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Using CROPWAT Model in Scheduling Irrigation and Determining Water Use of Cotton in Two Areas in Syria

استخدام نموذج (CROPWAT) في جدولة الري وتحديد كمية المياه اللازمة لمحصول القطن في منطقتين من سورية

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Abstract: Sustainability of cotton production depends on the development of irrigation methods that guarantee yield and meet best water management practices. This study aimed at determining local crop irrigation parameters for cotton grown at two locations in Syria, Hasakah and Aleppo, and to evaluate the performance of FAO's CROPWAT Model for on-farm irrigation application for cotton under arid conditions at these two locations. Crop yield data were collected at the two locations over two cotton growing seasons 2001-2002. At each location, experimental plots were established, and treatments consisted of two irrigation methods; basin and drip. Irrigation water was applied before sowing and then each time the soil root zone reached 75% of field capacity. Results determined local crop water use values in the first year at 850 and 890 mm, and in the second year 880 and 910 in Aleppo and Hasaka, respectively. The simulated crop water use by CROPWAT model were 825 and 906 mm in the first year and 850 and 885 mm in the second year in Aleppo and Hasaka, respectively. Simulated irrigation timing using the model showed that the model performed well at these two local conditions and that managers in the region would benefit from using it for planning purposes. The model can be used as a management tool to help farmers, extension services, and other agents to analyze, make decisions, and optimize water use management.

Keywords: *Irrigation scheduling, irrigation efficiencies, CROPWAT modeling, irrigation coefficients.*

المستخلص: إن استدامة إنتاج القطن تعتمد على تطوير طرق الري والإدارة الجيدة للمياه والتي تضمن الغلة المناسبة في نهاية الموسم. في هذا البحث، تم دراسة إنتاجية محصول القطن في منطقتين من سورية (حلب والحسكة) وذلك خلال موسمي 2001-2002، حيث تم في كلتا المنطقتين تصميم قطاعات تجريبية لمعاملتين ري هما الري السطحي والري بالتنقيط. وتم الري قبل عملية البذر وبعدها، حيث تم المحافظة على معدل رطوبي مناسب في منطقة توزع الجذور والتي كانت 75% من السعة الحقلية. لقد بينت النتائج أن الاستهلاك المائي المحلي كان 850 و 890 مم في حلب والحسكة في السنة الأولى، على التوالي، و880 و910 مم في حلب والحسكة للسنة الثانية، على التوالي. وكانت النتائج المحسوبة باستخدام النموذج الرياضي CROPWAT لمنطقتي حلب والحسكة هي، على التوالي، 825 و906 مم في السنة الأولي و850 و885 مم في السنة الثانية. كذلك تبين النتائج التي تم الحصول عليها فعالية هذا النموذج الرياضي في جدولة الري تحت الظروف المحلية، وأنه من الممكن استخدام هذا النموذج الرياضي في التخطيط وجدولة الري من قبل العاملين في هذا المجال ويمكن أن يساعد المزارعين وهيئات الإرشاد الزراعي وأصحاب القرار من أجل تحسين إدارة المياه.

كلمات مدخلية: *برمجة الري، كفاءة الري، النموذج الرياضي CROPWAT، معاملات الري.*

INTRODUCTION

Planning and management of water resources has become a very important issue everywhere in the world. In the arid and semi-arid areas high yields of crops can be achieved if irrigation water is managed properly. Limited water resources in these regions now represent a major constraint for further expansion of agriculture. Moreover, there are competing uses for the limited renewable water supply, which would require the optimization of water used in agriculture.

An understanding of water needs in agriculture is a critical input in resolving the scarcity of water resources issue that confront many dry areas in the world. Consumptive use (or Evapotranspiration) is a key function for estimating irrigation water requirements and for water resource management, especially under water limitation. Irrigation scheduling is the decision of when and how much water to apply to an irrigated crop to maximise net returns. The maximization of net returns requires high level of irrigation efficiency, and necessitates the accurate measurement of the volume of water applied, or the depth of application. Accurate information on evapotranspiration and yield response are essential in order to achieve the best irrigation management. Many studies have shown drip irrigation to be well suited for raw crops like cotton production (Yuan, *et al. 2003*; Waddell *et al. 1999*).

