Scheduling Irrigation Using an Automatic Weather Station: I. System Components, Implementation and Operation

Ahmed I. Al-Amoud and Fawzi S. Mohammad
Department of Agricultural Engineering, College of Agriculture,
King Saud University, Riyadh, Saudi Arabia

Abstract. An automatic weather station, was installed, calibrated and operated at the Educational Farm of the College of Agriculture, King Saud University. The purpose of this station is to collect the weather data required for irrigation scheduling of wheat crop grown at the site.

This paper describes the various components of the station together with the programming and software arrangements for handling the data. A discussion is made on the functioning of the station in the central region, Saudi Arabia and the impact of adoption of such irrigation scheduling technique on the conservation of water, energy and labour requirements. Some recommendations on proper management are reported.

Introduction

Proper irrigation scheduling is of major importance in acheiving better management of water for agriculture in Saudi Arabia. In this country, ground water is the main source of irrigation and the agricultural sector consumes more than 85% of the total annual consumption. As excessive water pumping may result in rapid depletion of this resource in the future, plans for water conservation are essential. One of the most effective means is through automatic irrigation scheduling.

Different methods are available for estimating daily reference evapotranspiration (ETr) in arid regions using measurements of microclimatic parameters as indepandant variables [1]. The climatic information can be obtained from conventional weather stations around the country. While automatic computerized weather stations can be used for continuous collecting, transmitting and processing of climatical data. Reliable and representative input data need to be gathered properly if accurate estimates of crop water requirements are to be obtained for adequate irrigation scheduling.

During the past twenty years, several models have been developed employing the local meteorological parameters, that can be used for irrigation scheduling in wide range of climatic conditions [2-7, pp. 189-232]. Some of the well known methods are Penman, Jensen-Haise and the Pan evaporation methods. Pan coefficients based on class A pan are used for predicting ETr [8].

The main objective of this paper is to describe the installation and operation of the automatic weather station used for irrigation scheduling of wheat crop grown at Riyadh area, Saudi Arabia, which include; the hardware and software of this station as well as the communication requirements. Guidelines for proper implementation of such stations for irrigation scheduling under local environmental conditions are suggested.

Installation and Implementation

An automatic weather station (Campbell scientific*) equipped with 21XL micrologger was installed at the Educational Farm of the College of Agriculture, King Saud University. The site was planted with Bermuda grass and located at the corner of a sprinkler irrigation experimental plot designed for growing wheat crop for the purpose of testing the irrigation scheduling based on automatic weather station collected parameters (Fig. 1).

The automatic weather station was provided with 220/110 V.A.C. supply and a solar panel. The wind direction sensor was directed towards north and the solar panel was inclined and turned to face the sun in such a way that it receives continuous solar energy throughout the day. The automatic weather station was connected to a personal computer (PC) through a short haul calling modem (model SC95C), twisted pair shielded cable and a short haul answer modem (model SC95A) for data transfer, as shown in Fig. 2. After installation, the sensors were calibrated and the data obtained from them were tested and compared with similar sensors of a conventional weather station existing at the same site.

Hardware
1- The micrologger
All the weather station sensors are connected directly to the micrologger as shown in Fig. 3. without signal conditioner, which measures, scans and processes the received meteorological data, and sends this data to the remote PC unit.

