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Scheduling Irrigation Using an Automatic Weather Station: II. Field Experiment

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Abstract. An irrigation scheduling experiment was conducted on wheat crop using climatic data collected continuously from an automatic weather station previously installed and tested at the site. Irrigation scheduling was based on the estimation of evapotranspiration using modified Penman and Jensen Haise methods. Irrigation was started when the readily available water was depleted. The result of this experiment indicated that Penman method was more realistic than Jensen Haise method in estimating the actual crop water need. The use of automatic water station for scheduling have demonstrated that, not only water could be saved but crop yield could also be increased.

Introduction

Scheduling irrigation techniques using an automatic weather station could be easily implemented in arid regions. If this technique is applied properly it can result in efficient water management as the depleted soil water is replenished in time and water stress in the plants is avoided. This could result in minimizing irrigation costs, and facilitates farm operations. Appropriate measures must be taken to conserve water in arid regions such as the Kingdom of Saudi Arabia, because of water scarcity for irrigation purposes. In such areas, irrigation scheduling must be given a top priority. In general, a scientific irrigation scheduling provides the basis for imporved irrigation water management and enables the most efficient use of available water resources [1].

The progress in research for predicting crop water requirements using weather data, has promoted the development of methods which can be adopted in an efficient irrigation scheduling. With these methods, daily crop water use can be estimated from the available climatic, crop and soil data.

The crop water requirement or evapotranspiration (ET) is related to reference evapotranspiration (ETr) by a dimensionless crop coefficient (Kc) for the particular crop at the existing growth stage and surface soil water conditions [2]. A high level of precision in measuring climatic variables is required for accurate estimation of ET in areas where water is scarce. This could be achieved by taking advantage of recent advances in computer technology and automatic weather stations. Such station is provided with sensitive sensors and data logger which can sense, store and transmit the frequent measurements to the computer [3]. The stored data are processed, analyzed and used for estimating the ETr [4].

The modified Penman (FAO version) and Jensen Haise methods [5] were used to determine the ETr. The crop coefficient technique as given by Wright [2] was used to adjust the crop coefficient during the early stages of growth. The aim of this study is to accomplish the following:

1- Report on development of an irrigation scheduling model using an automatic weather station in arid areas.
2- Compare ET crop predictions using FAO Penman versus ET crop predictions with Jensen Haise-method.
3- Study the response of crop to the scheduling system developed.

Materials and Methods

The experiment was carried out on a plot 20m × 20m in size and situated at the Experimental Farm of the College of Agriculture, King Saud University, Riyadh. Wheat crop was selected to be grown as it is a crop of major importance in K.S.A. In general, the original land slope before land preparation, was 1.1% from west to east and 0.8% from north to south. Before planting, land preparations were carried out. It involves; subsoiling to a depth of 600 mm to break the hard pan, followed by plowing the top 300 mm layer then mixing, manuring and leveling the soil for seed bed preparation.

Soil samples were taken at two depths and two different locations. These samples were analysed mechanically and chemically as shown in Table 1. Permeability tests were conducted at three sites by the Auger Hole method and on soil samples in the Lab. (Table 2). Infiltration tests were also carried out using constant and variable head infiltrometers. Tests were repeated three times and the averaged rates are given in Table 3.

Table 1. Mechanical and chemical soil analysis

Soil	Mechanical analysis		Element	Chemical analysis	
	Upper layer	Lower layer		Upper layer	Lower layer
Sand	71%	18%	Ph	7.59	7.84
Silt	9%	34%	EC	1.05	0.37
Clay	20%	48%	SP	24.00	50.00
			CO_3	1.62	1.62
Soil Type	Sandy loam	Clay	Cl	1.43	0.46
			Ca^{++}	29.41	7.90
			Mg^{++}	0.88	0.20
Specific weight	1.61 gm/cm^3	1.78 gm/cm^3			