In dry areas, the availability of adequate amounts of water is the most significant single factor limiting crop production (Oweis and Hachum, 1998). This factor must therefore receive high priority. With increasing pressure on natural resources in the Near East, the need for reliable and systematic information on water and its use is increasingly recognized as being of prime importance for sustainable economic development in the region. Many factors determine crop water use, including crop type, crop density, amount of vegetative cover or leaf area, crop health, soil moisture levels, stage of growth, climate, irrigation timing and method, and environment (Soumi, 1993).

In Syria, where irrigated agriculture uses more than 80% of total water consumption (Ibrahim, 2005), more than 270,000 ha are irrigated cotton, with an annual production of about 1,000,000 ton and an average productivity of 3,700 kg/ha (CBS, 2005). Economically, cotton is the most important crop for Syria. Estimating the amount of water required to maximize crop yield is usually based upon the calculation of a reference crop evapotranspiration amount (ET_o) and the use of a crop water use coefficient (k_c) (FAO, 1998).

Models that simulate crop growth and water flow in the root zone can be a powerful tool for extrapolating findings and conclusions from field studies to conditions not tested, allowing predictions for deficit irrigation scheduling under various conditions of water supply and of soil and crop management (Darir, 2006). Models can play a useful role in developing practical recommendations for optimizing crop production under conditions of scarce water supply. Actual crop water needs are often only very roughly simulated (Yamashita and Walker, 1994). When simulated, FAO guidelines (Smith, 2000) are often used to estimate crop evapotranspiration from observed values of crop development (Ray and Dadhwal, 2001).

A number of researchers have demonstrated that crop simulation models are valuable tools for guiding irrigation management. These models can be used to estimate irrigation requirements at the farm level (Nijbroek, *et al.* 2003; Guerra, *et al.* 2002), as well as at the county and state levels (Heinemann, *et al.* 2002). However, these models need to be evaluated at the field level, and for which there is a need to develop site specific data for various environmental conditions using data sets that are independent of model development or calibration (Burk, 1986 ; Hoogenboom, 2000).

The objectives of this study were to determine typical crop irrigation parameters of cotton grown at two locations in Syria, Hasakah and Aleppo. Furthermore, the study aimed at establishing local water use crop coefficients (K_c), and to evaluate the performance of FAO's CROPWAT Model for on-farm irrigation application for cotton under arid conditions at these two locations.

MATERIALS AND METHODS

Experimental Plots

Data were collected from the two experimental plots in Hasakah and Aleppo over two cotton-growing seasons (April to September of 2001 and 2002). The dominant climate is Mediterranean continental. Hasakah (average annual rainfall 210 mm/yr and potential evapotranspiration 1810 mm/yr) and Aleppo (average annual rainfall 340 mm/yr and potential evapotranspiration 1600 mm/yr) have soil textures of clay loam and clay (Table 1), respectively.

At the each of the two research stations, experimental fields were established. The treatments consisted of two irrigation methods, basin and drip. The irrigation water was applied before sowing and then each time the soil root zone reached 75% of field capacity. Since all farmers in the area must irrigate in order to obtain an economical crop yield, all plots were irrigated. The effective root zone (ERZ) of the crop is the depth of soil where soil moisture needs to be controlled. Cotton was seeded by hand using a push-stick with two seeds per hole. Spacing between holes was 20 cm and between rows 75 cm. Fertilization consisted of phosphate at 100 kg/ha and nitrogen at 100 kg/ha before seeding and a further dressing of nitrogen at 80 kg/ha in early July. There was no need for potassium fertilization as the soil already potassium-rich. The above procedures follow typical farming practices in the two areas. Sowing was made in April 15th and harvesting was made in October in both years (2001 and 2002).

Soil moisture was monitored on a daily basis (for the most part; logistics caused a few missed days) via neutron probes (one installed in each of the 24 plots, 12x9 m). These measurements were used to determine the amount of soil water being used due to evapotranspiration. Data were collected for each 20 cm interval to a total depth of 80 cm. Timing of irrigation for each treatment depended upon soil moisture conditions; irrigation water was applied once the soil profile reached 75% of the field capacity.