---

* The use of trade names does not imply the indorsment of the product by the authors, but they are mentioned here for the benifits of the reader only.
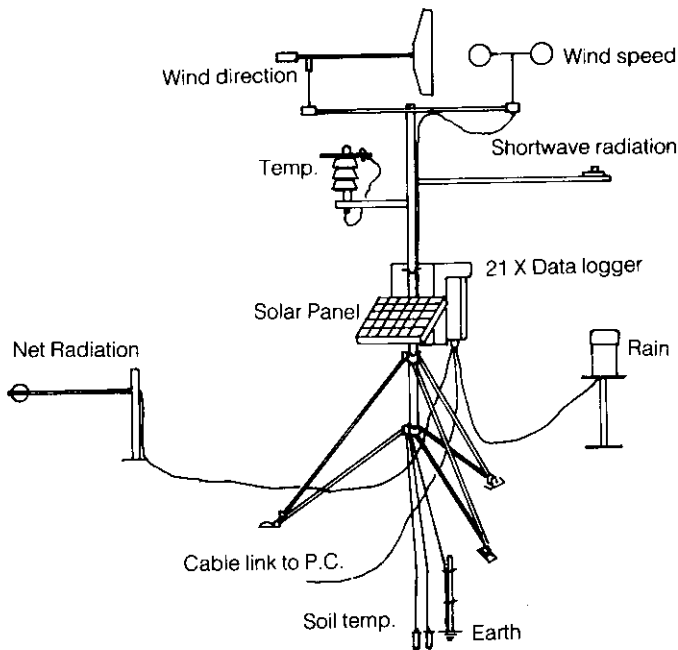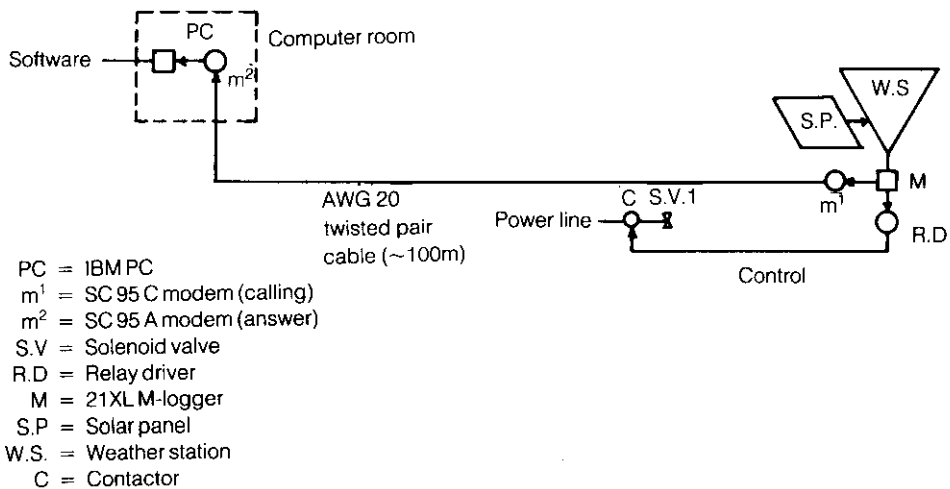
Fig. 1. **Automatic weather station components**

PC   = IBM PC
m^1 = SC 95 C modem (calling)
m^2 = SC 95 A modem (answer)
S.V = Solenoid valve
R.D = Relay driver
M   = 21XL M-logger
S.P = Solar panel
W.S. = Weather station
C   = Contactor

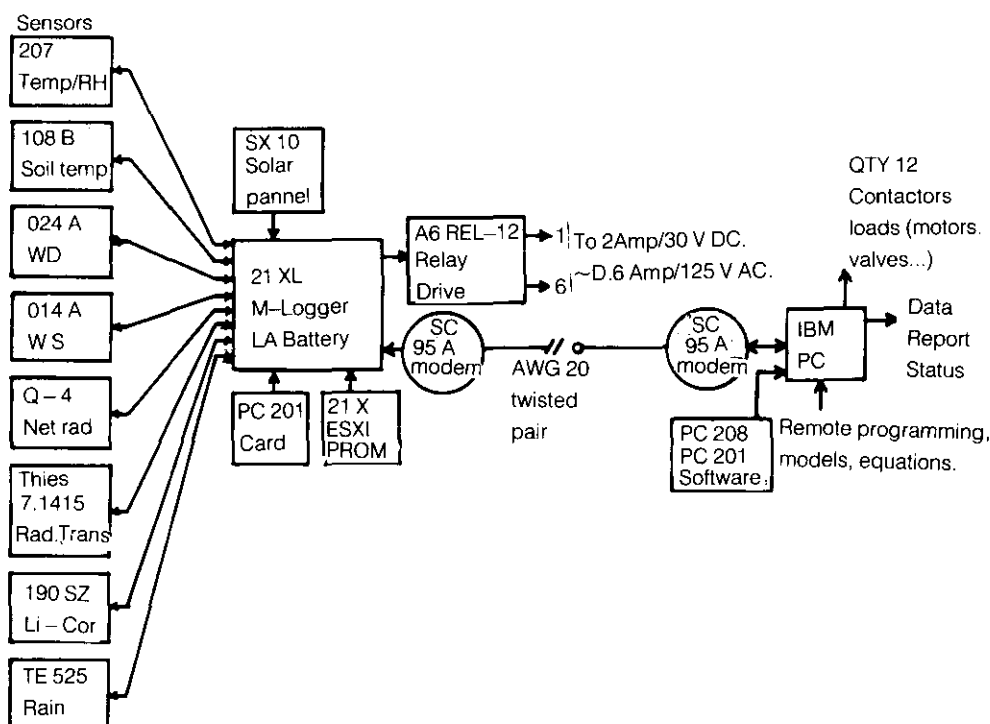**Fig. 2.** **Telemetry system for the automatic weather station**