Table 2. Soil physical properties at different depths and locations

Sample NO	Depth mm	Field capacity 0.1 Atmosphere WT. Basis %	Willting point 15 ATM. WT. Basis %	Saturated hydraulic cond. CM/HR
1	50	9.7	4.1	2.5
2	50	13.2	5.6	3.1
3	50	11.0	4.6	4.2
4	50	10.6	4.6	5.2
Ave.		11.125	4.725	3.75
5*	300	8.6	3.4	0.7
6	300	13.7	6.0	2.8
7	300	12.9	6.9	2.4
8	300	11.2	5.5	1.6
Ave.		11.6	5.45	1.25

* was neglected in calculating average

Table 3. The average values of cumulative depth, instantaneous infiltration rate and average infiltration rate

No. Variable	Constant head	Variable head
1- I(cum) = Cumulative depth = CT^n (in mm)	$2.6\,T^{0.87}$ (T in minutes)	$4.5\,T^{0.62}$ (T in minutes)
2- I(ins) = Instantaneous infiltration rate = $60\,C.n.\,T^{n-n}$ (in mm/hr)	$135.7\,T^{-0.23}$	$167.4\,T^{-0.38}$
3- I(av.) = Average infiltration rate = $60\,C.\,T^{n-1}$ (in mm/hr)	$156\,T^{-0.23}$	$270\,T^{-0.38}$

A permanent solid set sprinkler system was designed and installed at the site (Fig. 1). The system consisted of 9 impact sprinklers, spaced 10m apart and fitted on three laterals covering the entire plot. The laterals were connected to the main line and linked to a 5HP pump through solenoid valves (Fig. 2). The choice of the sprinklers was mainly based on the diameter of the required coverage, pressure, capacity of the sprinklers and the soil infiltration rate of the site. The system was field tested and evaluated by determining the uniformity coefficient and distribution uniformity. The values of these coefficients were found to be 84% and 81%, respectively, and hence were satisfactory for this study. The sprinkler system was again evaluated after harvesting the crop and it was found that no significant deviation occured during the entire growth season.

A subsurface drainage system was provided for the field to prevent any occurrance of water logging in the root zone due to the presence of the impervious layer at an average depth of 600mm. Perforated PVC pipes, 75 mm outside diameter were used and surrounded by properly packed gravel envelope. A slope of 100 mm/100 m, was provided along the natural sloping direction and a proper outlet and inspection gallery were also provided (Fig. 1).

Soil moisture status in the field, during the experiment was monitored by different means. Pairs of tensiometers and gypsum blocks were installed at two different depths at random locations in the field. Daily measurements were obtained and compared periodically with those from gravimetric method. The soil moisture contents on weight basis were measured by gravimetric method before and a day after each irrigation.

The plot was planted with wheat (variety: yecora rojo) manually on Nov. 30, 1989. The seeding rate was 160 kg/ha. and the seeds were drilled in rows 200 mm apart. Fertilizers were applied before planting at the rate of 100, 300 and 30 kg per ha of Nitrogen, P_2O_5 and K_2O, respectively. A slight shower of water was applied immediately after planting and light irrigations were applied daily till emergence.

Software

Crop evapotranspiration (ETc)

The climatic data measured by the automatic weather station was transmitted to the PC housed in the control room and utilized for estimating the ETc using the following relationship:

$$ETc = Kc.\ ETr \tag{1}$$

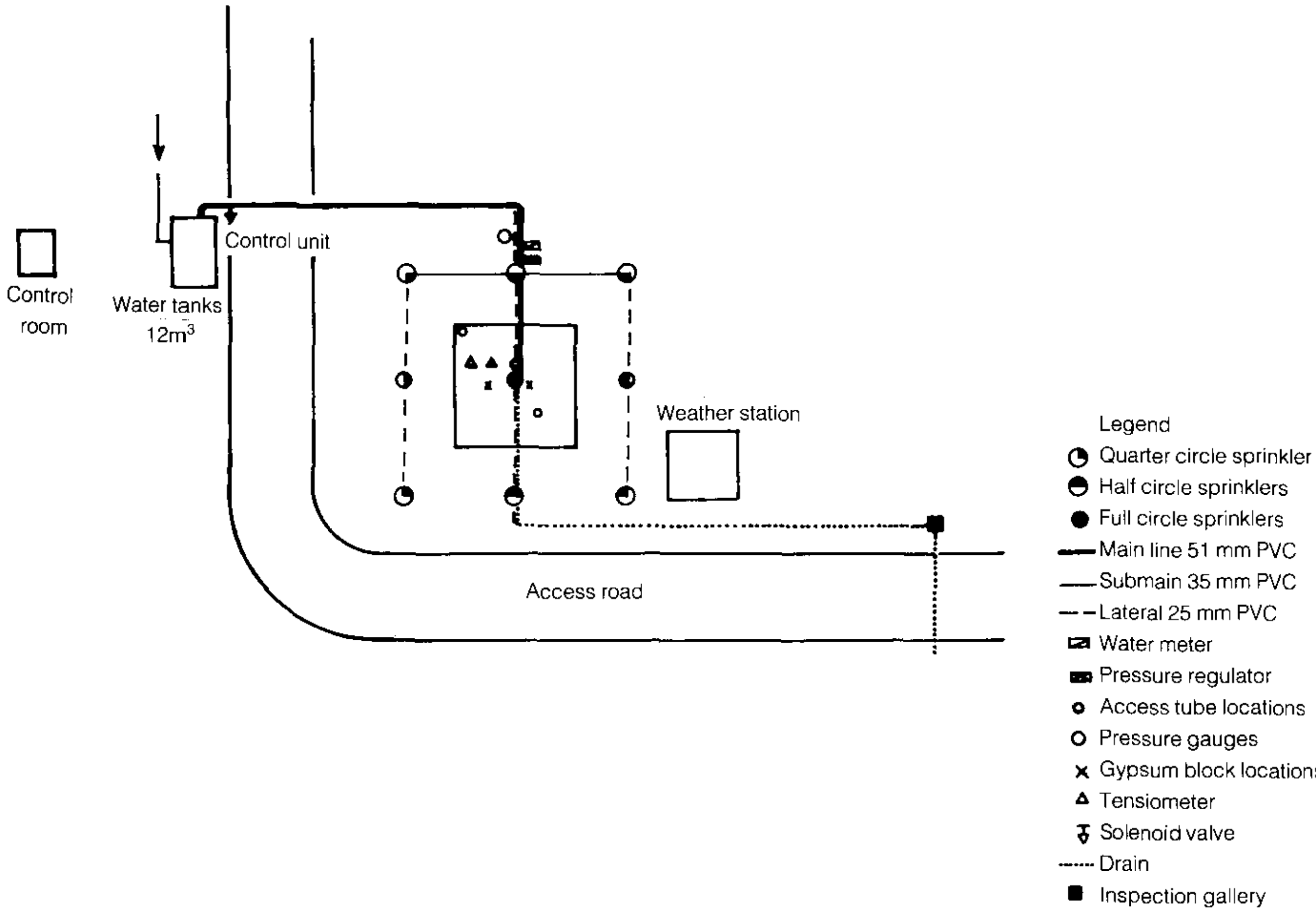

Fig. 1. Irrigation system layout

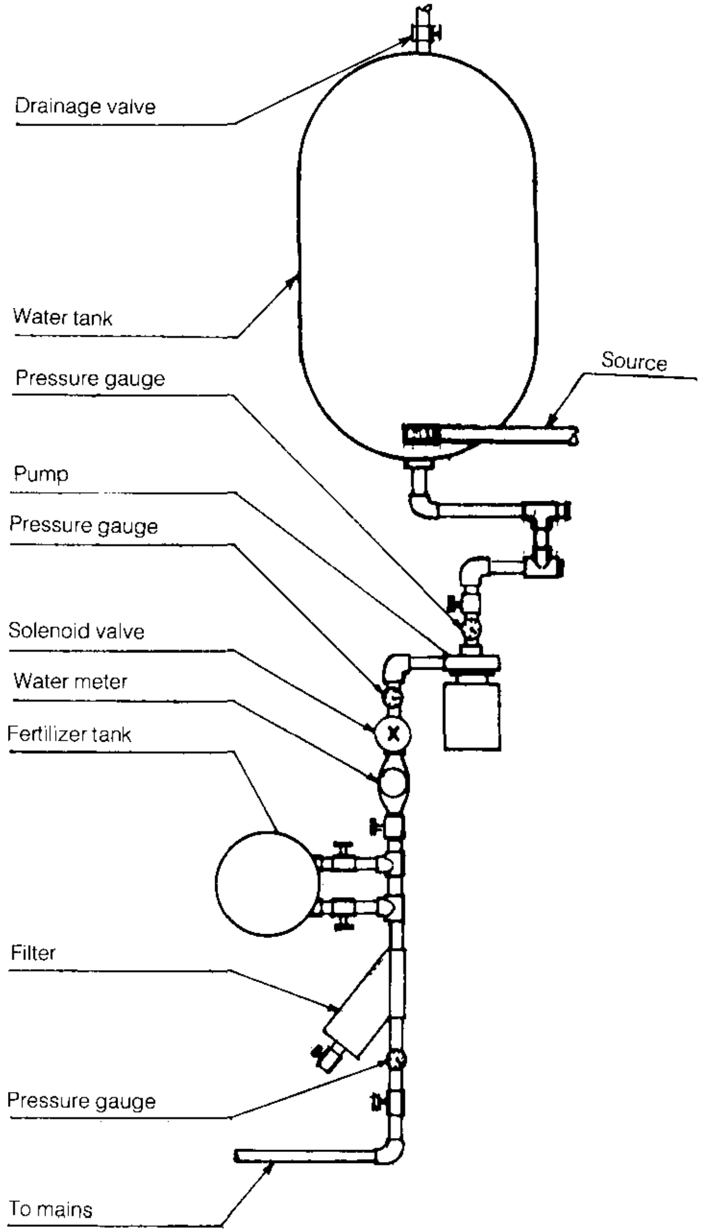

Fig. 2. Field pumping station

where:

ETc = crop evapotranspiration

Kc = crop coefficient based on the crop for which ETr is obtained

ETr = reference evapotranspiration related to either grass (ETo) or alfalfa (ETr).

The reference evapotranspiration was estimated, using the modified Penman method, FAO version as given by Doorenbos and Pruitt [6] and Jensen Haise [7]. Four different stages of growth were considered in evaluation of Kc, viz: initial (germination and early growth), crop development, mid season and late season. Based on local experience, these stages were considered as 15, 40, 60 and 20 days, respectively. However, they are dependent on climatic conditions and were adjusted as needed during the experiment.

The value of crop coefficient during the initial growth stage largely consists of evaporation and hence depends on climatic conditions and the frequency of irrigation (or rain). The basal ET crop coefficient technique [8,9] was adopted and adjusted for soil wetness and soil drying properties. The equation used was:

$$Kc = Kcb + (1 - Kcb)\left(1 - \sqrt{\frac{t}{td}}\right) f(w) \tag{2}$$

where:

Kc = adjusted crop coefficient

Kcb = basal crop coefficient

t = No. of days since irrigation

td = usual number of days for the soil surface to dry

= 1.1428 + 0.02381 TAW = 3.76 ; taken as 3

TAW = Total available water = 110 mm/m.

f(w) = relative portion of soil surface originally wet = 1

Readily available water (RAW)

RAW = TAW × Management allowed deficit (MAD)

= WHC × RD × MAD

where:

WHC = water holding capacity (110 mm/m),

RD = Root depth.

The initial root depth was taken as 200 mm during the initial stage and was increased linearly with time (days) until full cover. After full cover, the maximum root depth was assumed as constant and equal to 550 mm.

MAD = 0.4, 0.4, 0.3 and 0.3 during the 4 stages respectively (local weather and soil conditions were considered).