At each location there was a small automatic climatic station which recorded on a daily basis the various parameters required by Penman for the calculation of potential evapotranspiration (PET Penman) (FAO, 1998). At each location, a Class-A Pan was used for monitoring evaporation. It should be noted that the measured rainfall rate in Aleppo station showed high variations during the month of April between the two years, where it was 74.4 mm in April 2001 and 15.9 mm in April 2002 (Table 2). However, this variation had no significant effect on the experimental results, due to that in both cases the soil moisture reached 75% of field capacity**.** Table (2) shows the relevant climatic data for the two locations.

Table 1: Soil analyses for Hasakah and Aleppo research stations.

Stations	Depth (cm)	pH	EC (dS/m)	Density (g/cm^3)		Field Capacity (%)		Wilting Point (%)		Mechanical Analysis (%)			Soil Texture
				bulk	particle	weight	volume	weight	volume	sand	silt	clay	
Hasakah	0-25	7.8	1.7	1.18	2.25	28.5	33.9	15.3	17.9	25.4	41.8	32.8	Clay loam
	25-50	7.7	1.9	1.22	2.61	27.6	32.3	14.9	18.1	24.7	39.2	36.1	Clay loam
	50-75	7.6	2.3	1.17	2.25	26.1	31.3	13.9	16.8	19.5	38.4	42.1	Silty clay
	75-100	7.6	2.5	1.21	2.74	26.4	31.9	14.2	17.1	19.3	39.5	41.2	Silty clay
Aleppo	0-25	7.4	0.6	1.11	2.58	36.4	40.4	19.7	21.9	20	18	62	clay
	25-50	7.5	1.2	1.18	2.66	35.2	41.2	19.2	22.6	18	17	65	clay
	50-75	7.6	1.2	1.32	2.7	32.6	42.3	18.1	23.7	19	15	66	clay
	75-100	7.5	1.1	1.39	2.72	31.8	44.2	18	17.1	20	15	65	clay

Table 2: Climate data for Hasakah and Aleppo stations, April-September, years 2001– 2002.

Region	Year	variable	April	May	June	July	August	September
Hasakah	2001	P, mm	22	33.4	0	0	0	2.4
		T, ^{0}C	17.2	19.9	29.0	31.1	30.8	24.9
		RH, %	56	50	46	43	42	46
		v, m/s	1.9	2.2	2.4	2	2.6	1.8
		PET, mm	4.7	6.3	7.5	8.1	7.9	5.0
	2002	P, mm	43.3	6	0	0	0	0
		T, ^{0}C	15.2	19.7	29.5	32.4	31.7	26.9
		RH, %	73	59	37	40	44	58
		v, m/s	1.7	1.9	2	2.1	2.4	1.6
		PET, mm	4.2	6.0	7.9	8.5	8.2	5.8
Aleppo	2001	P, mm	74.4	12.4	0	0	0	0
		T, ^{0}C	16.5	19.3	25.9	30.1	29.4	25.2
		RH, %	52	48	37	39	43	43
		v, m/s	2.1	1.7	2.8	3.5	3.4	2.2
		PET, mm	4.2	5.5	7.0	7.7	7.4	5.0
	2002	P, mm	15.9	6.3	0	0	0	0
		T, ^{0}C	16.1	20	26.7	30.3	30.1	26.2
		RH, %	55.5	38	31	40	43	49
		v, m/s	2.7	2.5	2.6	2.5	2.9	2.5
		PET, mm	4.1	5.9	6.9	8.1	7.9	5.0

Notes: P (monthly rainfall) mm; T^0C (average daily temperature); RH (average relative humidity) %; v (wind velocity) m/s; and PET mm (monthly potential evapotranspiration as calculated using Class A pan).