Fig. 3.   System configuration for automatic irrigation scheduling using automatic weather station

The data stored in the computer database is used by an evapotranspiration (ET) model designed for this purpose to determine the next irrigation and depth of water to be applied by the irrigation system, the automatic irrigation scheduling is thus, based on open loop system logic, illustrated by a block diagram shown in Fig. 4. The micrologger of the weather station is powered with chargeable lead acid 12 V cells as a backup in event of power failure. The micrologger has 8 double ended channels (which could be used as differential 8 channels or 16 single ended channels), 4 excitation channels, 4 pulse counters and 2 continuous analog output channels. It has 40960 bytes of random access memory (RAM). The micrologger was programmed to collect the data every 1 min. and averaged each hour and 24 hr. From the I/O port on the micrologger, serial communication to the PC. was established with the use of suitable peripheral connectors and short haul modems set through a cable link.

The micrologger provides three types of measurements; fast and slow sequence, single ended and differential voltage and thermocouple measurements as follows;
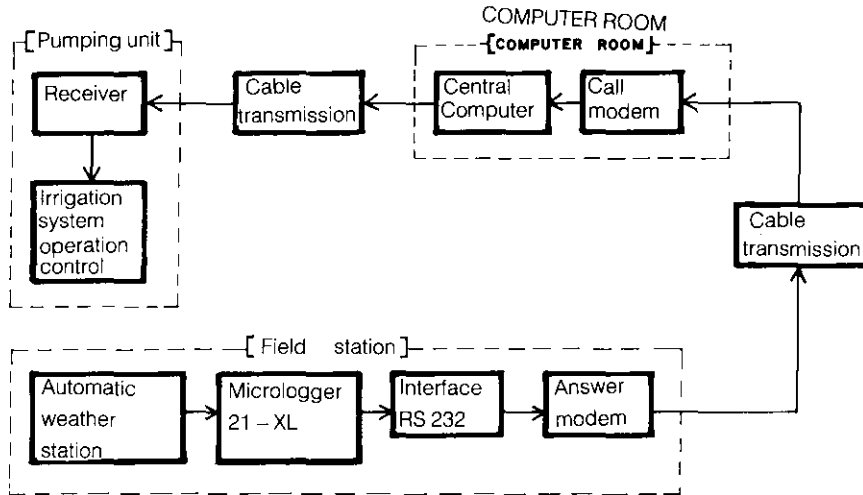
Fig. 4.   Block diagram of open–loop system for automatic irrigation scheduling

A- Fast and slow measurement sequence: The 21XL makes voltage measurements by integrating the input signal for a fixed time and then holding the integrated value for the analog to digital (A/D) conversion. The A/D conversion is made with a 14 bit successive approximation technique which resolves the signal voltage to approximately one part in 15,000 of the full scale range on a differential measurement.

B- Single-ended and differential voltage measurement: A single-ended measurement is made on a single input which is referenced to ground. A single integration is performed for each measurement. A differential measurement measures the difference in voltage between two inputs. The measurement sequence on a differential measurement involves two integrations: First with the high input referenced to the low, then with the inputs reversed. The 21XL computes the differential voltage by averaging the magnitude of the results from the two integrations and using the polarity from the first **.

C- Thermocouple measurements: the 21XL determines thermocouple temperatures using the following sequence. First, the temperature of the reference junction

_____

** Campbell Scientific, " 21XL Micrologger Manual". 1988. and, Campbell Scientific," PC208 Data Logger Support Software". 1988.

is measured. If the reference junction is the 21XL panel, the temperature is measured with the built-in thermistor. The reference junction temperature in Celsius (C) is stroed in an input location which is accessed by the thermocouple measurement instruction. The 21XL calculates the voltage that a thermocouple of the type specified would output at the reference junction temperature if its reference junction were at 0.0 C, and adds this voltage to the measured thermocouple voltage. The temperature of the measuring junction is then calculated from a polynomial approximation.

