hiler; 1971; Teare and Kanemasu, 1972; Kanemasu *et al* 1973). However, these methods are either too crude and subjective or call for the use of specialized instrumentation. The major drawback of these methods however lies in the fact that the decision to irrigate would have to be taken after the plant has suffered some degree of moisture stress which may sometimes irreversibly damage the plant and affect yield. Besides, these methods do not lend themselves easily to automation.

Soil-based measurements as indicators of irrigation requirements by plants include appearance and feel (Merriam, 1960; Hansen, 1962), gravimetry (Stegman *et al*, 1980), soil matric potential using tensiometers (Stegman *et al*,1980; Fischback and Schleusener, 1961; Bauder and Lundstom, 1977), electrical resistance using gypsum blocks (Schearer, 1963; Fischbach, 1965; Stegman *et al*, 1980) and neutron probes (Stegman *et al*, 1980). Like plant indicator methods, these techniques provide a *a posteriori* measure of irrigation needs when the plant might already have been adversely affected by water stress. These methods also involve disturbing the soil in the vicinity of the plant.

The water balance method involves solving for irrigation requirement (I) in the water balance equation, written as:

$$P + I = ET \pm R_0 \pm Dc \pm \Delta s \quad (1)$$

where P = precipitation (rainfall) (mm)
I = irrigation (mm)
ET = crop evapotranspiration (consumptive use) (mm)
R_0 = surface runoff into (-) or out of (+) the field in question (mm)
Dc = capillary drainage towards the surface (-) or into the subsurface (+) (mm)
Δs = residual moisture in the soil (mm)

1. Département de Géographie, Université de Montréal,Montréal, Qc 2. CARTEL, Université de Sherbrooke, Sherbrooke, Qc 3. Envirotec Ltee, Rosemere, Qc 4. Hydro-Quebec, Montreal, Qc

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By rearranging equation (1), the irrigation requirement (I) is derived as:

$$I = ET - P \pm R_o \pm D_c \pm \Delta s \qquad (2)$$

In most agricultural settings, especially where the surface is flat, surface runoff ($\pm R_o$) is negligible (Curwen and Massie, 1985). Also in situations where the ground water table is well beneath the rooting depth of the soil, capillary rise (-Dc) is negligible. So is downward percolation (+Dc) where dense and heavy soils such as clay restrict downward drainage of soil moisture.

In situations where R_o and D_c can be ignored, as is most often the case, equation (2) can be simplified as:

$$I = ET - P \pm \Delta s \qquad (3)$$

Since P and ET are normally measured, one needs to set the value of Δs at some threshold value, depending on soil and plant conditions, so as to solve for I in equation (3)

Alternatively, the residual soil moisture, Δs, for a given day, can be evaluated as (James, 1988):

$$\Delta s_i = \emptyset_{i-1} - \{100 \frac{(ET - P)}{RD}\} \qquad (4)$$

where

Δs_i = soil moisture content of a particular day (i) (%/volume)
$\emptyset_{i-1}$ = soil moisture content of the preceding day (%/volume)
ET = total evaporation for the day in question (mm)
P = total precipitation for the day in question (mm)
RD = rooting depth of plant according to its growth stage (mm).

Furthermore, not all the rainfall over a specified crop area reaches the rooting zone. Moisture losses can occur because of interception and evaporation by the crop, of windiness, and of surface runoff. In order to correct for these losses, rainfall (P) has to be adjusted by a correction factor that is less than unity so as to derive effective rainfall (Pe) (Burman *et al*, 1980). Similar adjustments have to be made to irrigation (I), especially for aerial irrigation systems.

By applying an effective precipitation factor to P (Pe), equation (4) is then rewritten as:

$$\Delta s_i = \emptyset_{i-1} - \{100 \frac{(ET - Pe)}{RD}\} \qquad (5)$$

Several computer-assisted irrigation scheduling techniques, relying on the water balance method are in existence (Crouch *et al*, 1981; Harrington and Heerman, 1981, Feperes *et al*, 1981; Brase *et al*, 1981; Curwen and Massie, 1985, Fulton *et al*, 1990; Fangmeier *et al*, 1990; Camp *et al*, 1990).

In this paper we describe the Surface Energy and Water Balance System (SEWBS). The irrigation scheduling is prescribed using the water balance technique as described in equations (2) to (5)above.

SEWBS is unique among computer-assisted irrigation scheduling techniques by the manner in which ET is calculated, and by the sophistication of the field equipment, including the use of solar power.

2.1 The Surface Energy and Water Balance System (SEWBS)

The field collection of data and the *in-situ* irrigation scheduling, on a real-time basis is done using the Surface Energy and Water Balance System (SEWBS). The SEWBS is a portable, fully automated system for scanning, monitoring and storing the various micrometeorological and soil data required for calculating crop evapotranspiration (ET) and for measuring rainfall (P) and soil moisture (Δs) required for the water balance (equation 3) and for scheduling the timing and amount of irrigation water application.

The SEWBS is designed along the lines of the Surface Energy and Radiation Balance System (SERBS) of Fritschen and Simpson (1989). The SEWBS, which is field portable and easy to install consists of the following components: a portable tower, on which are mounted the micrometerological instruments; a data acquisition system; and support peripherals including solar panels for supplying power to the system (Figure 1).

The data acquisition system consists of a customized 12-bit integrating analog to digital (A/D) converter (Remote Measurements) that is used to sample a maximum of 16 analog input channels as well as 4 digital inputs. This system has a voltage resolution of 50 microvolts with a ± 200 millivolt full scale value permitting an overall temperature accuracy of 0.005°C on all temperature measurement channels. Highly accurate offset voltages are used to provide accurate psychrometric temperature data.

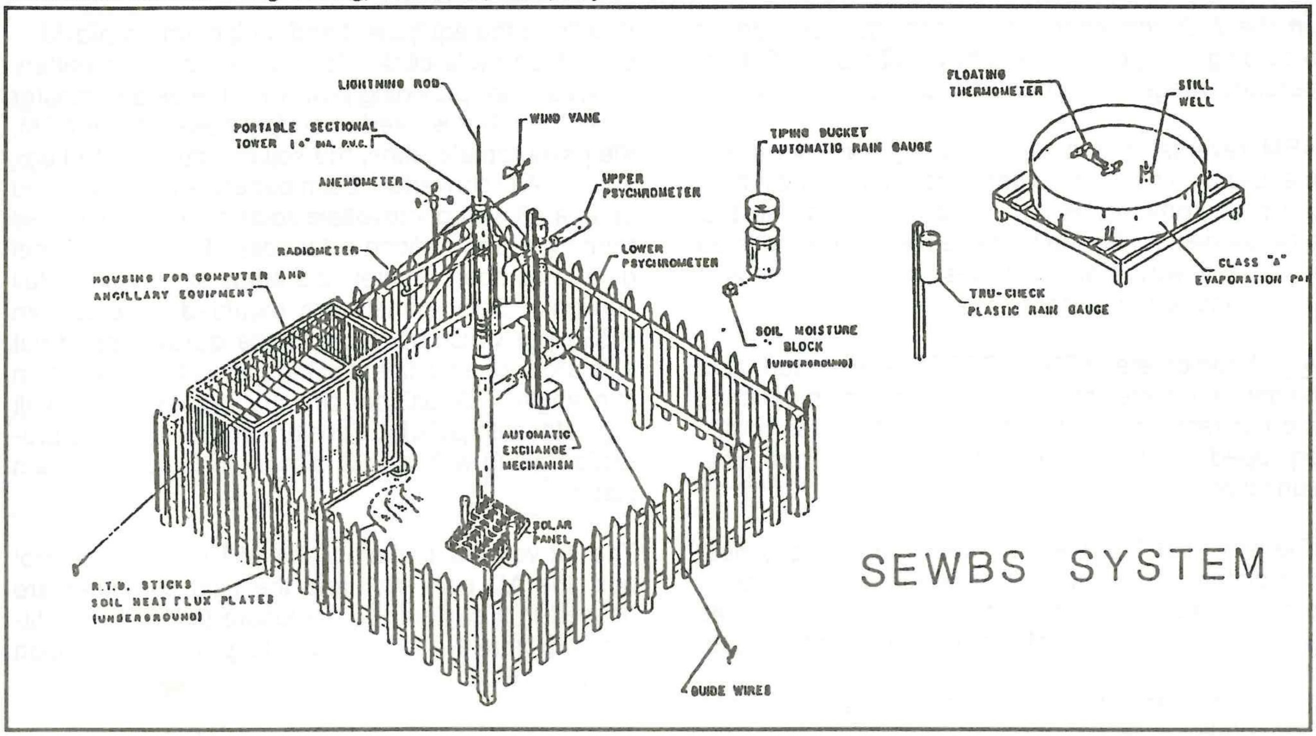

Figure 1 Components of the fully automated surface energy and water balance system (SEWBS). Also shown are a back-up rain guage and a class "A" evaporation pan

The A/D converter also handles up to a maximum of 6 controlled outputs which can deliver a maximum of 100 mA to any external device.