Theoretical crop coefficients were calculated for each irrigation condition using the following equation:

$$ET_c = K_c \times PET$$

where ET_c is the amount of irrigation used by the crop, as measured in the field (mm/d); K_c is the crop coefficient; and PET is the potential evapotranspiration as measured using Class A Pan (mm/d). At the end of the growing season, grain yield production per ha was measured on a dry weight basis.

Modeling

Crop water use models were proposed as useful tools for farming management and analysis of economic risk. CROPWAT is a computer program used for irrigation planning and management, developed by the Land and Water Development Division of FAO. Its basic functions include the calculation of reference evapotranspiration, crop water requirements and time of irrigations (FAO, 1998). The model includes standard data for main crops and it is possible to adjust them to match local conditions. Through a daily water balance, the user can simulate various water supply conditions and estimate yield reductions and irrigation and rainfall efficiencies. Typical applications of the water balance include the development of irrigation schedules for various crops and various irrigation methods, the evaluation of irrigation practices, as well as rain-fed production and drought effects. The model can be used to predict the effects of water stress, but requires local calibration of the main crop parameters.

Calculations of water and irrigation requirements utilize inputs of climatic, crop and soil data, as well as irrigation data. The climatic input data required are Penman-Monteith monthly evapotranspiration and rainfall rates. Reference evapotranspiration (ET_o) can be calculated from actual temperature, humidity, sunshine/radiation and wind-speed data, according to the FAO Penman-Monteith method (FAO, 1998). The required crop parameters include type of crop, root depths (at early and mature stages), date of planting, and length of various growing stages. Soil inputs include; heavy, light or medium soil, initial soil moisture and total available soil moisture. The Crop Coefficient (K_c) values can be default values set by the model based upon crop type, or can be modified for local conditions. For this simulation, the K_c values determined in the field (Table 4) were used. Finally a set limit of soil moisture depletion was defined (set at 75% in this simulation).

RESULTS AND DISCUSSION

The various soil and climatic information relevant to the region of concern are presented in Table (1) and (2). One can see that during the growing season, there is almost no rainfall and that potential evapotranspiration ranges from 4.1 to 8.5 mm/day. The soils are uniformly clay loam to a depth of one meter. The crop yield data collected in Aleppo and Hasakah are presented in Table (3). The table presents the calculated water use efficiency (kg/m^3) and the efficiency of irrigation method in water use (%). Furthermore, the table indicates that the advantage of one irrigation method over the other becomes apparent if one considers water use efficiency, with drip irrigation method always the most water efficient. Figure (1) shows that the two irrigation methods resulted in, more or less, similar crop yields at the two locations.

Table 3: Efficiencies of water use and productivity for Cotton in Hasakah and Aleppo, 2001 and 2002.

Region	Year	Parameters	Drip	Basin
Hasakah	2001	Productivity, kg/ha	4475	3560
		Total depth of water applied, mm	700	1506
		Water used, mm	635	890
		Efficiency of water use, kg/m^3	0.64	0.25
		Efficiency of Irrigation methods, %	91	59
	2002	Productivity, kg/ha	4500	3800
		Total depth of water applied, mm	698	1554
		Water used, mm	645	910
		Efficiency of water use, kg/m^3	0.64	0.24
		Efficiency of Irrigation methods, %	92	58
Aleppo	2001	Productivity, kg/ha	4585	3820
		Total depth of water applied, mm	672	1454
		Water used, mm	609	850
		Efficiency of water use, kg/m^3	0.68	0.26
		Efficiency of Irrigation methods, %	90	85
	2002	Productivity, kg/ha	4390	3695
		Total depth of water applied, mm	698	1468
		Water used, mm	629	880
		Efficiency of water use, kg/m^3	0.63	0.25
		Efficiency of Irrigation methods, %	90	60

In terms of efficiency of water used (cotton yield (kg) versus amount of water used (kg/m^3)), it was consistent in Hasakah, which resulted in the largest yield per unit of water used in both years; Aleppo had its largest yield per unit of water used in the first year. The conclusion to draw is that drip irrigation uses the least amount of water and that drip irrigation in Aleppo in the year 2001 results in the greatest yield per unit of water used.

