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Computer-Aided Irrigation Scheduling A Case Study: Design of Irrigation Schedules for St. Mary Banana Estates, Jamaica

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The IRSIS (Irrigation Scheduling Information System) computer software package was used to evaluate irrigation of the 1999 banana crop at the St. Mary Banana Estates Limited, Jamaica Producers Group. In addition, the software was used to plan irrigation schedules for dry, normal and wet conditions for banana grown at the same estate. Crop and field parameters were either measured in the field or obtained from published texts; whereas, the climatological input was collected from the meteorological station located at the estate. The irrigation schedules using IRSIS were planned in such a way that for the convenience of operation, the irrigation depth was kept constant throughout the growing season and the irrigation interval varied as a function of changes in the climatological situation (principally rainfall) or the water consumption pattern of the banana crop. Simulation results showed that the time of starting or terminating irrigation within the year in the banana estate would vary according to whether the rainfall depths were dry, normal or wet. For instance, while irrigation for the dry year should ideally occur between April and October, it is only required between June and September for the wet year, with abundant rainfall.

1. Introduction

Scientific irrigation scheduling is the best management practice for improving farm irrigation management. One of the objectives of irrigation management is to plan irrigation schedules, that is, to determine the correct water depth and interval of future irrigations in a locality so as to achieve optimal crop productivity. Irrigation efficiency decreases when water deliveries are untimely or not in desired volume. Limited supply will lead to a reduction in crop yields; whereas, excess water results in percolation losses, leaching of nutrients and may cause temporary water-logging. Optimal irrigation practice requires accurate planning of the irrigation schedule. To anticipate unknown future climatological situation, it is recommended at the start of a new growing season to formulate irrigation patterns, for dry, normal and wet conditions. The irrigation schedules predicted for each of these situations should not only guarantee optimal yield but should also keep percolation losses to a minimum. The challenge in irrigation scheduling is to therefore achieve optimum crop yield with minimum water losses. The complexity of factors involved in irrigation scheduling at times necessitates the use of computer programmes.

This paper reports the result of a study undertaken to collect, collate and analyse weather, crop and field data from the Polo Common project site of the St. Mary Estates, a part of the Jamaica Producers Group. With the help of computer software, the data were used to evaluate irrigation carried out for the 1999 banana crop as well as used to plan optimal irrigation schedules for banana crop grown at different rainfall conditions that may occur at the project site.

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2. Materials and Methods

2.1 IRSIS Software Package

Raes *et al.* [1] developed Irrigation Scheduling Information Systems (IRSIS) computer software used to plan irrigation schedules at the field level. For a given climate, crop and field, it offers the possibilities of:

(1) computing the net irrigation requirements and the optimal water distribution resulting in the highest yield under conditions of limited water,

(2) planning or forecasting irrigation schedules for different operational conditions, and

(3) evaluating past irrigation schedules.

IRSIS shows the consequences of the irrigation schedules in terms of expected yield response and application efficiency. The yield response is calculated following the methodology of Dorrenbos and Kassam [2]:

$$(1 - Y_{act} / Y_{max}) = K_y (1 - ET_{act} / ET_{crop}) \qquad (1)$$

where K_y is the yield response factor, ET_{act} and ET_{crop}, the actual and potential crop evapotranspiration respectively and $(1 - Y_{act} / Y_{max})$ represents the relative yield reduction. The application efficiency (E_a) of irrigation and rainfall (%) is calculated as:

$$E_a = 100\,(Q - losses) / Q \qquad (2)$$

where Q is the applied amount of water and losses is the amount of water lost by deep percolation out of the maximal root zone. In the case of rainfall, the losses are increased with runoff while zero runoff is assumed in the case of applied irrigation. The software also assumes that the applied water uniformity is 100%.

The main strength of the IRSIS software is its ability to ease the calculation of alternative irrigation schedules, their consequences and the effect on the different entities of the soil water balance.

