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The Relationship between Reference Evapotranspiration, Crop Yield, and Water use Efficiency for Alfalfa Crop under Different Irrigation Treatments in an Arid Climate

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ABSTRACT. The relation between the applied irrigation water, plant water consumption and plant yield production are having the interest of most investigators especially in arid regions such as the Kingdom of Saudi Arabia, where water resources are limited. In this study, field experiments were made to study the relationship between the applied irrigation water, alfalfa plant (Hassawi cultivar) water consumption by evapotranspiration (ET), alfalfa yield production (fresh and dry), and water use efficiency during two successive seasons, summer 1997 and winter 1998. Four irrigation treatments were considered based on four different soil moisture depletion ratios 9, 18, 36, and 55%, respectively. The irrigation scheduling was designed for these four treatments where, the different irrigation frequencies (1, 2, 4, and 6 days) and the corresponding water application rates were calculated. A total of seventeen plant cutting was followed during the different plant seasons, where these cuttings were illustrated as affecting factor in crop ET and yield. The statistical analysis was made by considering the irrigation treatments and plant cutting number as main effects whereas the studying variables were plant ET, plant yield (fresh and dry), and water use efficiency. The mathematical functions that fit for the dry yield production (Yd) obtained during the summer with the amount of applied irrigation water were linearism whereas, the function during winter was linearism but relatively low. The function of fresh yield production (Yf) with the amount of irrigation water during summer was linearism but relatively low, and the function of fresh yield and the amount of water applied during winter season was a second-degree polynomial. The results showed that during summer season, cut number has a significance effect on evapotranspiration, the amount of irrigation water (W) and the Irrigation Water Use Efficiency (IWUE). On the other hand, during winter season cut number has a significant effect on all variables while irrigation treatment has only significant effect on plant ET and the water use efficiency (WUE).

1. Introduction

Water is the only solution that has the ability to exist in the solid, liquid, and vapor phases at the same time within the variation of earth's temperature. Only a small amount of water is available as fresh water for terrestrial life (Rosenberg *et al.,* 1983). To manage with the limited water for agricultural practices, it is essential to adopt water-saving agriculture countermeasures. In the Kingdom of Saudi Arabia, alfalfa is one of the most important irrigated forage crop used for animal feeding and is cultivated in different agricultural regions in the Kingdom with an estimate of 2 million tons (Ministry of Water and Agriculture, 2002).

Efficiency is one of the important criteria for measuring the performance of the irrigation systems. The term efficiency is used in many ways, sometimes as an index of performing a task with a minimum waste effort or as a ratio of the results actually obtained compared to results that could be obtained theoretically. On occasion, irrigation efficiency is not rigidly defined and may have different interpretations. The term efficiency is frequently modified to assure specific interesting interpretation, *i.e.* application efficiency, conveyance efficiency, required efficiency, water use efficiency, runoff ratio, and deep percolation ratio. Numerous investigators have researches in estimation and identification of the different kinds of irrigation efficiencies, among them are: Stewart and Hagan (1973), Keller (1992), Bos (1980), Jensen (1983), Kiwan (1992), Kiwan and Soliman (1993). They divide the system into three levels, *i.e.*, the reservoir system, the delivery system and the on-farm system, and find three types of water efficiencies *i.e.* on farm irrigation efficiency, conveyance efficiency over irrigation network, and storage efficiency. Martin *et al.* (1984) developed a practice to assess irrigation efficiency based on the relationship between evapotranspiration, yield, and irrigation, with the hypothesis that at little irrigation level all the water applied as irrigation goes toward ET. The Water Use Efficiency (WUE), is defined as the ratio between economic yield and total growing season evapotranspiration and irrigation water use efficiency (IWUE) is defined as the relation between crop yield to the volume of applied irrigation water.

The limited irrigation water in a dry and semi dry environment such as the Kingdom of Saudi Arabia means that the soil water deficit is controlled at certain stages of crop growth. Decline in WUE and IWUE can result from factors such as inadequate fertilization, pest control, planting date, soil water storage, deep percolation, runoff, and extreme evaporation from soil (Howell *et al.*, 1995; and Howell, 2001). Many studies have been conducted on the effects of limited available water for different irrigated crop. For example, in New Valley Agricultural Research Station in Egypt, Sayed *et al.* (1996) found that alfalfa water consumption was 229.671 cm and 276.556 cm during the 1994 and 1995 growing years, respectively and the WUE were 0.427 and 0.437 ton/cubic meter during the two growing years, respectively. Li (1982), Fapohunda *et al.* (1984), and Sharma and Alonso Neto (1986) showed that crop yield and product quality could be largely improved with a limited irrigation volume. Aggarwal *et al.* (1986) concluded that the ratio between grain yield and total growing season evapotranspiration for wheat decreased with increasing evapotranspiration. However, Musick *et al.* (1994) showed that water use efficiency showed no changes with seasonal evapotranspiration.