Data is fed from the A/D conventer via the RS232 port to a laptop field computer (Panasonic -80C286) with 60 megabytes of memory space on its hard disk and a 1.44 megabyte disk drive. The field computer not only collects and stores data, but also controls the switching of the Automatic Exchange Mechanism (AEM) and displays updated data summaries. The computer also directs the A/D converter to sample the data channels at 30 sec. intervals. The raw data is averaged over a six minute period and then stored on the hard disk of the field computer. Data is actually collected for 3 minutes, the remaining 3 minutes being required to allow the psychrometers to reach equilibrium with their new positions after each reversal. Data processing and analysis could then be either carried out directly in the field if needs be, or the data can be retrieved on diskette using the 1.44 megabyte (3-1/2 inch) disk drive for later analysis on a desktop computer.

An automatic exchange mechanism (AEM) (see Fig. 1) on which is housed 2 fan- aspirated updraft psychrometers with an adjustable 1 to 2 m vertical separation is used to measure dry-bulb (ΔT) and wet-bulb (ΔTw) temperature gradients. In order to avoid sensor bias and systematic error, the psychrometers are interchanged at 3 minute intervals. The AEM is a 12 volt DC battery operated unit constructed of 9.525 mm aluminium alloy suited for outdoor use. The drive system is composed of a polyethylene drive chain complete with bi-directional motor, bi-stable relay and double-gauged limit switches. The guide consists of ultra-high molecular weight polyethelene for abrasion resistance and low coefficient of friction for long life. Because the materials are primarily made of a polymer plastic, the system requires little or no lubrication. A pair of factory-calibrated (Brian Engineering) 500 Ohm platinum resistance temperature sensors (PRTD's), encased in a stainless steel tube, is housed in each psychrometer. The sensing tips of the RTD's are mounted four diameters from the end of a 0.0254m polyvinyl chloride (PVC) intake tube. The PVC intake tube is insulated with a 0.03m layer of plastic foam which is in turn covered with reflective aluminized mylar. The psychrometers are connected to separate exhaust stacks, each containing a 12 VDC fan which aspirates at 4 m s^{-1}, thus reducing the effect of ambient wind direction on psychrometer ventilation. Each fan uses 450 mA of current. The wet-bulbs are encased in 1 bar low-flow ceramic wicks that are moistened by a cloth wick originating from a pressure-adjusted reservoir. The 4 RTD's are connected in series to a constant current source (Fritschen and Simpson, 1982). This technique allows the same current to flow through all 4 RTD's and the voltage drop across each RTD is determined after it is offset with one of the offset voltages on the A/D converter. This technique provides a recording sensitivity of 0.005°C with a 40°C temperature range (Fritschen and Simpson, 1989).

AEM reversal and data monitoring and storage is menu-driven by the field computer. Information from the psychrometers is accessed through a sub 9-D type connector. During field use the AEM is mounted in such a way that the lowest psychrometer is 1 meter above the surface.

A net radiometer (Q*4: REBS) is mounted at a height of 1 meter above the surface for measuring the net radiation (Q*). This net radiometer comes equipped with heavy domes that do not require pressurization.

The soil heat flux (QG) is measured using 3 heat flux plates (Middleton) connected in series so as to provide an average value of 3 sites. The flux plates are placed at a depth of 5 cm beneath the surface. In order to correct for soil heat divergence between the surface and the 5 cm depth in the soil, 3-100 Ohm platinum RTD's encased in stainless steel are used. The sensors are positioned diagonally in the soil, next to the corresponding soil heat flux plate. The RTD sensors are also wired in series to get an average value of soil temperature. The change in temperature over a given time interval when multiplied by the approximate value of the heat capacity of the soil gives the soil heat divergence (Fritschen and Simpson, 1989).

Windspeed and direction are measured by means of a rotating pulse-type cup anemometer and a wind vane (Remote Measurements) respectively. The anemometer is sensitive to wind speeds between 1.4 and 180 km/h and the wind vane provides a resistive output between 0 and 360°, with a blind spot between 0 and 7°. The anemometer and wind vane are mounted at a height of 2 m so as to be usable in the Penman equation. (Doorenbos and Pruitt, 1977).

Rainfall is measured by means of a tipping bucket rain gauge (Rainwise) with a pulse output that provides 0.254 mm resolution.

Soil moisture is measured by a single gypsum block that is placed at an appropriate rooting depth. The gypsum block (Aguatronics) functions on the principle of the dissipation of a heat pulse over a given time interval, with the dissipation being a function of soil moisture. A control box containing the heat pulse source and precision amplifiers and filters are used to condition and calibrate the soil moisture sensor. Soil moisture can be measured over a wide range of matric potential ranging from nearly saturated (~0 bars) down to about 90 bars.

Power for the equipment and peripherals is provided by 2 deep cycle customized batteries. One battery is needed for providing power for the field computer while the other is used to supply power to the AEM, the psychrometer fans, the soil moisture control box and the A/D converter. Each battery is in turn hooked up to a 43 watt photovoltaic solar panel, constructed from high grade silicon solar cells. Each solar panel generates approximately 2.5 amps at 16 volts in full sunlight. Solar panels are mounted on 63.5 mm ABS pipes which not only provide sturdy support but also allow for adjustment of the panels to the optimum sun angle. Additional circuitry includes a 12 volt regulator with polarity, transient and overcharge protection along with a LED display to indicate system status.

The 12-volt DC batteries, the soil moisture control box, the AD converter and the field computer are housed in a customized enclosure (Igloo cooler) fitted with intake and exit fans to provide ventilation for the computer.

The major component of the water balance is crop consumptive use (ET). The SEWBS provides the necessary micrometeorological, soil and plant data required for calculating ET.

2.2 Evapotranspiration Data Analyzer (EDA)

ET is computed by a variety of micrometeorological methods, using the software package EDA, developed by the authors. In EDA, ET is calculated simultaneously using the Bowen ratio-energy balance (BREB) (Bowen, 1926), the Priestley-Taylor (1972), the Penman (1948) and the Penman-Monteith (Monteith, 1965) methods.