To run IRSIS, the following data has to be specified:

(a) The Climatological data, which consist of the reference crop evapotranspiration (ET_o) and the rainfall data. For evaluation of past irrigation schedules, the actual ET_o and rainfall values that occurred during the evaluation periods are used. For the preliminary planning purposes, Doorenbos and Pruitt [3] suggested the use of monthly climatological normals of ET_o and monthly levels of rainfall that will be exceeded in four out of five years (D_{80}). In addition, D_{50} and D_{20} which represent rainfall values that will be exceeded in one every two years (50% dependable rainfall) and one out of five years (20% dependable rainfall) respectively are used to represent normal and wet rainfall years. The water balance model of IRSIS is operated on a daily time step. The monthly climatological data are distributed into daily values by the software before they can be used in the water balance.

(b) The crop data consist of information about the length of crop development stages of the crop, the variation with time of the rooting depth, the p-factor, the crop coefficient (K_c) and the crop yield response factor to water (K_y). The p-factor is the fraction of the soil water that can be extracted at the potential rate by the roots. It is given as the ratio between the readily available and the total available soil water. Readily available water is also referred to as the maximum allowable depletion in irrigation literature.

(c) The field data comprise the soil water content at field capacity and at the permanent wilting point together with the basic infiltration rate.

2.2 Case Study: Polo Common Project Site (St. Mary Banana Estates)

The St. Mary Banana Estates (SMBE) Limited Farms occupy most of the coastal flood plains of the Wagwater river, the Pencar river and the Dry river, in North Central St. Mary Parish of Jamaica. The estate is owned by the Jamaica Producers Group and comprises 662 ha of land under banana production. The 662 ha are divided into four farms that are further sub-divided into 14 sections. The entire farm is irrigated using the surface drip system. At the centre of the estate is the town of Annotto Bay. In order to carry out the study, a test area had to be identified. The selected area - Polo Common (32 ha in area), is found on the Agualta Vale farm. It is representative enough of the entire estate with regards to daily operations, soil type and size. Polo Common is the location of the main office and the main meteorological station of the estate. The water supplied to the section at Polo Common comes from the Wagwater River Alluvial Aquifer at Agualta Vale.

TABLE 1: *Values of Evapotranspiration (ET_o) and Rainfall for Different Months in Polo Common*

Months	ET_o (mm/day)	Mean Rainfall (1989-1998) (mm)	Rainfall 1999 (mm)	Effective Rainfall (mm) Wet Year (D_{20})	Normal Year (D_{50})	Dry Year (D_{80})
January	2.8	192.9	280.0	263.4	165.5	104.0
February	3.3	127.1	73.0	174.4	108.2	67.1
March	3.6	130.7	225.0	176.6	114.5	74.2
April	4.0	134.7	17.0	191.6	96.4	48.5
May	4.1	193.6	165.0	274.6	124.7	56.6
June	4.3	86.7	157.0	119.9	71.8	43.1
July	4.5	80.2	56.2	113.3	66.0	39.2
August	4.2	92.6	78.0	128.6	76.3	45.2
September	3.8	81.3	100.4	107.4	73.1	49.8
October	3.4	131.5	147.5	182.3	109.5	65.7
November	3.0	320.8	185.6	441.8	271.1	166.4
December	2.7	204.4	161.7	288.5	159.9	88.6
Year (Mean/Total)	3.6	1,776.5	1,646.4	2,462.4	1,437.0	848.4

Table 1 shows the mean rainfall depths and the ET_o values. ET_o values were computed with CROPWAT computer software [4] using the Penman-Monteith method. This method is the one recommended by the International Commission for Irrigation and Drainage (ICID) and the Food and Agriculture Organisation (FAO) of the United Nations. Its use has been found promising within the Caribbean region by Simon *et al.* [5] The weather data used for ET_o computation as well as the rainfall data were collected from the Polo Common (project site) meteorological station. The monthly rainfall depths for 10 years (1989 - 1998) were processed statistically using the DISTRIB computer software [6] to derive the 80%, 50% and 20% monthly dependable rainfall values (**Table 1**). **Figure 1** produced directly from the IRSIS software illustrates the crop data for banana. For instance, the root depth varied from 0.3 m to 0.7 m. The values of p, K_c, K_y and root depth were selected from the data presented by Doorenbos and Pruitt [3] and Doorenbos and Kassam [2]. **Table 2** lists the field data for five blocks as well as the mean data for the Polo Common project site.