2- The Sensors
The measured parameters by the automatic weather station include; minimum and maximum air temperatures, relative humidity, short wave radiation, net radiation, soil temperature (at 100 and 200 mm depths), wind speed, wind direction and rainfall (Fig. 3). A brief description of the sensors follows:

A- Temperature and relative humidity (R.H.) probe: Generally, the four most common temperature transducers are the thermocouple, the resistance-temperature detector, the thermistor and the integrated circuit sensor. Classically temperatures are measured by thermocouples [9, 10].

The model 207 probe was used which consists of a R.H. sensor chip and a thermistor for air temperature measuremments configured for use with the micrologger. Although both sensors are combined into one probe, separate instructions were used to read each sensor.

The probe gives temperature readings in degree centigrade. The micrologger was programmed to calculate the saturation vapor pressure (es) and ambient vapor pressure (ea), in kilo Pascal.

B- Radiation: Three types of sensors were used to measure radiation in this experiment;
    i. Quantum radiation: LI-COR radiation sensor type LI-190 SZ was used for the measurement of shortwave radiation. This sensor is characterized by a silicon photodiode with enhanced response in the visible range and having the cable sensor terminated with the two bare wire leads of the coaxial cable. The sensor measures photosynthetically active radiation (PAR) in the 400 to 700 nm[***] wave band. The unit of measurement is micromol S^{-1} m^{-2} per microamp. The sensor was mounted at a height of 1.80 m above ground surface.

[***] nm: Nanometer ($= 10^{-9}$m).

ii. Radiation transmitter: A radiation sensor type Thies 7.1415 was used for the measurement of shortwave radiation (spectral range: 0.3 - 3.0 μm). It utilizes the temperature difference between black and white surface to measure global radiation by means of thermoelements with measuring range 0 - 1300 wm. The sensor was mounted at a height of 1.8 m above ground surface.

iii. Net radiation: Radiation energy balance system (REBS) net radiometer, Q4, was used. It contains a high output thermopile and the net radiation is obtained from the thermopile voltage as:

$$Rn = Vt \times \text{Calibration factor } (11.9 \text{ w/m}^2 \text{ /mv})$$

Where Rn is the net radiation in wm^{-2} and Vt is the thermopile voltage in mV.

The sensor was mounted on a horizontal arm 600 mm above ground and positioned so that it is never shaded from the tripod or any other source.

C- Soil Temperature: The soil temperature probes were thermocouples of the type 108 B. They were installed at 100 and 200 mm depths from the soil surface. Good contact was insured between the soil and the sensor when placing the thermocouples.

D- Wind speed and direction:
● *Wind speed:* A 3 cup anemometer with a photochopper transducer produces a pulsed output which is monitored with a pulse count instruction, configured for high frequency pulses. The sensor used is 014A and mounted at a height of 2 m above ground. The micro-logger was programmed to give wind speed in m/s from the pulsed input.

●*Wind direction:* The Met-one 024A wind vane sensor used to measure wind direction from 0 to 360 degrees ($\pm$ 5 degree accuracy). The sensor was oriented so that the counter weight pointed towards South. The sensor was mounted on the same arm (i.e. same height, 2 m) as that for wind speed.

E- Precipitation: Texas electric rain gage No TE 525 was used for precipitation. This tipping bucket rain gage measures rain with the Pulse Count Instruction configured for switch closure. Output is given in mm. The sensor is programmed to activate only when the event occurs. The height of the catch can was 600 mm above ground. The hardware of the scheduling system used is shown in Fig. 3.

Software and operation
1- Software requirements
The software developed for the irrigation scheduling based on the weather station system performed the following functions:

A- Collection and processing of sensed data.

B- Monitoring, storage and reporting of weather data.

C- Irrigation scheduling (decide time and quantity of irrigation).

D- Operation and control of solenoid valve and pump.

It is possible to categorize the software developed for the weather-based system into two main categories : (a) datalogger driven software which performs the measurements functions through the set of sensors connected to the automatic weather station, and (b) irrigation scheduling software which utilizes these data to perform irrigation computation necessary for the scheduling process. The first category is programmed in the datalogger "machine" language while the second one may be programmed in any other programming language.