A field experiment at the Hada Al-sham Experimental Station, King Abdulaziz University, Saudi Arabia was therefore conducted for alfalfa to study the effect of different irrigation treatments on crop yield and evapotranspiration. The results of this study should provide tools to farmers and irrigation managers in the region on how to minimize crop evapotranspiration and irrigation water use, while maintaining high yield productivity.

2. Materials and Methods

2.1 Experimental Site

The field experiments were conducted at the Hada Al-Sham Agricultural Experimental Station of King Abdulaziz University, Jeddah, Saudi Arabia. The station occupies an area of 1,000,000 m^2 located about 125 km northeast of Jeddah at an elevation of about 100 m above sea level (latitude 21º45'N, longitude 39º39'E). It has an average annual rainfall of less than 50 mm, and groundwater table lower than 40 m beneath soil surface. The climate is arid with a mean monthly maximum temperature during summer of 43.5ºC and means monthly minimum temperature during winter of 17.6ºC.

2.2 Planting and Land Preparation

Before site planting, the land was tilled perpendicularly two times using moldboard plow at depth 25-30 cm. Then the land surface was leveled two times: in dry condition and after wetting by initial irrigation water. The experimental area was divided into sub-basins, each having 5 m by 5 m dimension. The Alfalfa cultivars was (*Medicago Sativa* L.) (Hassawi), where the seeds were distributed randomly by hands. The fertilization types and rates for each basin were fixed where the illustrated treatments were the irrigation treatments only. The applied fertilizers before planting were potassium sulphate (50%) by a rate of 400 kg/ha and superphosphate (46%) by a rate of 400 kg/ha. After planting, nitrogen (urea) fertilizer was added by a rate of 150 kg/ha during the crop cutting.

2.3 Design of Irrigation Scheduling and Data Collection

The field experiments were conducted during the period from July 1st, 1997 to July 28th, 1998, were Alfalfa crop was cultivated and a total of seventeen-crop cuttings were made. The total area of the site was 432 m^2 12 m by 36 m. The experiment was designed by using the Complete Randomized Block Design method where four different irrigation treatments (regimes) with three replications were considered.

The different agriculture and irrigation treatments were designed and followed continuously at every crop cut. Four irrigation treatments (I1, 12, 13 and 14) were followed to study the effect of irrigation frequency and soil-moisture stress on the crop water consumption and crop productivity. The other agriculture treatments were fixed during the experiments, *i.e.* fertilization, plant population, pesticides, cultivar, etc. The applied irrigation system was the surface flood (small basin) method. The basins area was divided into three replications; each had four basins with 5 m by 5 m dimension. Each replicate had four irrigation treatments (I1, I2, I3 and 14). The irrigation water delivery system was a PVC pipe network having 2-inch diameter, while the main pipe was a P.E. having 3-inch diameter. Different pipefitting and gate valves were allocated through the network to control the water flow (volume and time) into each basin. A flow meter, 2-inch inside diameter, was installed at the network inlet to measure the delivered water volume at each water application. At each replication, the four basins were irrigated by four pipe exits (P.E. pipes) having four gate valves.

The moisture depletion ratio method was applied for designing the irrigation scheduling and estimation of irrigation regimes. The method assumed a constant rate of water losses by evapotranspiration during the decided irrigation frequency, while the available water in soil was assumed as the main factor for scheduling process. Following this method, the total quantity of applied water for irrigation over the season was considered the same under the different irrigation treatments. Only, the frequency and the applied rate of irrigation water were the variables in the scheduling process.

Based on the depletion ratio method, four different irrigation treatments (frequency and application rate) were followed. The four considered irrigation frequencies were 1, 2, 4, and 6 days, respectively. The corresponding application water was calculated as the equivalent water depths (cm) for each irrigation interval (I1, I2, I3, and 14).