TABLE 2: *Field Parameters for Polo Common Project Site*

Block	Soil Texture	Field Capacity (% weight)	Permanent Wilting Point (% weight)	Bulk Density (Mg/m^3)	Total Available Water (mm/m)	Basic Infiltration Rate (mm/day)
1	Sandy loam	15.8	9.5	1.27	80	600
2	Sandy loam	17.6	11.8	1.33	77	600
3	Sandy clay loam	25.0	20.5	1.45	65	235
4	Clay loam	35.2	25.5	1.37	133	192
5	Silty clay loam	33.7	17.8	1.49	237	15
Mean	Loam	25.5	17.0	1.38	118	328

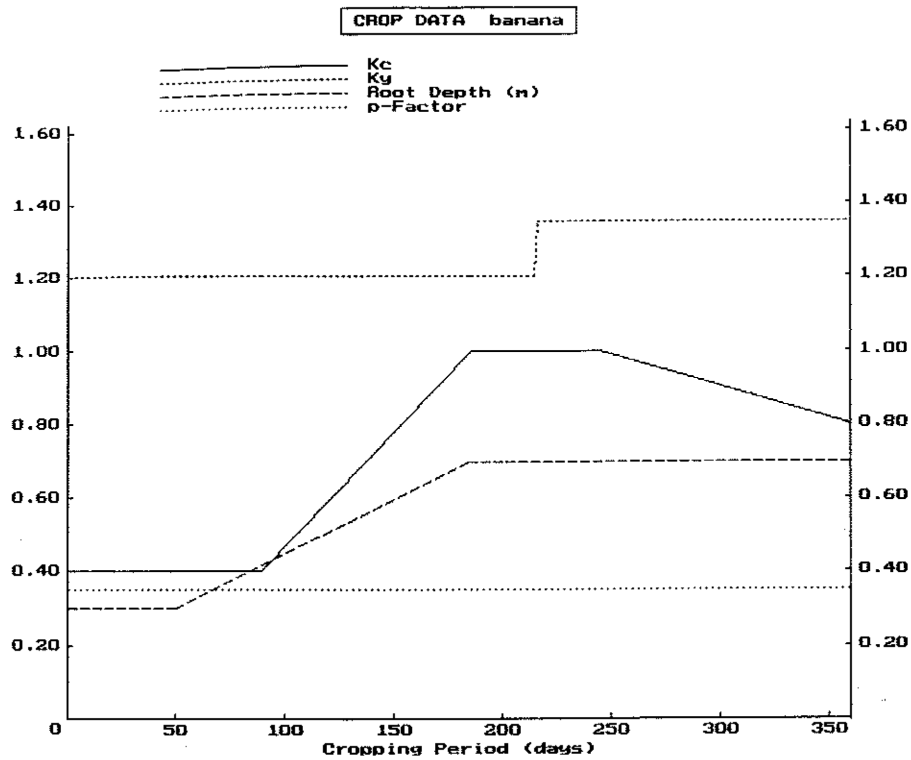

FIGURE 1: *Simulation Data for the Banana Crop*

All the values apart from the infiltration rates were measured. The infiltration values for the four soil textures at the site were estimated using values presented in the IRSIS software manual [1]. Separate sensitivity analysis showed that values of infiltration have little or no effect on the simulation of irrigation schedules.