Irrigation scheduling

Irrigation was started when the readily available water was depleted. The depletion on any day was calculated as:

$$D(i) = D(i-1) + ETc\,(i) - Irr(i) - Prec.(i) \ldots\ldots \qquad (3)$$

where:
D(i) = depletion or soil moisture deficit (SMD) at the end of any day.
D(i–1)= depletion or SMD on the previous day
Irr(i) = irrigation applied, if any, on the day
Prec(i)= precipitation, if any, on the day

The cumulative deficit D(cum) was calculated by integrating the daily deficits as:

$$D(cum) = \sum_{i=1}^{i=n} D\ (i) \qquad \ldots\ldots\ldots \qquad (4)$$

Decision making

With the help of the software, the PC retrieved from its memory all the data received during the previous 24 hr, calculated the reference ETr, combined it with the appropriate crop coefficient for the Julian day and soil characteristics to determine the depletion. The estimated depletion was then compared with RAW to determine whether an irrigation was required or not. If yes, the depth of irrigation to bring the root zone back to field capacity was calculated as the time the sprinklers must be operated and the water applied. This was accomplished by starting or stopping the 5HP pump and simultaneously releasing or shutting off the water to sprinklers through solenoid valves. A printout of daily predicted irrigation scheduling was provided by the PC.

Results and Discussion

The main sequential steps outlining the irrigation scheduling model for estimating water requirements from the local climatic parameters are presented in a flow chart as shown in Fig. 3. Two methods of prediciting ETr were used in this model viz: Modified Penman and Jensen-Haise equations. The results of these methods were compared with each other during the entire wheat growing season 1989-1990. Soil moisture status was measured periodically throughout the season using different means and used for evaluation of the model.

Flow chart

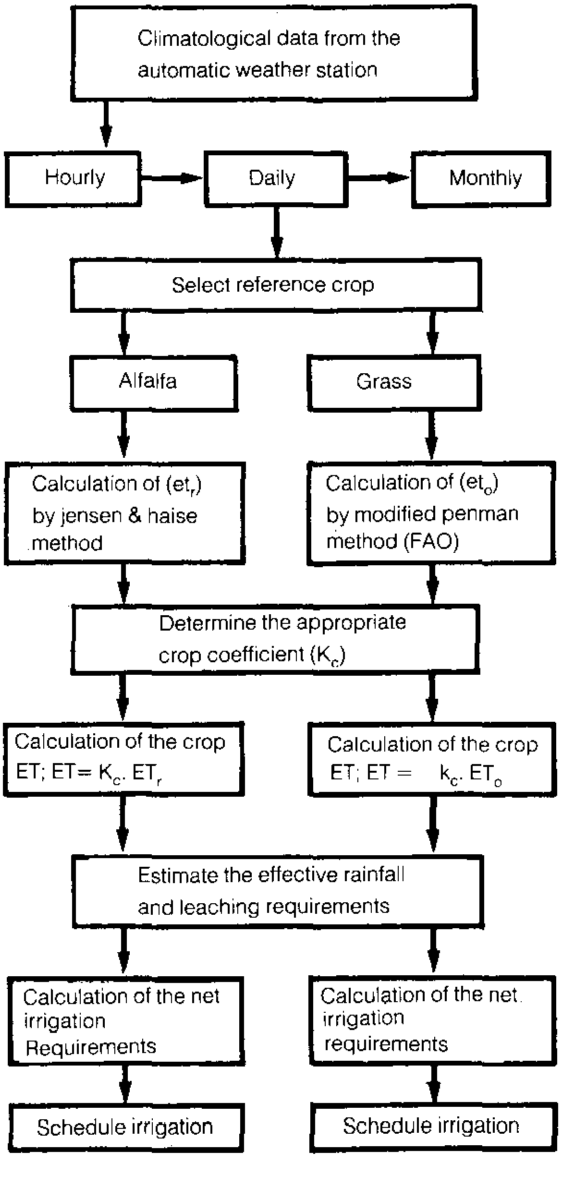

Fig. 3. Flow chart for scheduling irrigation

Results of the soil mechanical analysis showed that the soil profile consisted of two distinct layers as given in Table 1. The upper layer (0-300 mm) was sandy loam soil and the lower one (300 - 600 mm) was clay soil. While the permeability tests in the laboratory showed the average value as 37.5 mm/hr for the top layer and as 22.7 mm/hr for the lower one. In the field, the average permeability was found 102 mm/hr for the upper layer and 60 mm/hr for the lower layer. The results of permeability for the lower layer in both tests are higher than that expected for the clayey soil. This is mainly due to the presence of scattered pockets of sand. the presence of sand layers can give sometimes a deceiving results.