The steps for calculating the irrigation water treatment can be described as follows:

$$TAW = \frac{FC - WP}{100} \frac{B.D}{\rho_w} dr \tag{1}$$

Where, *TAW* is the total available water (cm) in soil-root depth (cm), *FC* and *WP* are the percentages of soil moisture at field capacity and at permanent wilting point (based on weight), *B.D.* and ρ_W are the soil bulk density and water density (gm/cm^3), and *dr* is the soil-root depth (cm).

The net water depth *Dn* (cm) required for irrigation can be calculated by knowing priori the irrigation frequency *f* (days) as follows:

$$Dn = f \ ETr \tag{2}$$

Where *ETr,* is the crop (reference) potential evapotranspiration (cm/day) during irrigation interval as shown in Table (1). The gross irrigation water depth D_g (cm) required for application at each irrigation frequency can be calculated by knowing the different irrigation water losses/or the farm irrigation efficiency E_a, as follows:

$$Dg = Dn / Ea \tag{3}$$

The corresponding depletion ratio *R* for each irrigation application can be calculated by using the following ratio:

$$R = Dn / TAW \tag{4}$$

The crop evapotranspiration, which was applied in these calculations, was calculated by using the modified FAO method for the Blaney and Criddle method and the climatic data of 1996 were applied for this calculation. The reference *ETr* of 1996 was applied in the irrigation scheduling calculation as shown in Table (1). An assumption was made for plant *ET* estimation is that the evapotranspiration during each crop-cutting interval (a fixed number of 20 days) was assumed constant. Then during each crop cutting, irrigation frequency, and water depths (net and gross) were considered for each irrigation treatment. The gross water depth D_g (cm) was converted to the total gross water volume (m^3) for each cultivated basin of irrigation treatment (5 m by 5m). The calculation was made for each crop cutting. The rooting depth *dr* was estimated from previous studies and experiments in the same experimental station, there was a gravel and boulder near the soil surface, blocking the extension of plant root downward.

TABLE 1. Daily evapotranspiration *ETr* (mm/day) of Hada Al-Sham Experimental Station (1996).

Day no.	Daily *ETr* (mm/day)											
	Jan.	Feb.	Mar.	Apr.	May	June	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
1	2.34	2.86	4.225	3.185	8.06	8.84	5.85	12.09	6.11	4.29	2.86	1.69
2	2.99	2.6	4.81	3.38	8.58	7.54	6.5	7.54	4.94	6.37	3.64	1.82
3	2.99	4.29	5.2	2.99	2.34	6.5	5.85	9.23	5.2	7.41	4.16	2.275
4	2.34	3.12	4.81	4.81	6.63	5.72	5.07	5.98	5.85	9.49	4.29	2.145
5	2.34	4.16	3.38	4.03	5.98	5.07	6.5	12.74	4.81	6.89	3.25	1.43
6	4.55	2.99	1.69	4.94	4.81	7.8	6.5	9.49	4.29	5.85	4.03	1.105
7	2.665	4.29	4.42	4.42	3.64	4.68	5.33	2.99	5.2	5.72	4.81	0.715
8	2.21	4.16	4.81	2.99	5.85	8.58	5.98	6.63	4.68	5.07	4.29	0.975
9	2.145	2.86	0.78	5.915	2.47	11.96	6.565	5.85	5.33	4.81	4.29	1.56
10	2.275	3.51	4.03	5.07	4.03	9.75	11.7	8.19	4.55	6.5	4.29	1.95
11	3.25	4.68	3.9	4.03	8.06	7.28	9.36	9.75	4.16	5.33	4.55	1.69
12	2.99	2.86	0.65	5.85	6.5	3.51	2.99	9.23	4.55	5.85	5.98	1.43
13	3.51	2.6	2.86	3.25	5.915	8.45	8.32	6.63	1.17	1.755	3.77	0.91
14	2.34	2.99	3.64	5.85	8.58	3.38	8.71	5.33	6.5	4.81	4.16	1.43
15	2.21	4.29	4.55	3.12	5.85	7.15	6.24	7.8	8.32	4.81	5.2	2.86
16	3.51	1.3	1.69	3.38	5.85	6.5	6.89	6.89	6.76	4.225	4.42	1.82
17	2.99	2.99	5.59	3.51	6.11	5.33	7.15	8.06	2.99	4.94	4.55	1.3
18	2.6	2.86	4.16	3.64	7.41	4.16	6.63	7.8	5.85	3.9	4.03	1.69
19	3.25	2.73	1.69	1.56	4.94	4.29	5.72	7.15	3.9	3.77	4.55	1.43
20	2.47	4.81	3.64	4.81	6.76	5.59	10.92	7.8	2.6	4.55	4.29	1.95
21	1.95	4.16	4.81	3.9	5.59	2.47	11.18	5.59	5.85	4.55	4.16	2.08
22	2.21	10.4	1.43	4.55	6.76	8.71	6.63	4.81	6.89	4.94	3.77	2.94
23	4.29	1.82	2.99	3.9	5.33	7.54	7.02	5.07	6.76	4.55	5.98	5.33
24	3.705	3.9	4.55	4.29	6.5	8.06	6.89	5.46	2.73	5.2	3.12	2.08
25	8.19	2.99	2.86	5.2	2.145	4.94	4.81	4.42	7.15	6.37	4.29	1.43
26	3.64	3.25	4.335	1.3	7.54	6.76	6.76	8.06	7.02	6.89	3.38	2.08
27	4.68	3.12	3.185	4.55	6.11	6.24	7.41	2.99	2.34	6.89	2.6	2.145
28	3.51	3.77	5.07	3.9	5.85	8.19	8.45	5.33	2.34	6.5	2.47	2.08
29	2.73	3.445	4.42	1.95	6.5	8.06	8.32	7.67	5.85	5.07	2.08	3.38
30	3.25		2.6	5.2	9.1	4.81	9.36	3.38	4.68	4.68	1.95	2.015
31	3.12		2.925		8.97		10.725	4.745		4.615		2.21