Table (4) presents the calculated values of crop coefficients (K_c) for various growth stages under basin irrigation for the two locations over the two growing seasons and the results are graphically illustrated in Figure (2). The typical pattern of low K_c values at early and late growth stages and highest during vegetal growth and grain filling is clear in 2002. The Class-A Pan approach for calculating K_c values always resulted in smaller values compared to the Penman method in Aleppo and Hasakah. Moreover, the K_c values in Hasakah were generally smaller than those in Aleppo, except at stage 3, where the K_c in Hasakah was larger than those in Aleppo. The K_c values obtained can be used as a guide for future water use planning in these two locations.

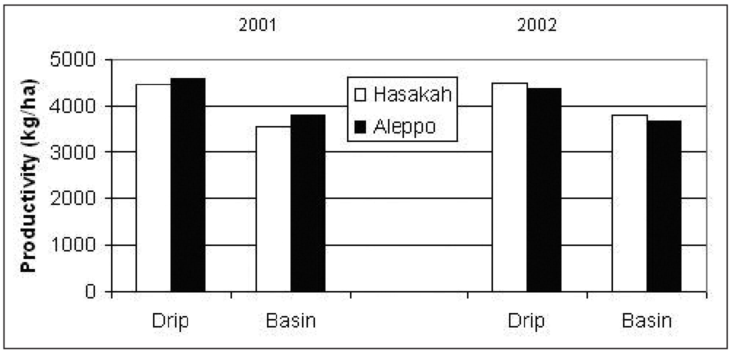

Fig. 1. Productivity of Cotton in Hasakah and Aleppo, 2001 and 2002.

Table 4: Calculated crop coefficients values various growth stages.

Region	Year		Growth Stages 1	2	3	4	Sum
Hasakah	2001	Days	68	10	48	59	185
		ET, mm	177	79	442	187	885*
		PET, mm	471	131	385	330	1318
		K_c (Class A pan)	0.55	1.15	1.13	0.64	
	2002	Days	60	18	46	61	185
		ET, mm	148	73	458	231	910*
		PET, mm	435	133	413	361	134 2
		K_c (Class A pan)	0.34	0.55	1.15	0.64	
Aleppo	2001	Days	60	14	56	40	170
		ET, mm	149	87	452	162	850*
		PET, mm	358	129	423	240	1150
		K_c (Class A pan)	0.41	0.67	1.07	0.67	
	2002	Days	59	14	55	38	166
		ET, mm	135	76	503	166	880*
		PET, mm	346	121	457	237	1161
		K_c (Class A pan)	0.62	1.1	1.07	0.67	

Notes: ET, mm: actual water used by the crop as monitored in the soil root; PET (mm): potential evapotranspiration as calculated by Class A pan; K_c = ET/PET.

** This figure represents crop water use under basin irrigation system only*

The standard crop data given in the CROPWAT model were calibrated first by adjusting K_c values and the critical depletion factor so that they meet conditions and data for the optimal irrigation treatment, with which no stress was applied. Application depth and irrigation timing for each irrigation were reported for all treatments (Table 3; Figures 3 and 4). In addition, consumptive water use and grain yield weight were determined for each treatment.

An example of CROPWAT model simulation is also shown in Figures (3) and (4). The simulated curves follow closely those of the actual plot irrigations. The number of irrigation events between the simulated and the actual were essentially the same, thus water use was essentially the same. Simulated irrigation events at sometimes vary before and after the actual irrigation events by few days. This minor difference can be explained by actual variation in daily climatic conditions.

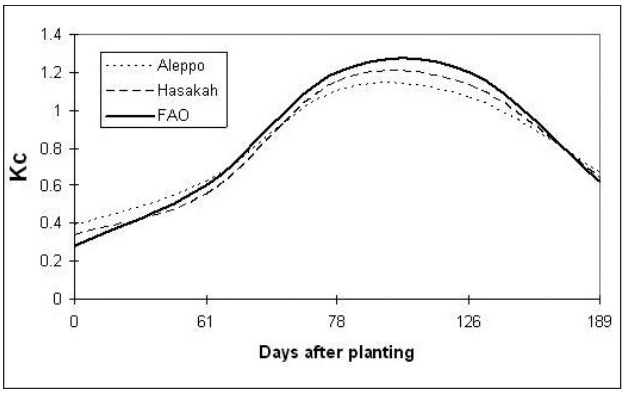

Fig. 2. Crop water coefficient (K_c) for Cotton in Hasakah and Aleppo.