The hardware manufacturer supplies a software package consists of three separate programs; the first is the editor program called EDLOG used to develop a document and programs for the 21XL. The second, is the TELECOM program to establish comunication link between the computer and the 21XL. The third software is the terminal emulator TERM that provides computer-datalogger communication for real time display of data and uploading/downloading of data logger programs.

2- The irrigation scheduling program

The first step taken in developing the software for scheduling irrigation was to arrive at a reliable estimate of the crop water use or crop evapotranspiration... ETc. The irrigation scheduling program algorithm consists of two main parts; the estimation of ETr and the computation of the soil moisture depletion.

A simplified version was used employing Penman and Jensen-Haise methods in the development of software for ETr estimation. Basal crop coefficients as given by Doorenbos and Pruitt [1] and Wright [11-13] were used. Since these coefficients were derived under dry soil surface conditions, adjustment for surface wetness was carried out before using them with ETr for calculating... ETc.

The depth of irrigation to bring the root zone back to field capacity was calculated and the sprinklers were operated to provide the required depth. With the help of the designed software, the PC retrieves from its memory all the data received during the previous 24 hr, calculates the ETr, combines it with the appropriate crop coefficient for the Julian day and soil characteristics to determine the soil deficits. By comparison with the readily available water it determines whether an irrigation is required or not and calculates and prints an irrigation schedule. Irrigation is initiated at 8.00 A.M. (to eliminate evaporation losses) on the day it is needed.

Monitoring and Controlling Pump: A system of solenoid valve and pump was installed and will be switched on through the software to release water to sprinklers when needed and will switch the pump and solenoid valve off to shut the water supply when the necessary depth of water is applied. Practical operation of the station with all its components including the software were tested through the actual performance of an automatic irrigation scheduling experiment on wheat crop that will be discussed in detail in the second part of this study.

Discussion and Conclusions

The automatic irrigation scheduling approach based on climatic parameters gathered by an automatic weather station have proven to be suitable technology for achieving water management objectives. It works in satisfactory manner without any major malfunctioning. Although it was considered as highly advanced technology yet it have demonstrated to be simple enough and does not require high technical skill to operate it.

Calibration of weather station sensors is very important to insure accurate data, it is done simply by comparison with outputs from conventional weather station at / or near the site. Sensors need to be tested after installation then, once every one or two years as suggested by manufacturer. However, due to the extreme hot arid climate of the country it is advised that a calibration test be conducted every six months. Maintenance, is also another factor to insure prolong trouble free operation, solar panel, wire connections, battery, radiation sensor cap, and other components need to be checked every now and then to clean, mend or replace the worn parts. Although, station devices are reliable, it should be realised that, some involve electronical parts especially the micrologger, hence, malfunctioning is possible due to extreme hot arid climate, therefore, a shelter for protection is important.