The depletion ratios corresponding to each irrigation treatments were calculated. The ratio varied from 5% to 13.8% for irrigation treatment I1, from 7% to 30% for irrigation treatment I2, from 15% to 59% for irrigation treatment 13, and from 22% to 89% for irrigation treatment 14. The average depletion ratios for the four irrigation treatments were, 9%, 18%, 36%, and 55% respectively.

2.4 Plant Growth and Yield Measurements

Different plant characteristics were measured during the growing season in order to calculate plant yields (fresh and dry), and evapotranspiration has been related to the crop growth and yield. The plant yield here however includes the fresh and dry weights of all plant after each plant cutting. Three-square meters planting area was collected during crop cutting of each irrigation treatment, where the fresh and dry weights of plant (kg/m^2), were measured. The three square meters were chosen randomly using a square wooden frame having 1 m by 1 m dimension and throw it randomly.

The actual water consumption by plant as *ETr* was calculated by using the water balance concept over the soil-water control volume corresponding to the soil-root zone. Continuous measurements (two times daily) for soil water content using the Neutron Probe device were made during the seasons. These soil water contents were applied as one component for the water balance equation where the exifiltrated water from soil as evapotranspiration was calculated assuming no water percolated downward. Then the actual water losses and evapotranspiration were calculated as the soil moisture stress changes corresponding to the four different depletion ratios in the irrigation treatments. The water use efficiency (WUE) and the irrigation use efficiency (IWUE) were calculated based on the crop yield production (fresh yield), plant ETr, and the irrigation water use. These efficiencies were calculated as follows:

$$WUE = \frac{\text{Fresh crop yield (kg/m}^2\text{)}}{\text{Evapotranspiration (m}^3\text{/m}^2\text{)}} = \frac{Yf}{ETr}\ (\text{kg/m}^3) \tag{5}$$

and

$$IWUE = \frac{\text{Fresh crop yield (kg/m}^2\text{)}}{\text{Irrigation Water Use (m}^3\text{/m}^2\text{)}} = \frac{Yf}{ETr}\ (\text{kg/m}^3) \tag{6}$$

2. Results and Analysis

The one-year experiments covered the four different seasons of the year for the period from July 1st, 1997 to July 28th, 1998. However, for better representation of the data, they were classified into summer and winter seasons and the different ststistical analysis were processed based on this classification. The analysis of variance for the summer and the winter seasons are shown in Tables (2) and (3), respectively, where the two factor analysis was followed by using the (SPSS) software package. The main effect factors in the analysis were the cutting number (CN) and the irrigation treatments (T). The dependent variables were the fresh yield (Yf), the dry yield (Yd), the evapotranspiration (ET), the irrigation water applied (W), the water use efficiency (WUE), and the irrigation water efficiency (IWUE). Two separated seasons analysis was followed in the analysis. Table (2) shows the analysis of variance for the whole summer season data, where all dependent variables (Yf, Yd, ET, W, WUE, and IWUE) and the different statistical parameters (sum of squares differences, degree of freedom, mean squares, f-value, and the level of significance are included). It can be noticed that cutting number (CN) has a significant effect on the ET, W, and IWUE (0.4%, 0.0%, and 1.1% respectively) but has no significant effect on the fresh and dry yield and water use efficiency (10.4%, 47.3%, 11.4%, respectively). The irrigation treatment (T) has a significant effect on the ET (7.5%), while does not affect significantly the other variables (Yf, Yd,W, WUI,and IWUE). Table (3) shows the analysis of variance for winter season, where the (CN) has a significant effect on all the dependent variables Yf, Yd, ET, W, WUE, and IWUE with values of 1.3%, 5%, 0.1%, 0.0%, 0.5%, and 0.0%, respectively. The irrigation treatment (T) has a signifcant effect on the ET, and WUE with values of (0.0%) for both of them, while has no significant effect on the other variables, Yf, Yd, W, and IWUE.