Crop coefficient

Wheat evapotranspiration (ETc), was predicted using the estimated ETr and the crop coefficient based on alfalfa and grass from the published tables presented by Wright [2]. The given values were adjusted to accommodate the various growth stages according to the exisiting local climatic conditions.

The mean crop coefficient Kcm suggested by the Ministry of Agriculture and Water [6] and Al-Shamary, as given by Hunting report [10] are shown in Fig. 4. The vlaues which are presented by Al-Shamary for Hail region, are believed to result in excessive application of water. The coefficients from both sources do not show the daily variations in the crop coefficients in the early two stages of growth. Wright [2], has presented a basal crop coefficient curve for dry surface condition as shown in Fig. 4.

The use of basal ET crop coefficients along with procedures accounting for extra wet evaporation, provide a mean of good estimates of crop ETc where adequate data are available [11]. The Kcb values were adjusted for surface wetness by equation 2 before using them with ETr for calculating ETc. The Kc was not allowed to reach the Kcb values and the minimum values were not allowed to reach below 0.5 as shown in Fig. 4. This was done to avoid the drying of soil surface in early stages where emergence could be affected due to formation of hard crust, which is a common problem in this area. The high values of Kc, soon after irrigation will meet the evaporative demand and the mean vlaue of crop coefficient (Kcm) will provide for the usual crop growth.

Irrigation scheduling

The depletion as given by crop ET is determined, and integrated daily to obtain cumulative deficit. The value is compared with the RAW each day to reach the decision of making irrigation and the amount of water to be applied. Irrigation schedul-