The BREB method for calculating ET (E_β) when ignoring stability and advection effects (Singh and Taillefer, 1986) is written as:

$$E_\beta = \frac{(Q^* - QG)/L}{1 + \beta} \qquad (6)$$

where
E_β = evaporation or evapotranspiration (mm s^{-1})
Q^* = net radiation (Wm^{-2})
QG = soil heat flux (Wm^{-2})
L = latent heat of vaporisation (MJ Kg^{-1})
β = the Bowen ratio

where further β is given by:

$$\beta = \gamma \frac{\Delta T}{\Delta e} \qquad (7)$$

where

γ = the psychrometric constant (0.066 k Pa C^{-1})

ΔT = the vertical temperature gradient above the vapourising surface (°C)

Δe = the vertical vapour pressure gradient above the vapourising surface (k Pa)

Furthermore, Δe is derived as:

$$\Delta e = (S + \gamma)\, \Delta T\omega - \gamma\, \Delta T \quad (8)$$

where

S = slope of the saturation vapour pressure curve (k Pa C^{-1})

$\Delta T\omega$ = the vertical wet-bulb temperature gradient above the vapourising surface (°C)

The Priestley-Taylor (1972) approach for calculating ET (E_{PT}), when ignoring advection effects (Singh and Taillefer, 1986) is expressed as:

$$E_{PT} = \{\alpha' \frac{S}{S + \gamma} (Q^* - QG)\}/L \quad (9)$$

where,

E_{PT} = evaporation or evapotranspiration (mm s^{-1})

and α' is a surface evaporability term whose value varies according to surface type, surface wetness, and advection effects (Singh and Taillefer, 1986). Usually α' is derived using an alternate measure of ET. For instance, as is the case here using the BREB (E_β) method as a reference, α' is derived as:

$$\alpha' = \frac{S + \gamma}{S\,(1 + \beta)} \quad (10)$$

The Penman (1948) method for calculating ET (E_{PM}) is here expressed as:

$$E_{PM} = \frac{Kc}{L} \frac{S\,(Q^* - QG)}{S + \gamma} + f\,(U)\,(es - ea) \quad (11)$$

where

ea = actual vapor pressure at the reference height (2m) (g Kg^{-1})

es = saturation vapor pressure of the dry-bulb temperature at height reference (2m) (g Kg^{-1})

Kc = crop coefficient

and

f(U) = wind function

Furthermore, f(U) is expressed as:

$$f(U) = 0.26\,(1 + 0.54U) \quad (12)$$

where

U = wind speed at reference height (2m) (ms^{-1})

The crop coefficient Kc represents the ratio of real (ETr) to potential (ETp) evapotranspiration:

$$Kc = ETr/ETp \quad (13)$$

where

ETr = real evapotranspiration (mm s^{-1})

ETp = potential evapotranspiration (mm s^{-1})

In this study ETr was taken to be ET as calculated by the BREB approach (E_β) and ETp as ET calculated by the Priestley Taylor approach (EPT) with α' being equal to 1.26. Alternatively literature values of Kc (Doorenboss and Pruitt 1977) can be used.

In EDA, values of ET are calculated at six minute intervals (mm/6min) and then summed to provide half-hourly values. Half-hourly values of ET are then summed to give total daily ET.

2.3 Automatic Irrigation Scheduling (AIS IRRIG)

The scheduling of irrigation applications in terms of timing and amount, is handled by a software package called AIS IRRIG. The aim of AIS IRRIG is to provide a modern and sophisticated tool to help agrometeorologists to better understand the water requirements of a given crop and to assist them in determining the exact moment of irrigation and the exact amount of water needed by the crop in question, in an objective manner. To this end AIS IRRIG accesses the data collected and stored by the SEWBS and analyzed by the EDA, and through further calculations pertaining to equations (2) (3) (4) and (5) schedules the timing and amount of irrigation applications. AIS IRRIG is in turn divided into a series of sub-programs each performing a specific task.

AIS IRRIG sums the values of evapotranspiration (ET) and precipitation (P), applying an efficiency factor as required, so as to evaluate the daily water balance (equations 4 and 5) or the total water balance over a given period, usually a week (equation 3). AIS IRRIG also provides a screen display of cumulative ET (ΣET) and P (ΣP), of plant variables including crop name, number of days since planted and rooting depth, of soil water characteristics including field capacity (FC) permanent wilting point (PWP), readily available water (RAW), maximum allowable depletion (MAD) and of the probability of rain forecast.

In order to render AIS IRRIG operational, several variables, other than the ones available through the SEWBS and EDA have to be entered or created in a variety of sub-files. There is a CROP file that identifies the crop, its site and location, its planting date, its maximum rooting depth and the stages in its crop life cycle. Then there is a SOIL file that identifies the soil type, the field capacity (FC), the permanent wilting point (PWP), available water (AW), readily available water (RAW) and maximum allowable depletion (MAD=RAW/AW) (James, 1988). There is also a WEATHER file to enter the probability of rain forecast to withhold irrigation, if needed, for the day in question and the following day. Coefficients for determining effective rainfall, based on amount and intensity, and effective irrigation, based on type of system are also accessed via a separate file. Also the rate of capillary rise (Dc) or drainage is accessed through a file in which these values are entered manually each week depending on spot checks of the moisture gradients in the soil.

The timing of irrigation in AIS IRRIG is calculated using either of two methods.. In the first method, it is stipulated that irrigation must commence when:

$$\Delta s \leq RAW \qquad (14)$$

or $\Delta S \leq MAD\ (AW)$

where

ΔS = residual soil moisture as a percent by volume (equations 4 and 5) or as a depth in mm (equation 3)

MAD = maximum allowable depletion as derived from the literature (James *et al*, 1982)

AW = the available water expressed are a percent by volume or a depth in mm.

RAW = is the lower limit of readily available water (MAD x AW).

The problem is in defining a critical value of Δs (Δsc). It is known (James, 1988) that:

$$RAW = RD\ (FC - \Delta sc)\ /100 \qquad (15)$$

By rearranging equation (15) algebraically, Δsc can be calculated as:

$$\Delta sc = \frac{RAW \times 100}{RD} + FC \qquad (16)$$

where RAW, depending on the MAD value, is in mm, as is RD, FC is a percentage, and Δsc is a percentage soil moisture.

The decision of when to irrigate, if soil moisture is measured in the field ($\Delta sm\%$), is taken when $\Delta sm \leq \Delta sc$.

Alternatively, the timing of irrigation can be determined using the allowable depletion approach (Curwen and Massie, 1985). In this second method a daily balance (BAL) of soil moisture inputs and outputs into the soil is calculated as:

$$BAL = Pe + Ie - ET \qquad (17)$$

where

BAL = daily soil moisture balance (mm)

Ie = effective irrigation

A further parameter (AD-BAL) which daily adjusts the residual moisture in the soil is then calculated as:

$$AD\text{-}BAL_i = AD\text{-}BAL_{i-1} + BAL_i \qquad (18)$$

where

$AD\text{-}BAL_i$ = the residual soil moisture for the day in question (i) in mm

and $AD\text{-}BAL_{i-1}$ = the residual soil moisture of the preceding day (mm)

and BAL_i = soil moisture balance for the day in question (i) in mm.

However an initial value of AD-BAL has to be established. This value is normally close to the field capacity. In order to avoid water wastage and leaching, this value is usually set below field capacity. In this study, AD-BAL initial is set at the upper limit of the readily available water (RAW) in mm depth, when multiplied by the rooting depth, as:

$$AD\text{-}BAL_{init} = MAD \times RD \times (AW/100) \qquad (19)$$

where

AD-BAL init = initial AD-BAL (mm)

and

AW (%), MAD (0.65) and RD (mm) are as defined previously.

AD-BAL is adjusted daily and when AD-BAL ≤0, there is the need to irrigate.

The timing of irrigation is further modulated by the probability of rain forecast. In this paper only a 90 percent and above probability is used to withhold irrigation.

The question of the amount of irrigation water to apply will depend on crop, soil, weather and economic factors. If water is easily available and inexpensive full irrigation is practised. But where cost factors come into play, deficit irrigation may be practised, even at the expense of maximum yield.

The amount of irrigation, assuming that full irrigation is being practised is determined as:

$$IRRIG = \frac{RD\ (FC - \Delta sc)}{Ie} \qquad (20)$$

where

IRRIG = irrigation amount (mm)

RD = rooting depth (mm)

FC = field capacity (%/volume)

Δsc = critical soil moisture content for the day in question (%/volume)

Alternatively, IRRIG is simply calculated as:

$$IRRIG = FC - \Delta sc \qquad (21)$$

where

FC = field capacity in mm depth of water depending on rooting depth (mm)

and

Δsc = critical soil moisture content in mm depth of water depending on rooting depth (mm)

The amount decision is also flagged depending upon the probabillity of rain and amount of rain forecasted.