With the ET_0 crop and soil data specified for the test site, the irrigation schedule (water amounts and interval) for the 1999 banana crop at the site was evaluated using mainly the yield response factor and the irrigation application efficiency. The irrigation schedules were collected directly from the SMBE Limited. In this case, 1999 rainfall values (**Table 1**) for the different months were used in the simulation. In addition, irrigation schedules were produced for dry (80%), normal (50%) and wet conditions (20% level of dependable rainfall). In order to obtain an easy and manageable schedule for irrigation operation, the time criterion in the IRSIS software was set to "fixed interval" while the depth criterion was set at "fixed depth" for discrete periods of the irrigation season. The following approach was used. First, a constant irrigation depth was selected based on the soil type and the rooting depth of the banana crop as well as the drip irrigation system used at the project site. In the next step, it was investigated to see if the interval between irrigations could be kept constant for the whole irrigation season, without inducing deep percolation or crop stress. If not so, constant water depth with different irrigation intervals was selected for various parts of the season.

For the scheduling of irrigation of banana crop, after entering the constant depth and interval of irrigation, the irrigation simulation was carried out. Planting date was assumed as January 1. The diagram obtained for the root zone depletion of water for the crop was examined. Irrigation is ideal when the water depletion levels fall between the readily available water and the field capacity. The table of expected yield response is checked to ensure that at the different growth stages of the crop, the yield response is 100% or very close to it. The table on irrigation efficiency is also checked to make sure that irrigation efficiencies are very close to 100%. Depending on the results of the simulations, the schedule can be adapted or tested again until ideal root zone depletion pattern mentioned is achieved.

3. Results and Discussion

Figure 2 shows the irrigation water depths applied at the various dates for the banana plant in Polo Common project site in 1999. **Figure 3** gives a visual representation of the evaluation of this irrigation schedule. Small variations in water depletion levels, aside from the main trends, observed in **Figure 3** represent the small daily rainfall events that occurred at wet seasons when little or no irrigation water was applied. As can be seen from **Figure 2**, after the

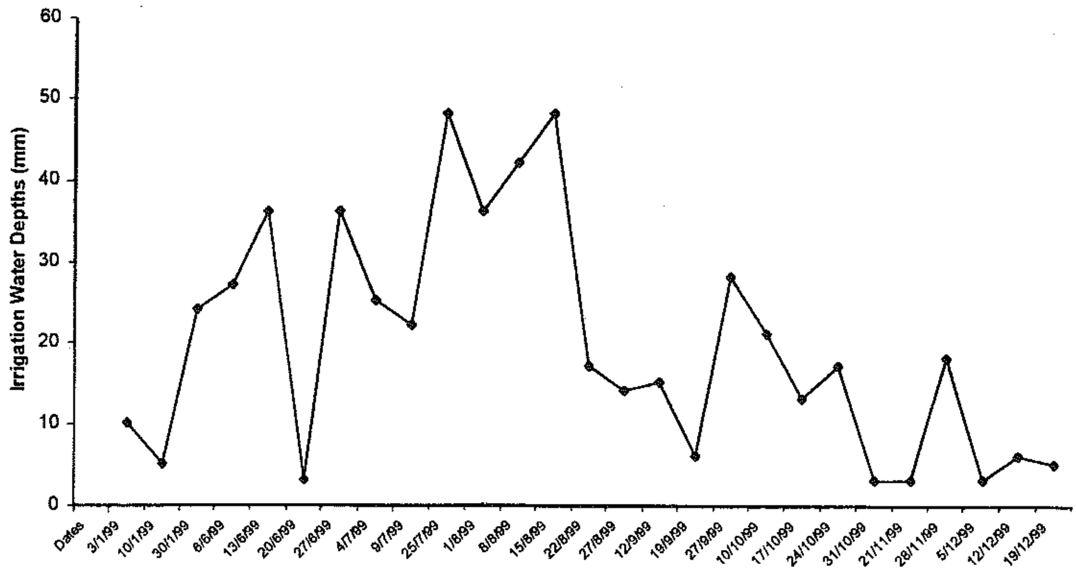

FIGURE 2: *The Irrigation Water Depths applied at different Dates in Polo Common Project Site in 1999*