TABLE 2. Analysis of variance for all illustrated variables during summer.

Source	Dependent variable	Type III sum of squares	Df	Mean square	F	Sig.
Corrected model	YF	8999106.481	8	1124888.310	1.674	.136
	YD	17182.407	8	2147.801	.678	.708
	ET	15558.409	8	1944.801	3.537	.004
	W	47073.499	8	5884.187	41.151	.000
	WUE	418.531	8	52.316	1.487	1.194
	IWUE	1.62	8	2.026E-02	2.727	.017
Intercept	YF	84093425.926	1	84093425.926	125.150	.000
	YD	3787505.787	1	3787505.787	1196.048	.000
	ET	902188.404	1	902188.404	1640.964	.000
	W	1497795.354	1	1497795.354	10474.766	.000
	WUE	4785.844	1	4785.844	136.002	.000
	IWUE	1.763	1	1.763	237.281	.000

TABLE 2. Contd.

Source	Dependent variable	Type III sum of squares	Df	Mean square	F	Sig.
CN	YF	6631349.074	5	1326269.815	1.974	.104
	YD	14709.491	5	2941.898	.929	.473
	ET	11454.826	5	2290.965	4.167	.004
	W	47069.448	5	9413.890	65.836	.000
	WUE	337.273	5	67.455	1.917	.114
	IWUE	.128	5	2.560E-02	3.447	.011
T	YF	2367757.407	3	789252.469	1.175	.332
	YD	2472.917	3	824.306	.260	.854
	ET	4103.583	3	1367.861	2.488	.075
	W	4.051	3	1.350	.009	.999
	WUE	81.258	3	27.086	.770	.518
	IWUE	3.404E-02	3	1.135E-02	1.528	.223
Error	YF	26205667.593	39	671940.195		
	YD	123500.694	39	3166.684		
	ET	21441.874	39	549.792		
	W	5576.642	39	142.991		
	WUE	1372.394	39	35.190		
	IWUE	.290	39	7.428E-03		
Total	YF	119298200.000	48			
	YD	3928188.889	48			
	ET	939188.687	48			
	W	1550445.495	48			
	WUE	6576.768	48			
	IWUE	2.214	48			
Corrected total	YF	35204774.074	47			
	YD	140683.102	47			
	ET	37000.283	47			
	W	52650.141	47			
	WUE	1790.925	47			
	IWUE	.452	47			

T = treatment, Cn = cut number, YF = fresh yield, YD = dry yield, ET = Evapotranspiration, W = irrigation water applied, WUI = Water Use Efficiency, IWUE = Irrigation Water Use Efficiency.

TABLE 3. Analysis of variance for all illustrated variables during winter.

Source	Dependent variable	Type III sum of squares	Df	Mean square	F	Sig.
Corrected model	YF	612688.492	9	68076.499	2.467	0.22
	YD	62974.058	9	6997.118	2.106	.048
	ET	43105.860	9	4789.540	8.569	.000
	W	27385.975	9	3042.886	61.481	.000
	WUE	259.825	9	28.869	6.037	.000
	IWUE	.526	9	5.843E-02	22.274	.000
Intercept	YF	103958750.000	1	103958750.000	3768.055	.000
	YD	4099517.907	1	4099517.907	1233.971	.000
	ET	1044363.234	1	1044363.234	1868.585	.000
	W	498579.350	1	498579.350	10073.701	.000
	WUE	6236.977	1	6236.977	1304.323	.000
	IWUE	8.210	1	8.210	3129.550	.000
CN	YF	508819.444	6	84803.241	3.074	.013
	YD	45872.718	5	7645.453	2.301	.050
	ET	15472.057	6	2578.676	4.614	.001
	W	27228.080	6	4538.013	91.690	.000
	WUE	105.634	6	17.606	3.682	.005
	IWUE	.518	6	8.638E-02	32.926	.000
T	YF	103869.048	3	34623.016	1.225	.301
	YD	17101.339	3	5700.446	1.716	.177
	ET	27633.803	3	9211.268	16.481	.000
	W	157.895	3	52.632	1.063	.374
	WUE	154.191	3	51.397	10.749	.000
	IWUE	7.627E-03	3	2.542E-03	.969	.415
Error	YF	1269117.063	46	27589.501		
	YD	152821.925	46	3322.216		
	ET	25709.673	46	558.906		
	W	2276.686	46	49.493		
	WUE	219.962	46	4.782		
	IWUE	.121	46	2.624E-03		