However the amounts in equations (20) and (21) could be further modulated depending on whether full or deficit irrigation is being practised and on the delivery capacity and efficiency of the irrigation system. Also in order to avoid over-irrigation in case of rain, and leaching, the amount may also be reduced. AIS IRRIG allows a signal to be displayed on the screen of the field computer, when irrigation is required. This signal can easily be used to trigger a siren or a horn or even to automatically turn on a sprinkler or drip system. When irrigation is completed, the amount is entered and the system is reinitialized.

Apart from the field display, detailed reports on irrigation scheduling can be printed in the field or using a desktop computer. A short report is printed based on equations (4) and (5) and a complete report in printed based or equation (2).

3.0 RESULTS AND DISCUSSION

Thus far, SEWBS has been tested over different crops including okra, rice and potatoes in Trinidad and Tobago (1989) and over 2 orchard crops, namely raspberries (1989) and apples (1991) in southern Quebec. In this paper results for the okra crop in Trinidad and Tobago are presented.

The soil at the site of the okra crop was a sandy clay alluvium. The crop was approaching maturity when measurements commenced. Rooting depth was close to 300 mm.

In Tables 1 and 2 and Figures 3 and 4 the hourly energy balance and evapotranspiration data for a typical day, namely, February 7, 1989, are presented using measurements collected by the SEWBS and analyzed by EDA.

In Table 1 and Figure 3, the net radiation (Q*) approaches 700 Wm^{-2} around midday, which is typical for this location, in the absence of clouds. The dip in the Q*, and subsequently the latent (QE), sensible (QH) and soil heat (QG) curves in Figure 3 is due to the passage of a cloud around midday. Table 1 and Figure 3 also show that most of Q* is expensed via QE, with lesser amounts going to QH and QG, as is to be expected over a vigorously growing crop. Also shown in Table 1 are half-hourly values of rainfall (P), air temperature (T air) wind speed (U) and direction (U dir) and soil moisture at rooting depth (HUMS).

Table 2 and Figure 4 provide the half-hourly and daily totals of ET according to the BREB (ET_β and $ET_{\beta a}$), Priestley-Taylor (ET_{PT}) and Penman (ET_{PM}) approaches. $ET_{\beta a}$ provides a revised value of ET if the Bowen ratio (βr) is rejected, being exceedingly high or low or at -1, which can sometimes occur. On the date in question βr was never rejected so that ET_β and $ET_{\beta a}$ were identical. Figure 4 shows a very strong correspondence between methods.

This is so because the radiation balance (Q*) is dominant in all methods, a fact which is evident in

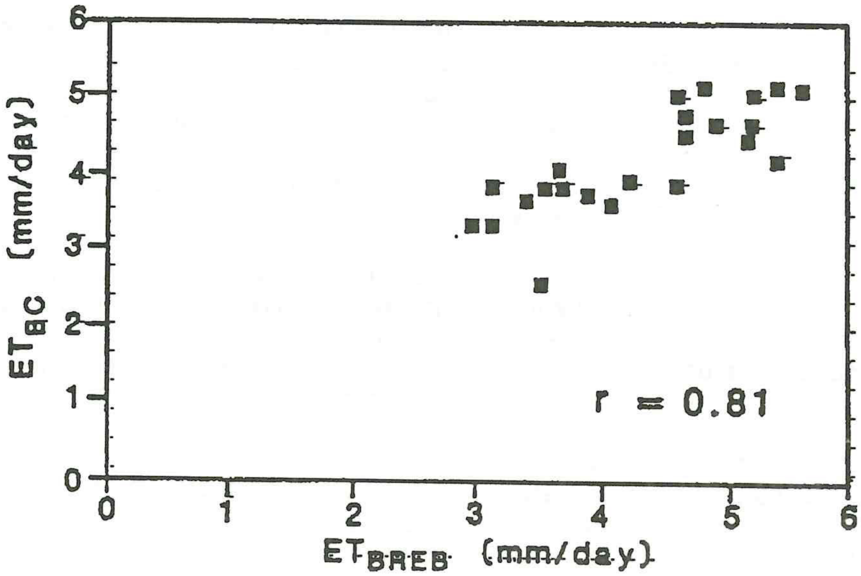

Figure 2 Relationship between ET_{BREB} and ET_{BC}

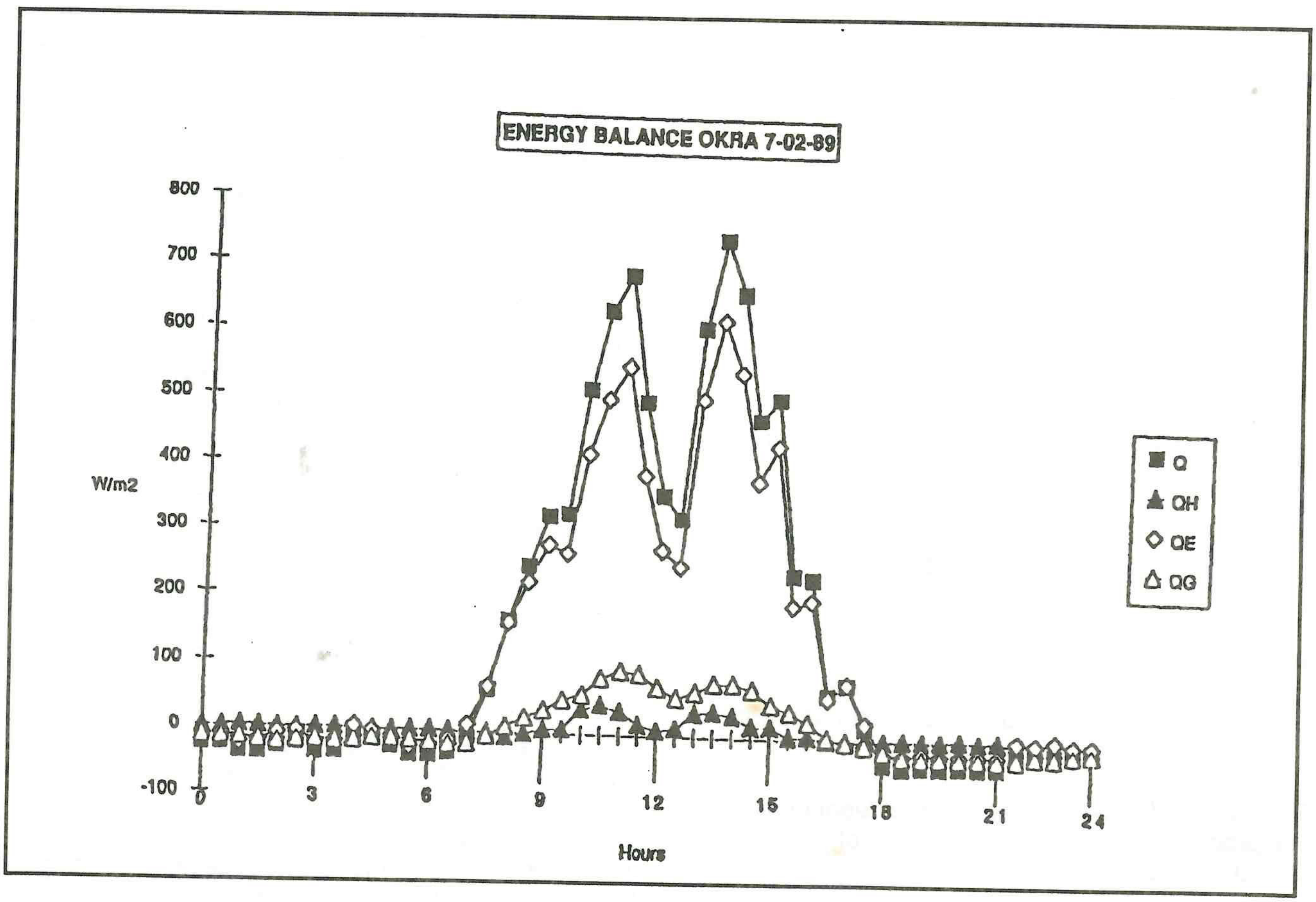

Figure 3 Diurnal half-hourly variation of the energy balance over the okra crop, on February 7th, 1989