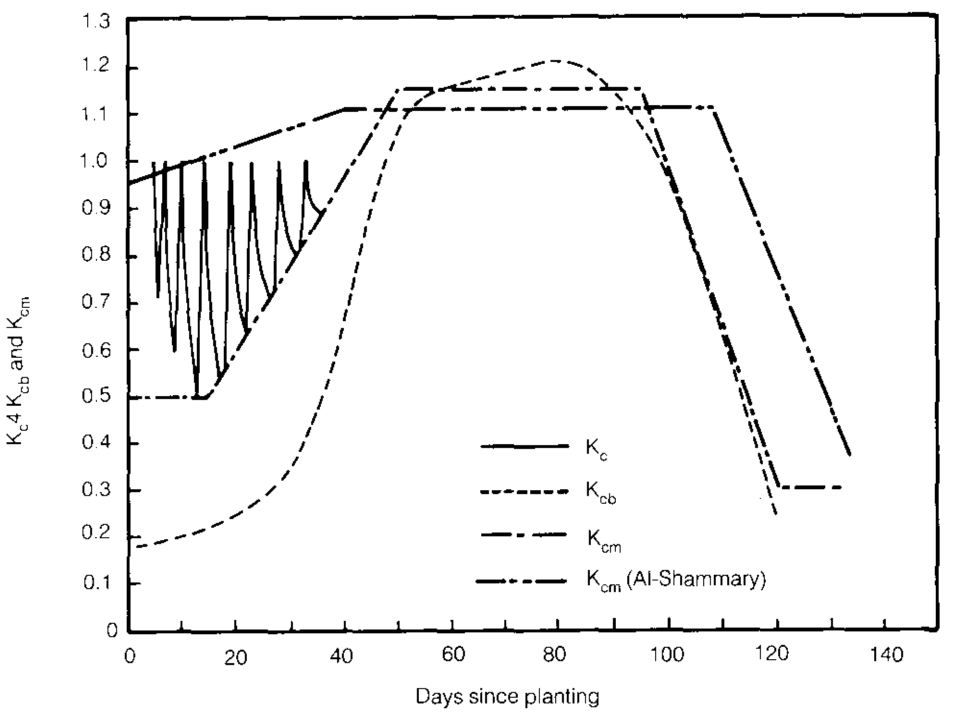

Fig. 4. Crop coefficients for wheat crop

ing for the entire growth period is given in Fig. 5. This figure shows that some irrigation events are initiated before the total deficit reaches the limit of RAW. This is done to avoid any water stress to occur. The feature of not allowing the total depletion to cross RAW on any day is incorporated in the program, and is achieved by making every day, at 12 p.m. a forecast of the deficit for the day on the basis of yesterday's data. Then, the forcasted deficit is added to the previous cumulative deficit to decide whether an irrigation is required on the day or not. As an example, from Fig. 5, on the day 70 (from planting day), the deficit was 11.2 mm and if the forecasted deficit (7.0 mm) for day 71, based on day 70 is added, the resulting deficit would be 18.2 mm which is in excess of RAW (18.15 mm) and hence irrigation must be carried out on day 71.

The irrigation scheduling scheme (Fig. 5) indicates that frequent irrigation were needed throughout the growth period. It is not unexpected because of the available shallow root zone and comparatively hot and dry climatic conditions. It is also noticed that the frequency of irrigation in the third stage is more than the other stages. This is attributed to the effect of several interrelated factors such as: the

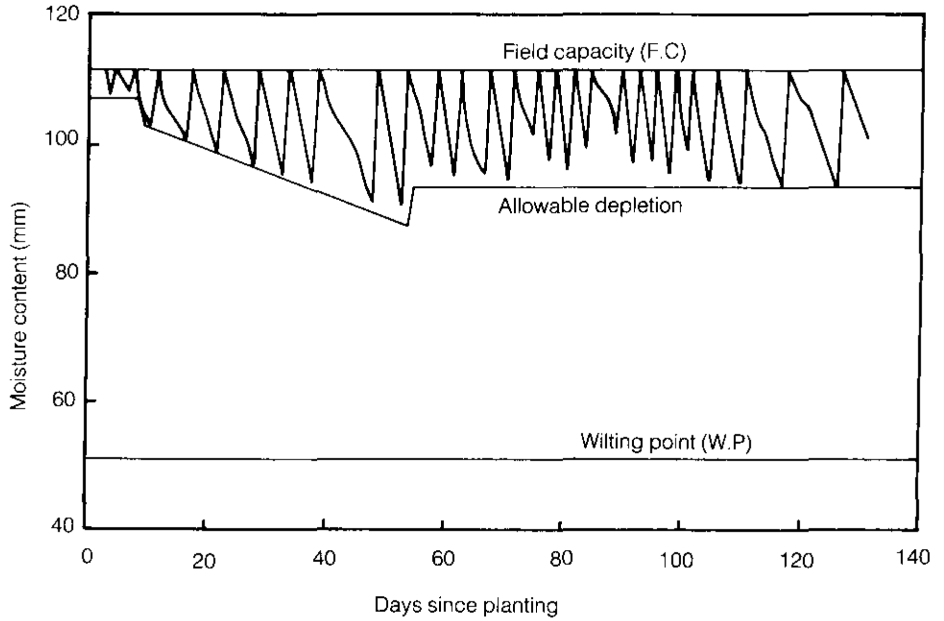

Fig. 5. Irigation scheduling for wheat crop

increase in temperature and decrease in relative humidity as the time advances as well as the increase in water requirements as needed by the physiology of the plants.

The ETc for the wheat crop as estimated by Penman was compared to that by Jensen-Haise method. The Jensen-Haise method underestimated the ET as compared to Penman method throughout the growth period (Fig. 6). This can be attributed to the absence of the effect of wind in Jensen-Haise equation, which is mainly based on radiation and temperature. Advective energy contributed by wind must be considered in predicting ET crop in desert areas and hence it is preferable to use the combination method as given by Penman in irrigation scheduling to avoid the possibility of any crop stress.