TABLE 3. Contd.

Source	Dependent variable	Type III sum of squares	Df	Mean square	F	Sig.
Total	YF	105840555.556	56			
	YD	4315313.889	56			
	ET	1113178.766	56			
	W	528242.010	56			
	WUE	6716.764	56			
	IWUE	8.857	56			
Corrected total	YF	1881805.556	55			
	YD	215795.982	55			
	ET	68815.532	55			
	W	29662.660	55			
	WUE	479.787	55			
	IWUE	.647	55			

T = treatment, Cn = cut number, YF = fresh yield, YD = dry yield, ET = Evapotranspiration
W = irrigation water applied, WUI = Water Use Efficiency
IWUE = Irrigation Water Use Efficiency.

The best curve fitting among some of the dependents variables are represented from Figure (1) through Figure (4) for summer and winter seasons. As shown in Figure (1), the linear fitting is strongly recommended between the irrigation water and dry yield for summer season, where the coefficient of determination was 53.26%. Moreover, during winter season, Fig. (2) shows that the linear fitting between the W and Yd has a coefficient of determination reaching 20.4% which is relatively smaller than the summer fitting. Fig. (3), shows that the power fitting is the best fitting between the irrigation water and the wet yield where, the coefficient of determination was 23.9% during summer season whereas a coefficient of determination of 44.4% during winter time as shown in Figure (4).

4. Conclusions

It can be concluded that the actual water consumption as evapotranspiration is affected significantly by the irrigation treatments and the irrigation cutting numbers of alfalfa, where the same conditions were obtained for the applied irrigation water, while it differs significantly between irrigation cutting and treatments. The correlation coefficient was relatively low between the variables

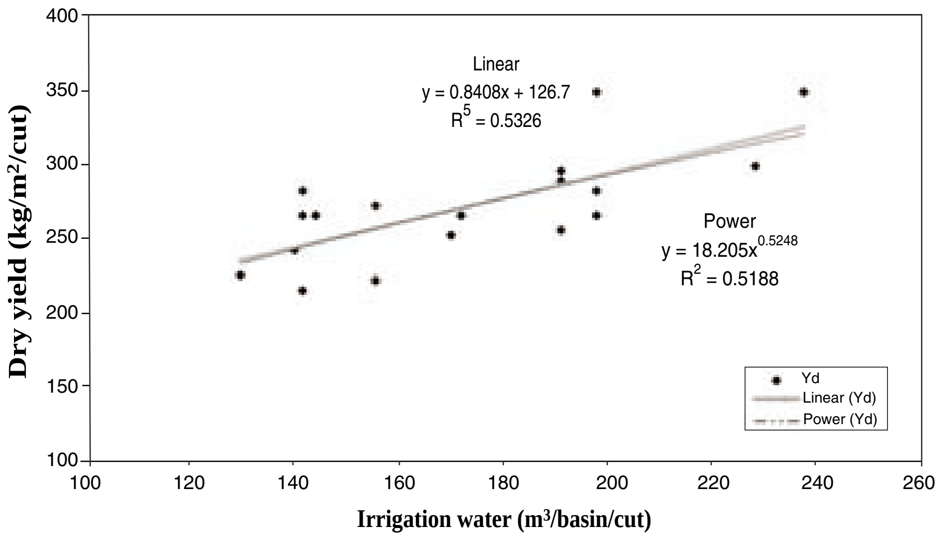

FIG. 1. Dry yield and irrigation water relationship during summer season.