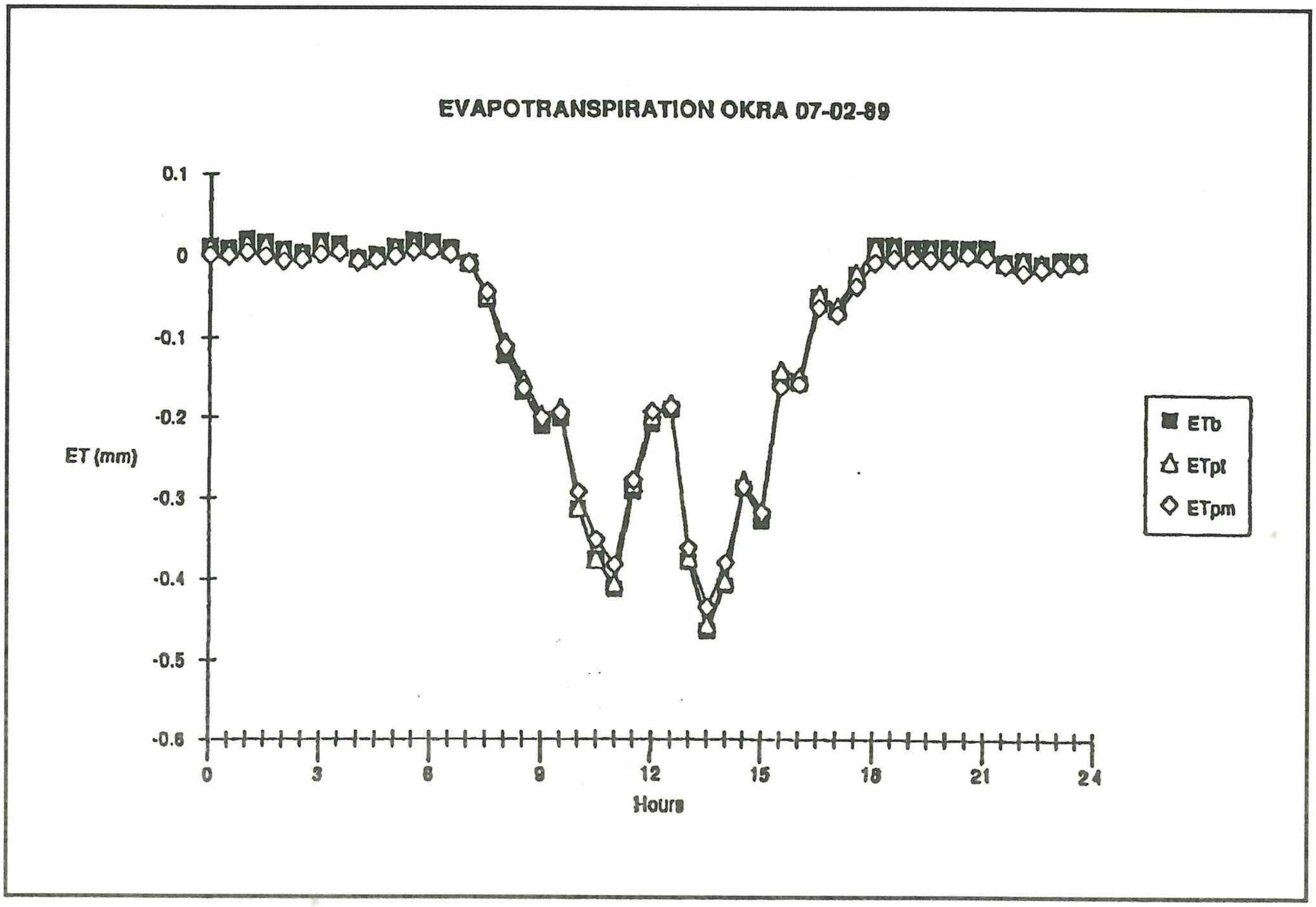

Figure 4 Diurnal half-hourly variation of ET according to the BREB (ETb and ETba), Priestley-Taylor (ETpt) and Penman-Monteith (ETpm) methods for the okra crop on February 7th, 1989

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ENERGY BALANCE SUMMARY REPORT

TIME hh:mm:ss	Q* Wm^{-2}	QG Wm^{-2}	QH Wm^{-2}	QE Wm^{-2}	ET_β mm	P mm	Tair °C	U m/s	Udir °	HumS %
00:00:00	-27.1	-14.0	1.3	-14.4	0.01	0.00	22.33	0.00	NE	31
00:30:00	-25.6	-14.6	0.7	-11.7	0.01	0.00	22.25	0.00	N	32
01:00:00	-38.8	-16.0	2.7	-25.5	0.02	0.00	22.04	0.00	N	32
01:30:00	-38.7	-19.2	1.7	-21.3	0.02	0.00	22.38	0.00	N	32
02:00:00	-29.3	-20.8	1.1	-9.5	0.01	0.00	22.71	0.00	N	32
02:30:00	-23.2	-18.5	0.3	-5.0	0.00	0.00	22.21	0.00	E	32
03:00:00	-36.7	-16.6	2.5	-22.6	0.02	0.00	22.25	0.00	SE	32
03:30:00	-35.2	-18.6	2.6	-19.2	0.01	0.00	20.98	0.00	SE	43
04:00:00	-14.0	-17.2	-0.7	3.9	0.00	0.00	21.77	0.00	NE	32
04:30:00	-13.8	-12.5	0.1	-1.4	0.00	0.00	21.82	0.97	E	32
05:00:00	-25.8	-12.3	0.9	-14.4	0.01	0.00	21.63	1.30	NE	32
05:30:00	-37.5	-14.4	2.0	-25.1	0.02	0.00	21.35	0.00	N	32
06:00:00	-37.8	-17.3	2.1	-22.7	0.02	0.00	20.41	0.00	N	32
06:30:00	-32.9	-19.8	0.9	-13.9	0.01	0.00	19.83	0.00	N	32
07:00:00	-8.7	-18.3	-0.2	9.8	-0.01	0.00	20.78	0.00	N	32
07:30:00	63.2	-6.2	0.3	69.1	-0.05	0.00	23.42	0.0	N	33
08:00:00	166.3	9.6	-6.6	163.3	-0.12	0.00	25.17	1.74	N	33
08:30:00	248.5	23.9	-0.1	224.7	-0.17	0.0	26.17	3.14	N	33
09:00:00	324.9	36.1	6.4	282.3	-0.21	0.00	26.01	3.76	N	33
09:30:00	329.3	52.0	7.2	270.0	-0.20	0.00	26.20	3.78	N	33
10:00:00	519.5	60.7	38.2	420.6	-0.31	0.00	26.99	3.00	N	33
10:30:00	636.4	85.5	45.7	505.1	-0.37	0.00	27.78	3.54	N	33
11:00:00	689.6	97.3	36.6	555.7	-0.41	0.00	27.94	4.40	N	33
11:30:00	502.4	93.3	17.9	391.2	-0.29	0.00	27.77	4.36	N	33
12:00:00	361.1	74.0	8.5	278.6	-0.21	0.00	26.73	3.37	N	33
12:30:00	326.3	58.9	13.5	263.9	-0.19	0.00	26.88	3.21	N	34
13:00:00	613.1	68.0	36.4	508.7	-0.38	0.00	28.01	4.69	N	34
13:30:00	746.9	82.0	39.3	625.7	-0.46	0.00	28.43	5.32	N	34
14:00:00	665.6	82.0	33.8	549.8	-0.41	0.00	28.47	4.15	N	34
14:30:00	478.3	74.3	18.9	385.1	-0.29	0.00	28.20	4.65	N	34
15:00:00	510.2	52.0	19.2	439.0	-0.33	0.00	28.26	4.29	N	34
15:30:00	244.0	42.0	3.3	198.7	-0.15	0.00	27.50	3.65	N	34
16:00:00	238.9	26.6	5.2	207.1	-0.15	0.00	26.73	2.97	N	34
16:30:00	67.7	4.2	0.3	63.2	-0.05	0.00	25.36	2.28	N	35
17:00:00	82.7	-3.1	0.3	85.5	-0.06	0.00	25.44	1.57	N	35
17:30:00	18.8	-7.4	-0.2	26.4	-0.02	0.00	25.36	1.16	N	35
18:00:00	-36.5	-16.5	1.2	-21.1	0.02	0.00	24.61	0.00	N	35
18:30:00	-41.8	-22.7	2.3	-21.4	0.02	0.00	23.42	0.00	N	35
19:00:00	-38.5	-23.5	2.3	-17.3	0.01	0.00	22.27	0.00	SE	35
19:30:00	-40.0	-22.9	2.2	-19.3	0.01	0.00	22.28	0.00	SE	35
20:00:00	-37.9	-22.7	4.1	-19.3	0.01	0.00	22.02	0.00	E	35
20:30:00	-39.0	-23.1	2.5	-18.5	0.01	0.00	20.77	0.00	N	35
21:00:00	-38.8	-24.1	4.4	-19.1	0.01	0.00	20.82	0.00	N	35
21:30:00	-19.5	-23.6	-0.2	4.2	0.00	0.00	20.92	0.00	N	35
22:00:00	-16.8	-18.2	-0.2	1.6	0.00	0.00	22.30	1.83	SE	35
22:30:00	-12.8	-19.0	-0.5	6.6	0.00	0.00	22.36	0.00	SW	35
23:00:00	-13.3	-14.3	-0.1	1.1	0.00	0.00	22.06	0.00	E	35
23:30:00	-11.00	-11.7	0.0	0.7	0.00	0.00	21.65	0.00	NE	35
TOTAL					-4.58					