The values of solar radiation from the automatic weather station were compared with the values from a nearly two conventional weather stations (Dirab - 40 km west of Riyadh and Kharj - 80 km east of Riyadh) for the same period of time. The values were very close to each other as shown in Fig. 5. This indicates that the performance of the automatic weather station is quite satisfactory. The solar radiation data for eight years were also taken from Dirab station and plotted in Fig. 6. An envelope curve was fitted to the maximum values to get the representative clear day sky radiation curve for Riyadh area. The cumulative values from this curve were plotted versus time (Fig. 7). The cumulative average values of eight years as well as the cumulative solar radiation values from the automatic weather station were also plotted in the same figure for comparison purposes. As expected the values from the automatic
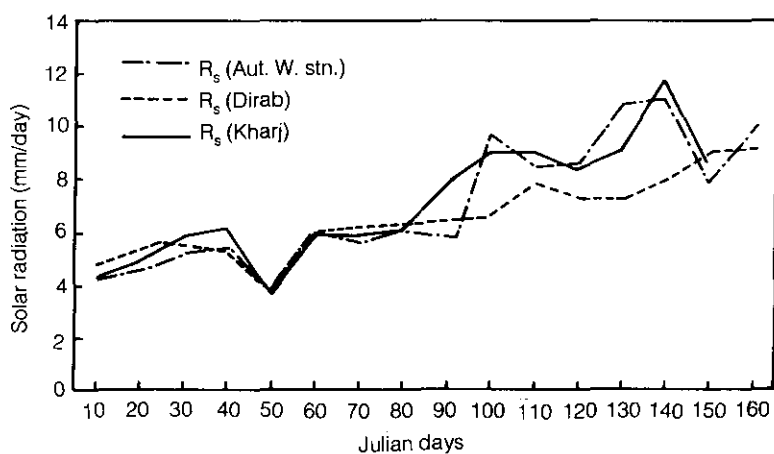
Fig. 5.   Solar radiation versus time for three different weather stations (1990)
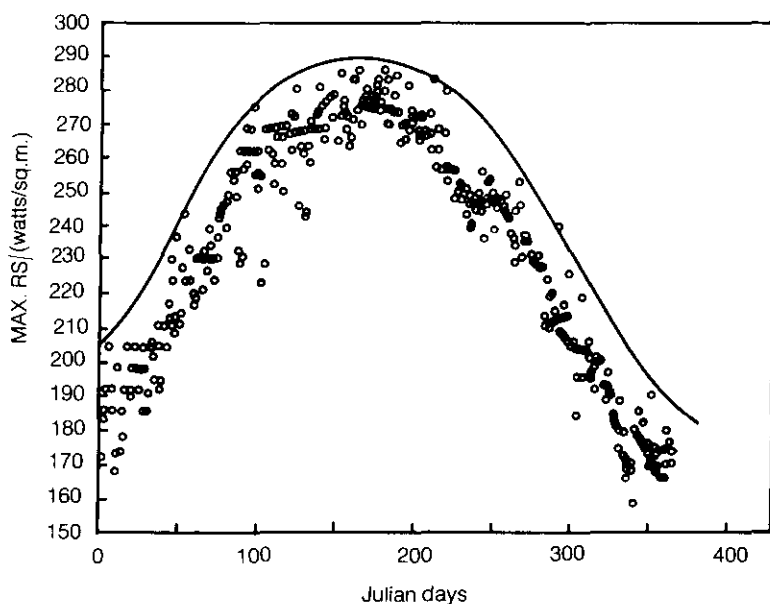

Fig. 6.   Solar radiation data for eight years from dirab weather station
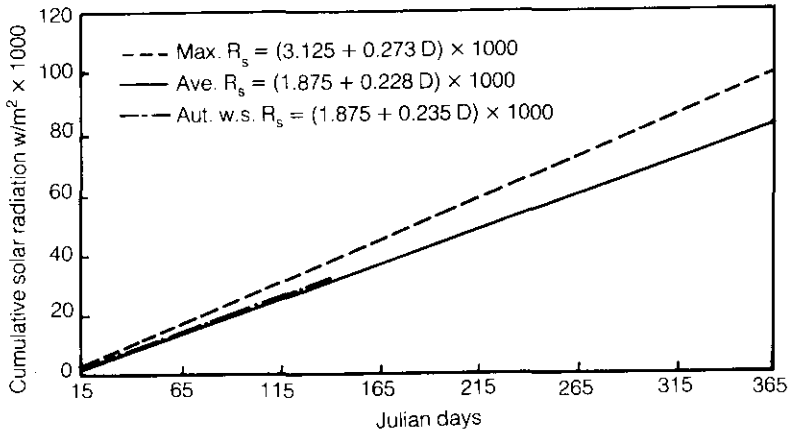
Fig. 7.   Cumulative solar radiation from automatic weather station as compared to that measured at Dirab.

weather station fitted very well with the average values and were lower than the maximum (clear day sky radiation). Since they did not deviate much from the straight line, they could be described by straight lines. The equations are:

$(Rs) \max = (3.125 + 0.273D) \times 1000$

$(Rs) \text{ave.} = (1.875 + 0.228D) \times 1000$

$(Rs) \text{aws} = (1.875 + 0.235D) \times 1000$

where, D; no. of days, aws; automatic weather station.

In conclusion, scheduling based on climateological data gathered by an automatic weather station is practical and advantageous since the atutomatic station can offer the following benefits;

1- Climateological information automatically gathered by the station could be transmitted to a remote area, a base station or an office where a PC is located, through a cable connection, telephone, radio or infra-red telemetry systems using suitable modem.

2- Programming of the automatic station could be done either remotely through the PC using the software EDLOG or at the station site through micrologger keys.

3- The station can gather and store a large number of information, calculates average daily, monthly and annually and could review these data through the PC for any period instantly.

4- The automatic station can be operated either electrically, or by a dry cell battery or by solar power which makes it easy for the station to work under any condition.