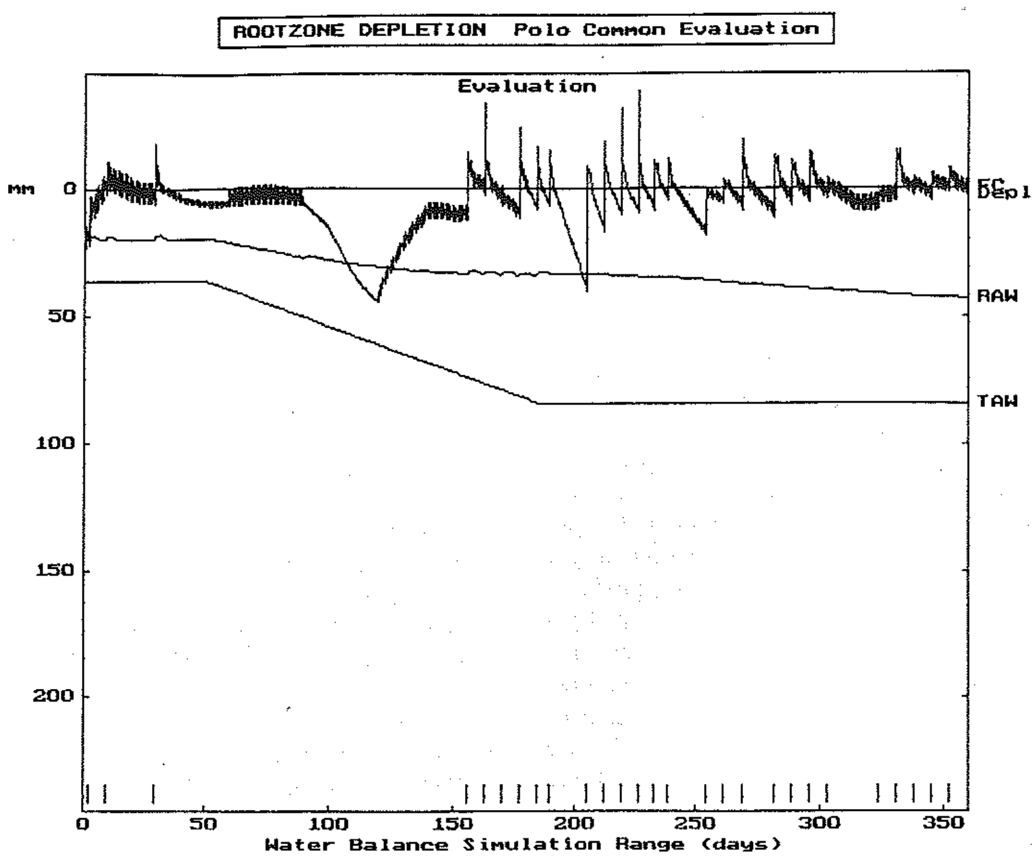

FIGURE 3: *Root Zone Water Depletion for Banana (1999 Irrigation Evaluation)*

TABLE 3: *Values of Parameters for Evaluating Irrigation Schedule Simulations*

Irrigation Schedule Simulation	Rainfall Depth (mm)	Rainfall Efficiency (%)	Net Irrigation Depth (mm)	Irrigation Application Efficiency (%)	Yield Response (%)
Year 1999 evaluation	1,618	47.8	531	61.2	98.6*
Dry year planning	836	87.8	416	99.7	98.0
Normal year planning	1,414	81.0	208	100.0	98.3
Wet year planning	2,418	66.2	80	98.5	98.3