Table 1: Half-hourly values of the components of the energy balance (Q*, QG, QH, QE) for February 7th, 1989 over the okra crop. Also shown are evapotranspiration (ET_β), rainfall (P), air temperature (Tair), wind speed (U) and direction (Udir) and soil moisture (HumS).

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TIME hh:mm:ss	ET_{β} mm	$ET_{\beta a}$ mm	ET_{PT} mm	ET_{PM} mm	βr Accepted	βr Rejected	α'	Kc
00:00:00	0.01	0.01	0.01	0.00	-0.080	-	1.56	1.00
00:30:00	0.01	0.01	0.01	0.00	-0.052	-	1.51	1.00
01:00:00	0.02	0.02	0.01	0.00	-0.105	-	1.61	1.00
01:30:00	0.02	0.02	0.01	0.00	-0.078	-	1.57	1.00
02:00:00	0.01	0.01	0.01	-0.01	-0.085	-	1.59	1.00
02:30:00	0.00	0.00	0.00	0.00	-0.120	-	1.65	1.00
03:00:00	0.02	0.02	0.01	0.00	-0.109	-	1.61	1.00
03:30:00	0.01	0.01	0.01	0.00	-0.130	-	1.67	1.00
04:00:00	0.00	0.00	0.00	-0.01	-0.117	-	1.64	1.00
04:30:00	0.00	0.00	0.00	0.00	-0.045	-	1.50	1.00
05:00:00	0.01	0.01	0.01	0.00	-0.054	-	1.52	1.00
05:30:00	0.02	0.02	0.01	0.01	-0.079	-	1.57	1.00
06:00:00	0.02	0.02	0.01	0.01	-0.093	-	1.61	1.00
06:30:00	0.01	0.01	0.01	0.00	-0.068	-	1.58	1.00
07:00:00	-0.01	-0.01	-0.01	-0.01	-0.020	-	1.48	1.00
07:30:00	-0.05	-0.05	-0.05	-0.04	0.005	-	1.43	1.00
08:00:00	-0.12	-0.12	-0.10	-0.11	-0.027	-	1.47	1.00
08:30:00	-0.17	-0.17	-0.15	-0.16	0.036	-	1.38	1.00
09:00:00	-0.21	-0.21	-0.19	-0.20	0.020	-	1.38	1.00
09:30:00	-0.20	-0.20	-0.19	-0.19	0.012	-	1.38	1.00
10:00:00	-0.31	-0.31	-0.31	-0.29	0.089	-	1.27	1.00
10:30:00	-0.37	-0.37	-0.37	-0.35	0.091	-	1.26	1.00
11:00:00	-0.41	-0.41	-0.40	-0.38	0.066	-	1.28	1.00
11:30:00	-0.29	-0.29	-0.28	-0.28	0.046	-	1.31	1.00
12:00:00	-0.21	-0.21	-0.20	-0.19	0.007	-	1.37	1.00
12:30:00	-0.19	-0.19	-0.18	-0.18	0.051	-	1.31	1.00
13:00:00	-0.38	-0.38	-0.37	-0.36	0.067	-	1.28	1.00
13:30:00	-0.46	-0.46	-0.46	-0.43	0.063	-	1.28	1.00
14:00:00	-0.41	-0.41	-0.40	-0.38	0.061	-	1.28	1.00
14:30:00	-0.29	-0.29	-0.28	-0.28	0.047	-	1.30	1.00
15:00:00	-0.33	-0.33	-0.31	-0.31	0.044	-	1.32	1.00
15:30:00	-0.15	-0.15	-0.14	-0.16	0.013	-	1.36	1.00
16:00:00	-0.15	-0.15	-0.14	-0.15	0.013	-	1.36	1.00
16:30:00	-0.05	-0.05	-0.04	-0.06	0.001	-	1.39	1.00
17:00:00	-0.06	-0.06	-0.06	-0.07	0.002	-	1.39	1.00
17:30:00	-0.02	-0.02	-0.02	-0.03	-0.011	-	1.41	1.00
18:00:00	0.02	0.02	0.01	0.00	-0.052	-	1.49	1.00
18:30:00	0.02	0.02	0.01	0.00	-0.105	-	1.60	1.00
19:00:00	0.01	0.01	0.01	0.00	-0.125	-	1.65	1.00
19:30:00	0.01	0.01	0.01	0.00	-0.112	-	1.53	1.00
20:00:00	0.01	0.01	0.01	0.00	-0.206	-	1.82	1.00
20:30:00	0.01	0.01	0.01	0.01	-0.130	-	1.68	1.00
21:00:00	0.01	0.01	0.01	0.00	-0.2117	-	1.90	1.00
21:30:00	0.00	0.00	0.00	-0.01	-0.144	-	1.71	1.00
22:00:00	0.00	0.00	0.00	-0.02	0.074	-	1.55	1.00
22:30:00	0.00	0.00	0.00	-0.01	-0.053	-	1.52	1.00
23:00:00	0.00	0.00	0.00	0.01	-0.048	-	1.50	1.00
23:30:00	0.00	0.00	0.00	0.00	-0.040	-	1.49	1.00
TOTAL	-4.58	-4.58	-4.46	-4.66			1.49	1.00

Table 2: Half-hourly and daily totals of ET according to the BREB (ET_{β} and $ET_{\beta a}$), Priestley-Taylor (ET_{PT}) and Penman (ET_{PM}) methods for February 7th, 1989 over the okra crop. Also shown are the Priestley-Taylor parameter α' and the crop coefficient Kc.