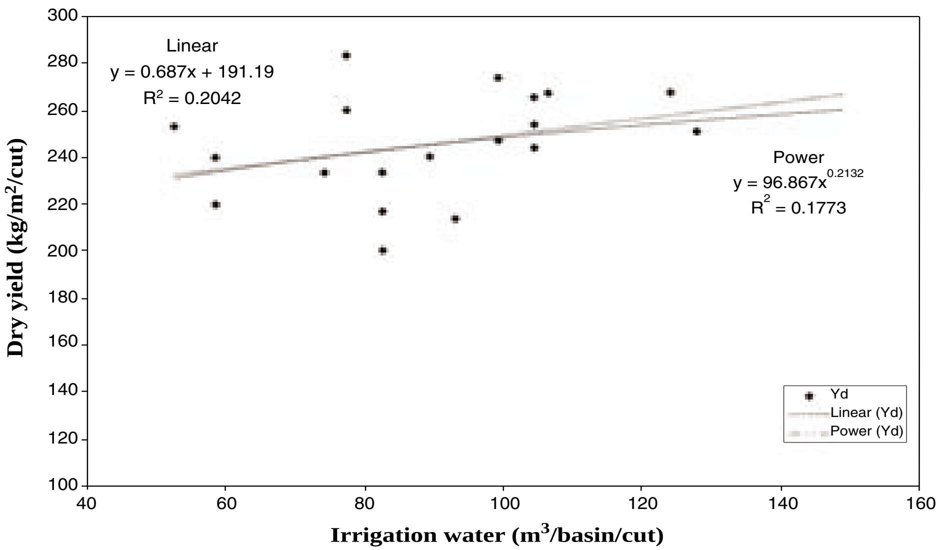

FIG. 2. Dry yield and irrigation water relationship during winter season.

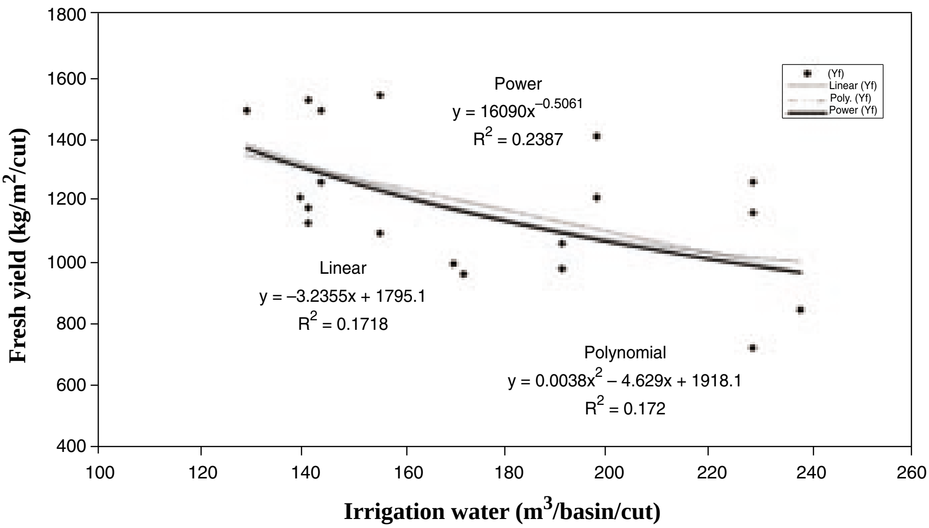

FIG. 3. Fresh yield and irrigation water relationship during summer season.

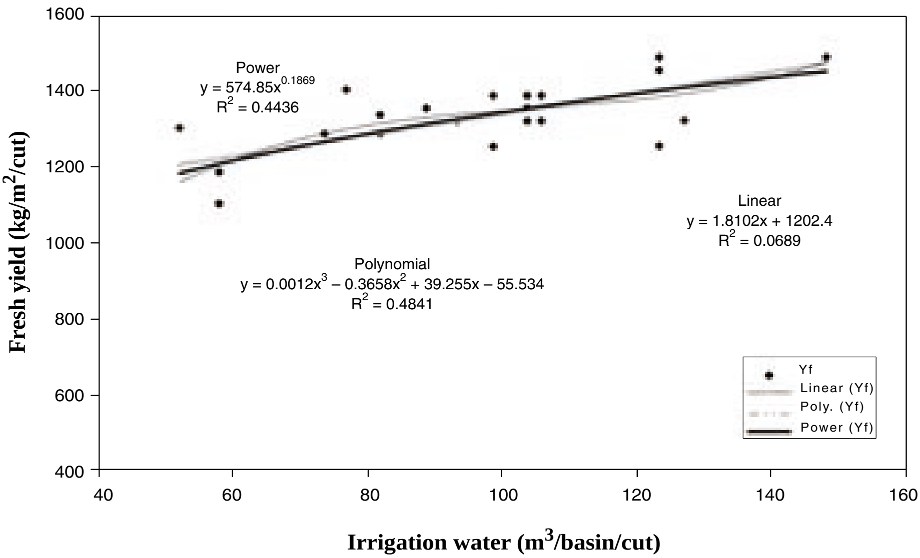

FIG. 4. Fresh yield and irrigation water relationship during winter season.