* Yield response values shown are for January. The value for the other months is 100% except for the Year 1999 evaluation where the yield response values were 85.3%, 97.1% and 99.5% in April, May and July respectively.

application of 24 mm of water on January 30, 1999, the next application of water was 27 mm on June 6, 1999, an irrigation interval of 127 days. This long irrigation interval was reasonable up to the end of March because of adequate rainfall during the period (**Table 1**). The evaluation diagram (**Figure 3**) shows that there was a slight water deficiency at the end of April (simulation day 120) because of low rainfall (17 mm) and lack of irrigation during this period. This is seen in **Figure 3**, where the water in the root zone dipped below the readily available water (RAW) line. Rainfall depths increased again in May and June (simulation days 120 to 151) and the evaluation diagram (**Figure 3**) shows that except for the little water deficiency that occurred in July (simulation day 205), irrigation amounts applied for the rest of the year were a little excessive leading to wastage of water. The excess water as a result of over-irrigation could have been lost by either runoff or deep percolation leading to decreased irrigation application efficiency of 61.2% and rainfall efficiency of 47.8% (**Table 3**). However, the yield response factor was 98.6% in January, 85.3% in April, 97.1% in May, 99.5% in July and 100% throughout the rest of the months. The high yield response values showed that though excess water was applied for most months of the year, the IRSIS software predicts that banana yields will not decrease significantly since the crops had enough water and can tolerate medium level of flooding. The small water deficiencies that occurred in April and July led to the slightly decreased values of yield response during these months. The cost of the low irrigation efficiency will be mainly in terms of extra costs incurred in applying excess water. The 1999 rainfall total was closest to the normal year rainfall making the year a normal one.

The results of the irrigation schedules designed for different rainfall conditions (dry, normal and wet) are shown in **Table 4**. For all schedules, the irrigation depth was kept constant at 16 mm throughout the growing season, and the irrigation interval was kept variable as a function of changes in the climatological situation or the water consumption pattern of the banana crop. The 16 mm depth of water chosen for simulation was a function of the root zone depth of the banana crop, the water storage capacity of the loam soil as well as the drip irrigation system adopted in the test areas. IRSIS simulation also showed that the time of starting or terminating irrigation within the year would vary according to whether the rainfall depths are dry, normal or wet. For instance, it is shown in **Table 4**, that, ideally, irrigation for the normal rainfall situation should start on May 30 and terminate on October 2. The software predicts that this will result in ideal root zone depletion levels (**Figure 4**) as well as irrigation efficiency of 100% and a rainfall efficiency of 81% (**Table 3**). The root zone depletion levels for the dry and wet weather conditions will also be ideal with expected

TABLE 4: *Designed Irrigation Intervals for the Polo Common Project Site for Different Rainfall Conditions*

Julian days	1	91	150	175	186	245	275	290	365
Actual dates	1-Jan	1-Apr	30-May	24-Jun	5-Jul	2-Sep	2-Oct	17-Oct	31-Dec
Dry condition		15*		7	5		8		
Normal condition				11	7	14			
Wet condition					12				

* Irrigation intervals in days. Applied irrigation water depth is 16 mm throughout