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Table 3: Soil moisture balance measurements, calculations and irrigation schedulings using the critical soil moisture approach for the okra crop, Trinidad

Date DD/MM/YY	P mm	Pe mm	ET mm	Δsm %	Δsc %	DΔS	I mm	Ie mm	ΔScp %	Iamtp mm
18/01/89	0	0	3.63	-	26.79	-	0	0	26.79	0
19/01/89	0	0	3.49	-	25.63	-	0	0	25.63	0
20/01/89	0	0	4.18	-	24.23	-	0	0	24.24	0
21/01/89	0	0	3.07	-	23.21	-	0	0	23.22	0
22/01/89	0	0	4.26 **	-	21.79	-	0	0	21.80	0
23/01/89	5.08	3.81	4.84 *	-	21.45	-	0	0	21.46	0
24/01/89	1.02	0.77	5.17	-	19.98	-	0	0	19.99	0
25/01/89	0	0	5.15	-	18.26	-	0	0	18.27	12
26/01/89	0	0	4.61	-	16.73	-	0	0	19.73	0
27/01/89	0	0	5.34	-	14.95	-	0	0	17.95	12
28/01/89	0	0	3.82	-	13.67	-	0	0	19.68	0
29/01/89	0.51	0.38	3.56	-	12.61	-	0	0	18.62	0
30/01/89	5.59	4.19	2.93	-	14.94	-	7.61	5.71	19.04	0
31/01/89	0	0	4.46 *	-	13.45	-	0	0	17.55	12
01/02/89	0	0	5.27 *	-	11.69	-	0	0	18.79	0
02/02/89	2.29	1.72	4.43 *	-	10.79	-	0	0	17.89	12
03/02/89	2.54	1.91	4.22 *	-	11.48	-	5.84	4.38	20.12	0
04/02/89	1.27	0.95	3.51 *	-	10.63	-	0	0	19.27	0
05/02/89	8.00	6.00	2.50 *	-	11.79	-	0	0	20.44	0
06/02/89	3.55	2.66	2.59 *	-	12.58	-	3.05	2.29	20.46	0
07/02/89	0.76	0.57	4.58	-	11.24	-	0	0	19.12	0
08/02/89	0.51	0.38	4.54	-	9.86	-	0	0	17.73	12
09/02/89	0.76	0.57	4.53 *	-	8.54	-	0	0	19.41	0
10/02/89	1.01	0.76	4.68 *	-	7.23	-	0	0	18.10	12
11/02/89	0	0	3.13 *	-	6.95	-	3.05	2.29	20.06	0
12/02/89	0	0	3.62 *	-	5.74	-	0	0	18.85	0
13/02/89	0.25	0.19	5.36	-	4.02	-	0	0	17.13	12
14/02/89	0.76	0.57	3.36	-	4.81	-	6.86	5.15	19.20	0
15/02/89	0.51	0.38	4.00	-	6.84	-	12.95	9.71	17.99	12
16/02/89	0	0	4.73	-	5.26	-	0	0	19.41	0
17/02/89	5.33	4.00	2.67 *	-	5.70	-	0	0	19.85	0
18/02/89	0.5	0.38	4.51	-	4.33	-	0	0	18.47	12
19/02/89	0.51	0.38	5.09	-	2.76	-	0	0	19.90	0
20/02/89	0	0	5.12 *	-	1.05	-	0	0	18.19	12
21/02/89	0	0	4.26 **	-	0.00	-	0	0	19.77	0
22/02/89	0	0	4.26 **	-	0.00	-	0	0	18.35	12
23/02/89	0	0	4.26 **	-	0.00	-	0	0	19.93	0
24/02/89	0	0	3.58	-	0.00	-	0	0	18.74	0
25/02/89	0	0	3.10	-	0.00	-	0	0	17.71	12
26/02/89	0	0	4.84	-	0.00	-	0	0	19.10	0
27/02/89	0	0	5.43	-	0.00	-	0	0	17.29	12

* Blaney-Criddle
** Average value

1. Initial soil moisture (ΔSc) on 17/01/89 : 28%
2. Field capacity (FC) : 29%
3. Permanent wilting point (PWP) : 13%
4. Available water (AW) : 16%
5. Readily available water (RAW) 31.2 mm : 10.4%
6. Maximum allowable depletion (MAD) : 0.65
7. Rooting Depth (RD) : 300 mm
8. Critical soil moisture ((ΔScr) : 18.6%
9. Potential soil moisture (ΔScp) on 17/01/89 : 28%
10. Precipitation efficiency (Pe) : 75%
11. Irrigation efficiency (Ei) : 75%

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Table 4: Soil moisture balance measurements and calculations and irrigation schedulings using the allowable depletion approach for the okra crop, Trinidad

Date DD/MM/YY	P mm	Pe mm	ET mm	I mm	Ie %	BAL mm	AD BAL mm	BALp mm	AD BALp mm	Iamtp mm
18/01/89	0	0	3.63	0	0	-3.6	24.4	-3.6	24.4	0
19/01/89	0	0	3.49	0	0	-3.5	20.9	-3.5	20.9	0
20/01/89	0	0	4.18	0	0	-4.2	16.7	-4.2	16.7	0
21/01/89	0	0	3.07	0	0	-3.1	13.6	-3.1	13.6	0
22/01/89	0	0	4.26 **	0	0	-4.3	9.3	-4.3	9.4	0
23/01/89	5.08	3.81	4.84 *	0	0	-1.0	8.3	-1.0	8.3	0
24/01/89	1.02	0.77	5.17	0	0	-4.4	3.9	-4.4	3.9	0
25/01/89	0	0	5.15	0	0	-5.2	0.0	-5.2	0.0	12
26/01/89	0	0	4.61	0	0	-4.6	0.0	7.4	7.4	0
27/01/89	0	0	5.34	0	0	-5.3	0.0	-5.3	2.0	0
28/01/89	0	0	3.82	0	0	-3.8	0.0	-3.8	0.0	12
29/01/89	0.51	0.38	3.56	0	0	-3.2	0.0	8.8	8.8	0
30/01/89	5.59	4.19	2.93	7.61	5.71	7.0	7.0	1.3	10.1	0
31/01/89	0	0	4.46 *	0	0	-4.5	2.5	-4.5	5.6	0
01/02/89	0	0	5.27 *	0	0	-5.3	0.0	-5.3	0.3	0
02/02/89	2.29	1.72	4.43 *	0	0	-2.7	0.0	-2.7	0.0	12
03/02/89	2.54	1.91	4.22 *	5.84	4.38	2.1	2.1	9.7	9.7	0
04/02/89	1.27	0.95	3.51 *	0	0	-2.6	0.0	-2.6	7.1	0
05/02/89	8.00	6.00	2.50 *	0	0	3.5	3.5	3.5	10.6	0
06/02/89	3.55	2.66	2.59 *	3.05	2.29	2.4	5.9	0.1	10.7	0
07/02/89	0.76	0.57	4.58	0	0	-4.0	1.9	-4.0	6.7	0
08/02/89	0.51	0.38	4.54	0	0	-4.2	0.0	-4.2	2.5	0
09/02/89	0.76	0.57	4.53 *	0	0	-4.0	0.0	-4.0	0.0	12
10/02/89	1.01	0.76	4.68 *	0	0	-3.9	0.0	8.1	8.1	0
11/02/89	0	0	3.13 *	3.05	2.29	-0.8	0.0	-3.1	5.0	0
12/02/89	0	0	3.62 *	0	0	-3.6	0.0	-3.6	1.3	0
13/02/89	0.25	0.19	5.36	0	0	-5.2	0.0	-5.2	0.0	12
14/02/89	0.76	0.57	3.36	6.86	5.15	2.4	2.4	9.2	9.2	0
15/02/89	0.51	0.38	4.00	12.95	9.71	6.1	8.5	-2.6	5.6	0
16/02/89	0	0	4.73	0	0	-4.7	3.8	-4.7	0.9	0
17/02/89	5.33	4.00	2.67 *	0	0	1.3	5.1	1.3	2.2	0
18/02/89	0.5	0.38	4.51	0	0	-4.1	1.0	-4.1	0.0	12
19/02/89	0.51	0.38	5.09	0	0	-4.7	0.0	7.3	7.3	0
20/02/89	0	0	5.12 *	0	0	-5.1	0.0	-5.1	2.2	0
21/02/89	0	0	4.26 **	0	0	-4.3	0.0	-4.3	0.0	12
22/02/89	0	0	4.26 **	0	0	-4.3	0.0	7.7	7.7	0
23/02/89	0	0	4.26 **	0	0	-4.3	0.0	-4.3	3.5	0
24/02/89	0	0	3.58	0	0	-3.6	0.0	-3.6	0.0	12
25/02/89	0	0	3.10	0	0	-3.1	0.0	8.9	8.9	0
26/02/89	0	0	4.84	0	0	-4.8	0.0	-4.8	4.1	0
27/02/89	0	0	5.43	0	0	-5.4	0.0	-5.4	0.0	12