5- The automatic system could be operated for small as well as large farm sizes, as a matter of fact, a number of farms in an area could share the benefit of the system by receiving instructions on scheduling based on weather parameters collected by the station.

6- The automation of the irrigation scheduling through automatic weather station could be operated using the open loop concept, where an operator recieves the scheduling instruction from the computer, to open or close water delivery system. A second option, is to adopt the closed loop system, where, scheduling calculations, decisions and operation is made by the computer with no human intervention.

References

[1]   Doorenbos, J. and Pruitt, W.O. Guidelines for Predicting Crop Water Requirements. In: *Irrigation and Drainage Paper No 24.* 2nd ed., Rome, Italy: FAO, United Nations, 1977.
[2]   Jensen, M.E., Robb, D.C.N. and Franzoy, C.E. "Scheduling Irrigation Using Climate-Crop-Soil Data". *Proc. ASCE, J. Irrig. and Drainage Div.,* 96 (IRI) (1970), 25-38.
[3]   Jensen M.E., Wright, J.L. and Bratt, B.J. "Estimating Soil Moisture Depletion from Climate, Crop and Soil Data". *Trans. ASAE,* 14 No. 5 (1971), 954-959.
[4]   Miyamato, S."A Model for Scheduling Pecan Irrigation with Microcomputers". *ASAE* Paper 27, No. 2 (1984), 456-463.
[5]   Kruse, E.G., Ells, J.E. and Mcsay, M.E. "Scheduling Irrigation of Vegetable Crops". *ASAE* Paper no. 86-2593, ASAE, St. Joseph, Michigan. (1986).
[6]   Field, J.G., James, L.G., Bassett, D.L. and Saxton, K.E. "An Analysis of Irrigation Scheduling Methods for Corn". *Trans. ASAE* 31, No. 2 (1988), 508-512.
[7]   Burman, R.D., Nixon, P.R., Wright, J.L. and Pruitt, W.O. Water Requirements. In: *Design and Operation of Farm Irrigation Systems.* M.E. Jensen (ed.), ASAE Monograph 3, 1983.
[8]   Hunting Agro Services Ltd. "A Report on Computer Assisted Irrigation Scheduling". United Kingdom, (1987).
[9]   Hewlett Packard. "Practical Temperature Measurements." *Application Note 290,* (1980)
[10] Behee, R.D. "Measuring Multiple Channels of Transient Data with a Microcomputer-Based Acquisition System". *CIME,* Jan. (1983), 18-23.

[11] Wright, J.L. and Jensen, M.E. "Development and Evaluation of Evapotranspiration Models for Irrigation Scheduling". *Trans.* of *ASAE* 21 No. 1 (1978), 88-96.

[12] Wright, J.L. "Crop Coefficients for Estimates of Daily Crop Evapotranspiration". In: *Proc. of the Irrigation Scheduling Conf.* Irr. Scheduling for Water and Energy Conservation in the 80's, ASAE, Dec. 1981.

[13] Wright, J.L. "New evapotranspiration Crop Coefficients". *Trans. ASCE, J. of Irrigation and Drainage Div.*, 108 (IR1) (1982), 54-57.

جدولة الري باستخدام محطة أرصاد آلية
١ ـ أجزاء النظام والتركيب والتشغيل

أحمد إبراهيم العمود وفوزي سعيد محمد

قسم الهندسة الزراعية ، كلية الزراعة ، جامعة الملك سعود، الرياض،
المملكة العربية السعودية

ملخص البحث . تم تركيب ومعايرة وتشغيل محطة أرصاد آلية في المزرعة التعليمية في كلية الزراعة بجامعة الملك سعود ـ الرياض . وكان الغرض من هذه المحطة هو جمع المعلومات المناخية المطلوبة لجدولة الري لمحصول قمح مزروع في الموقع . وتتعرض هذه الورقة للمركبات والأجزاء المختلفة للمحطة وتشغيلها بالإضافة إلى ترتيبات برامج الحاسب الآلي المطورة خصيصًا لمعالجة المعلومات لأغراض الجدولة . وفي المناقشة سنتعرض لأداء المحطة وتأثير استخدام النماذج الرياضية المبنية على حسابات محطات الأرصاد على توفير المياه والطاقة واحتياجات العمالة . كما تم أيضًا استعراض بعض التوصيات .