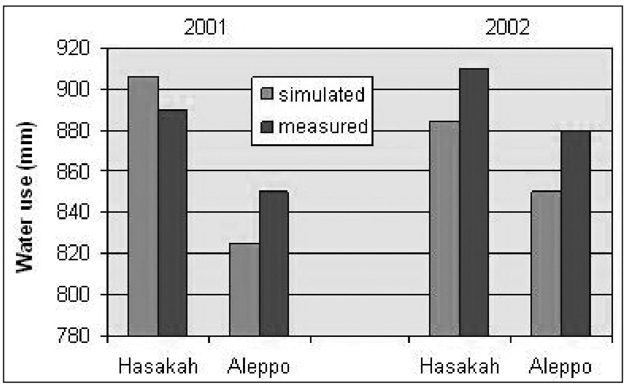

Fig. 3. Measured and simulated water use, in mm, for cotton (2001 and 2002) under basin irrigation.

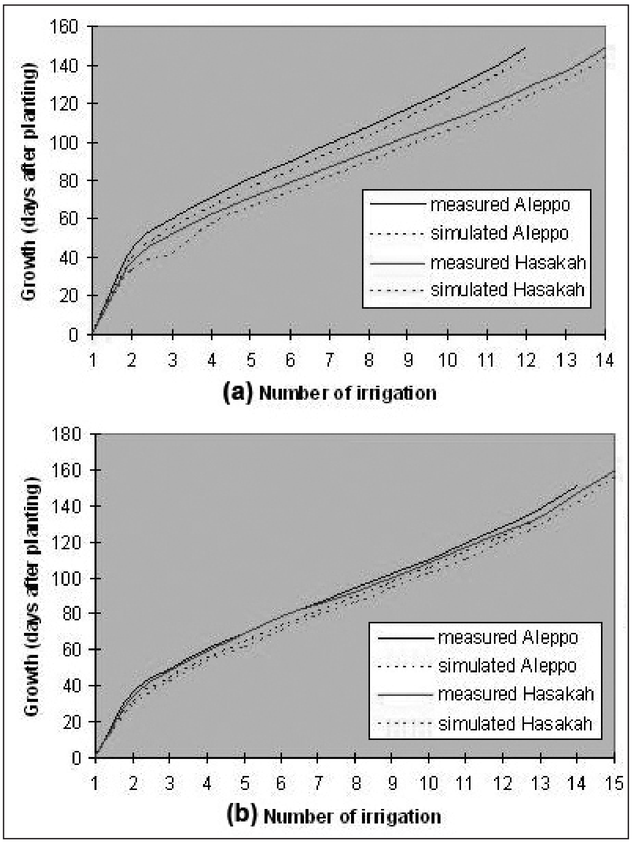

Fig. 4. Simulated and measured irrigation times in Hasakah and Aleppo years a) 2001 and b) 2002.

CONCLUSION

Data and results obtained in this research are important for this area of the Mediterranean region, for only limited values of crop water use coefficient (K_c) and irrigation efficiency have been established for the two irrigation methods used in the two studied areas. It has been demonstrated that the two used irrigation methods of drip and basin irrigation resulted in different crop yields, with drip irrigation demonstrating better results in terms of water use efficiency. The values of the crop water use coefficient in Hasakah and in Aleppo were similar. The crop water use coefficients determined follow the typical pattern of low values during early and late growth stages and higher values during vegetal growth and seed filling. The use of the CROPWAT model can provide useful insights into the design of irrigation studies and parameters selected for irrigation treatments, and can be used to explore the questions of what level of readily available soil moisture results in the best economic yield, the best use of water, and whether deficit irrigation is a viable option. The application of the model was adequate in calculating crop yield reduction, which makes it a valuable tool for irrigation planning.

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