* Blaney-Criddle
** Average value

1. Field capacity (FC) : 29%
2. Permanent wilting point (PWP) : 13%
3. Available water (AW) : 16%
4. Readily available water (RAW) 31.2 mm : 10.4%
5. Maximum allowable depletion (MAD) : 0.65
6. Rooting Depth (RD) : 300 mm
7. Critical soil moisture ((ΔScr) : 18.6%
8. AD BAL Initial on 17/01/89 : 28 mm
9. AD BALp initial on 17/01/89 : 28 mm
10. AD BALp max : 31.2 mm
11. Precipitation efficiency (Pe) : 75%
12. Irrigation efficiency (Ei) : 75%

Figure 4, where variations in ET are matched with the daily progression of Q^* (Figure 3). Also shown in Table 2 are values of α' of the Priestley-Taylor formulation and the crop coefficient, Kc.

Tables 3 and 4 present the irrigation scheduling results. ET values are for the BREB approach. Unfortunately, there were frequent equipment malfunctions which made necessary the use of an alternative measure of ET, namely the Blaney-Criddle approach (ETBC) and on occasion the mean seasonal value of ET. For the 4 days that the mean seasonal value was used conditions were mainly clear and rainless, so that the mean total daily ET value (4.26 mm) would not be far out of range. Also as shown in Figure 2, ETBC correlated quite closely with BREB (r = .81) in terms of daily ET values during the period of measurement (Boivin, 1989).

In Tables 3 and 4, are also presented the daily inputs [precipitation (P) and irrigation (I)] and outputs [evapotranspiration (ET) and residual soil moisture (Δs)]. For lack of a better method, the technique of Burman et *al* (1980), based on the climatological characteristics of mean monthly rainfall and mean monthly consumptive use was used to deduce effective precipitation (Pe) and effective irrigation (Ie). Based on this method Pe was set at 0.75. Since the irrigation system was an overhead sprinkler type, Ie was also set at 0.75. These values are however subject to variation, depending on rainfall amount and intensity, prevailing weather conditions, soil condition and stage of growth of the crop.

Using the critical soil moisture (Δsc) method (Table 3) for the okra crop in Trinidad, applied irrigation (Ie) was compared with potential irrigation (I_{amtp}). Field capacity (FC) was set at 29% and permanent wilting point (PWP) at 13% (Shastry, 1985). Using a maximum allowable depletion (MAD) of 0.65, this allows the readily available water (RAW) to be 10.4% or 31.2 mm based on a 300 mm rooting depth. In terms of equation (16) then, the critical soil moisture for determining irrigation was set at 18.6%.

Lack of facilities and the malfunctioning of the neutron probe unfortunately prevented daily field measurements of soil moisture (Δsm). However based on a tensiometer reading on 17/01/89, the soil moisture was supposedly at field capacity. The initial soil moisture was therefore set at 28%. Table 3 shows that the critical soil moisture (Δsc) was first reached on 25/01/91 (18.6%). However, the farmer, using a combination of a cycle method and rainfall frequency, did not irrigate until 30/01/91, meaning that the plant was presumably stressed for 5 to 6 days. Even so, the effective irrigation dosage (5.71 mm) combined with an effective rainfall of 4.19 mm, did not bring the soil moisture back to and above the critical value of 18.6%. For the rest of the growing season Δsc remained below the critical value of 18.6%, despite frequent light precipitations and frequent irrigations. Irrigation ceased on 15/02/89, since the crop was by then ready for final harvesting. Also, calculated soil moisture values (Δsc) showed that the soil moisture dropped below the permanent wilting point of 13%. This is so because calculations neglected the capillary movement of soil moisture, which can add from 2 to 3 mm/day of moisture to the rooting zone, if the water table is close to the surface (Tripathi, 1992). However this component was ignored because of insufficient knowledge on water table depth and soil moisture movements at the site.

The potential soil moisture (Δscp) was calculated by simulating irrigation applications (I_{amtp}) whenever Δscp dropped below the critical value of 18.6%. Table 3 shows that irrigation applications of 12 mm/day would have had to be applied every 5 days or so towards the beginning of the measurement period and every other day towards the end of the growing season, to maintain the soil moisture above the critical level of 18.6%. The values of I_{amtp} were set at a maximum of 12 mm/day based on the ability of the irrigation system to deliver water and the irrigation efficiency.

Table 4 presents the alternative approach for irrigation scheduling, using the allowable depletion (AD-BAL) method. Using a MAD value of 0.65 and equation (19) the initial value of AD-BAL on 17/01/89 was set at 28 mm, which is close to the maximum value of 31.2 mm, since the soil moisture was not quite at field capacity, as seen in Table 3.. The AD-BAL column in Table 4 shows that irrigation would first have needed to be applied on 25/01/89 as was the case using the critical soil moisture approach.

A potential allowable depletion (AD-BALp) was calculated by applying the maximum available irrigation (I_{amtp}: 12 mm) on days that AD-BALp fell to zero or less. These values of AD-BALp and I_{amtp} are shown in Table 4. This method also shows that irrigation was first needed on 25/01/89. It also shows that by applying the attainable irrigation dosage (12 mm) when required, would have resulted in an irrigation application every 3 to 5 days.

4.0 SUMMARY AND CONCLUSIONS

An outline has been given of the broad details of SEWBS, a computer-assisted system for monitoring and analyzing the requisite weather, crop and soil data for determining the timing and dosage of irrigation applications. The field data is monitored, analyzed and stored using the SEWBS. Specialized software algorithms are then used to further analyze the data. EDA handles the calculations of the half-hourly and daily ET. AIS IRRRIG analyses the field collection of data and the status of moisture in the rooting depth of the soil. An on-screen display indicates when to irrigate using the critical soil moisture or allowable depletion approach. The decision to irrigate is also modulated by a 48-hour probability of rain forecast.

The amount of irrigation water to be applied is also indicated, using equations (20) or (21). However these amounts are sometimes modulated by the capacity of the irrigation system and by the irrigation strategy being used, that is whether full or deficit irrigation is being practised.

As an extension to this work, SEWBS will be coupled to a trickle a sprinkler type system, so as to turn on the irrigation system automatically when required and to turn it off after the necessary amount of water would have been applied. Other refinements to the system would include detecting and incorporating capillary rise of soil moisture where applicable, and a more reliable and efficient method for determining effective precipitation and irrigation. Efforts are being made to make SEWBS as user-friendly as possible so as to facilitate its use by farmers with a minimal level of education and computer capability.

This sophisticated method of irrigation scheduling (SEWBS) can be most appropriately applied at the cooperative farm or research farm level, since cost and sophistication may limit its use at the single farm level. Furthermore, this technology (SEWBS) can find wide application in the Caribbean, where irrigation agriculture is prevalent during the dry season.

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