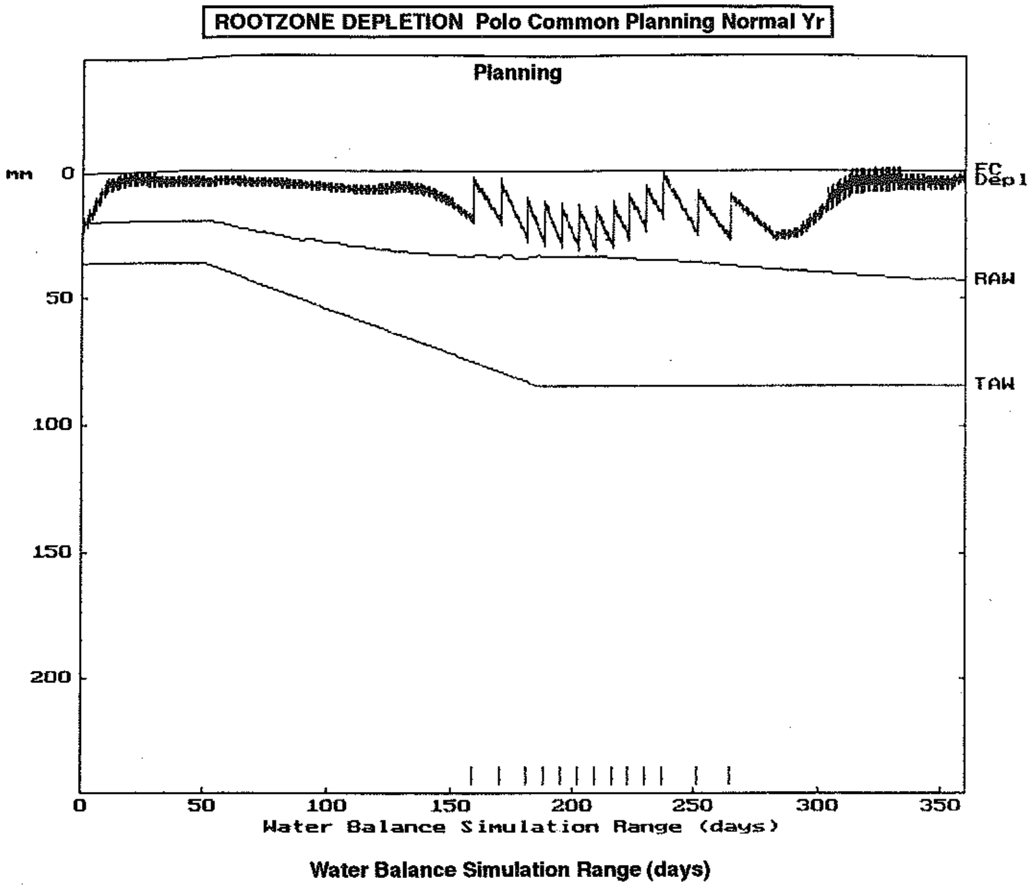

FIGURE 4: *Root Zone Water Depletion for the Normal Year Irrigation Planning*

irrigation efficiencies of 99.7% and 98.5% respectively (**Table 3**). However, while the rainfall efficiency for the dry year is expected to be high at 87.8%, it will be only 66.2% for the wet year showing that in a wet year, substantial amount of rainfall water is expected to be lost as deep percolation and runoff rather than being stored in the root zone of the banana crop. For the wet condition, irrigation may only be needed between June and September (**Table 4**), which constitute the driest months in Polo Common (**Table 1**).

There may be times during the irrigation season when the actual weather conditions, (mainly rainfall) deviate significantly from the climatological data used in planning the irrigation schedules. In that situation, with the aid of the actual field water status and a weather forecast for the next few days, an accurate estimate of the timing and quantity of the next irrigation could be obtained using the forecasting mode of the IRSIS software. However, rainfall patterns in different years are expected to be similar to those for the dry, normal or wet years, making the optimally designed irrigation schedules useable for different years.

Conclusion

The IRSIS software package is an easy tool to generate the optimal irrigation pattern of crops as well as evaluate past irrigations carried out in a location. This software has been used successfully to schedule irrigation projects in France and Brazil by Raes *et al.* [7] and De Goes *et al.* [8], respectively. The main strength of the software is that each of the designed schedules is evaluated in terms of crop response and deep percolation losses. The criterion used for the planning of the irrigation schedules is a constant irrigation depth, since farmers are more apt in managing a constant depth rather than a variable depth [9]. The irrigation interval then varied with the variations in the weather and water consumption pattern of the banana crop. The next line of research is to test the efficiency of these optimally derived irrigation schedules in the Polo Common banana project.

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