The average grain yield was 6.8 ton/ha and the total amount of water applied was 7812 cubic m/ha which also includes 12% leaching requirements and preirrigation. The yield have shown an increase of more than 56% when compared with yield of same area by conventional scheduling methods (4.3 ton/ha) [12]. A saving of more than 15% in crop water requirement have also been achieved as compared to that used by conventional methods [6]. Hence this model provides a useful tool and can be applied satisfactorily on a large scale. To make it more practical and versatile, further verification and testing at different locations and conditions would be necessary.

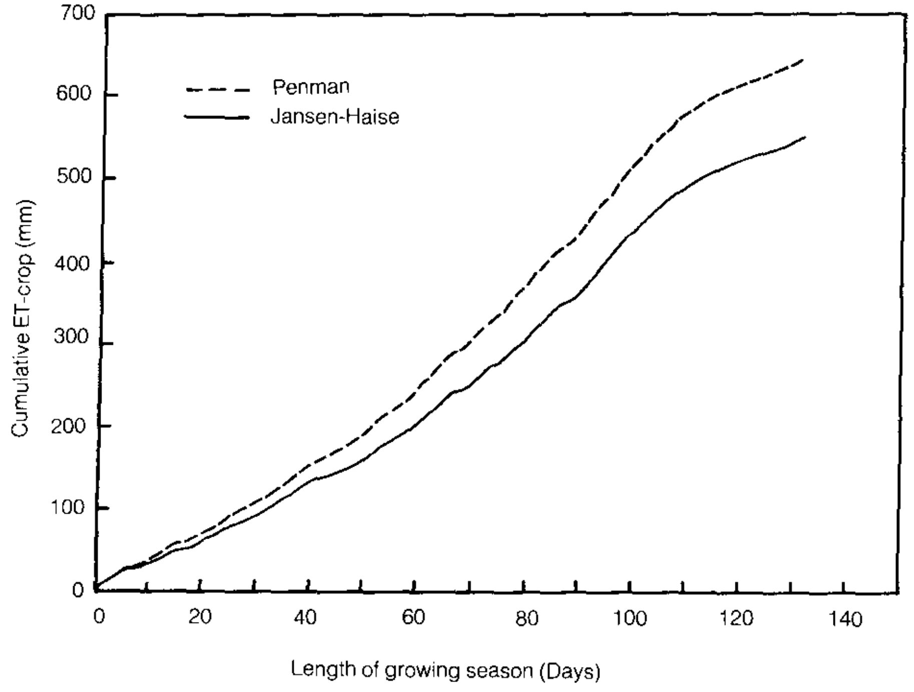

Fig. 6. Cumulative water requirements during entire growing season

Conclusions

An appreciable amount of water could be saved and crop yield increased by implementing the irrigation scheduling model based on climatical data collected continuously from an automatic weather station at the site. The model was applied for wheat, on small scale, during one season and found to work satisfactorily. The Penman method gave more reliable results as compared to Jensen Haise method. More tests are needed for evaluating the model on large scale.

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جدولة الري باستخدام محطة أرصاد آلية
٢ ـ تجربـــة حقليـــة

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ملخص البحث. أجريت تجربة لجدولة الري على محصول القمح باستخدام المعلومات المناخية المرصودة باستمرار بواسطة محطة أرصاد آلية تم تركيبها ومعايرتها لهذا الغرض بالقرب من موقع التجربة في المزرعة التعليمية التابعة لكلية الزراعة. وتعتمد فكرة البحث على تقدير معدلات البخر ـ نتح بتطبيق معادلة بنهان المطورة وطريقة جينسن ـ هيز، إذ تم وضع برنامج Model يلائم الظروف المحلية لمعالجة المعلومات لتحديد مواعيد الري وكميات المياه الواجب إضافتها. وتشير نتائج هذا البحث إلى أن جدولة الري باستخدام معادلة بنهان أكثر ملاءمة وواقعية من طريقة جينسن وهيز تحت الظروف المناخية الجافة، كما أن استخدام محطة أرصاد آلية في جدولة الري لا توفر كميات مائية فحسب، بل تزيد من إنتاجية المحصول أيضًا.