fresh yield, dry yield, ET, W, while the high correlation was between fresh and dry yield. The mathematical fitting failed to represent the relationship between the illustrative variables.

References

Aggarwal, P.K., Singh, A.K., Chaturvedi, G.S. and **Sinha, S.K.** (1986) Performance of wheat and triticale cultivars in a variable soil-water environment. II. Evapotranspiration, water use efficiency, harvest index and grain yield. *Field Crops Res*. **13:** 301-315.

Bos, M.G. (1980) Irrigation efficiencies at crop production level. *ICID Bull.* **29**(2): 18-25.

Fapohunda, H.O., Aina, P.O. and **Hossain, M.M.** (1984) Water use-yield relations for cowpea and maize. *Agric. Water Manage*. **9:** 219-224.

Howell, T.A. (2001) Enhancing water use efficiency in irrigated agriculture. *Agron. J.* **93:** 281-289.

Howell, T.A., Yazar, A., Schneider, A.D., Dusek, D.A. and **Copeland, K.S.** (1995) Yield and water use efficiency of corn in response to LEPA irrigation. *Trans. ASAE.* **38**(6): 1737-1747.

Jensen, M.E. (1983) *Design and operation of farm irrigation systems*. Chapter (6), ASAE, St. Joseph, MI49085. p. 218.

Keller, J. (1992) Implication of improving physical water use efficiency for agriculture water conservation, Paper Prepared For The Round-Table On Egyptian Water Policy, Sponsored By The Water Research Center (MPWWR), Egypt, Ford Foundation And Winrock International.

Kiwan, M.E. (1992) Estimated of the overall irrigation efficiency in Egypt. *Civil Eng. Scientific Magazine, Faculty of Eng., Al-Azhar Univ. Cairo*, **9:** 52-62.

Kiwan, M.E. and **Soliman, K.E.** (1993) Design of furrow irrigation system using simulation technique. *Journal of Eng., and Applied Science, Faculty of Eng., Cairo Univ., Cairo.* **4**(3): 1-18.

Li, Y.S. (1982) Evaluation of field soil moisture condition and the ways to improve crop water use efficiency in Weibei region. *J. Agron. Shaanxi Province* **2:** 1-8.

Martin, D.L., Watt, D.G. and **Gilleey, J.R.** (1984) Model and production function for irrigation management. *J. Irrigat. Drain. Eng.* **110**(2): 149-164.

Ministry of Water and Agriculture (2002) Agriculture Statistical Year Book. Fourteenth Issue. Riyadh, Saudi Arabia.

Musick, J.T., Jones, O.R., Stemart, B.A. and **Dusek, D.A.** (1994) Water-yield relationships for irrigated and dryland wheat in the US southern plains. *Agron. J.* **86:** 980-986.

Rosenberg, N.J., Blad, B.L. and **Verma, S.B.** (1983) *Microclimate: The Biological Environment.* John Wiley & Sons, p. 495.

Sayed, M.A., Attia, M.M. and **Osman, A.M.** (1996) Water consumption and water use efficiency for some of main crops grown at New Valley: I. Water consumption and water use efficiency for alfalfa at New Valley. Meteorology and Integrated Development Conference. pp. 79-85.

Sharma, P.N. and **Alonso Neto, F.B.** (1986) Water production function of sorghum for northeast Brazil. *Agric. Water Manage.* **11:** 169-180.

Stewart, J.I. and **Hagan, R.M.** (1973) Functions to predict effect of crop water deficits. *J. Irrigate. Drain. Div., Proc. ASCE,* **99 IR4:** 421-439.

العلاقة بين البخر – نتح المعياري والإنتاجية وكفاءة استخدام المياه لنبات البرسيم تحت معاملات ري مختلفة في المناخ الجاف

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المستخلص. إن العلاقة بين كمية المياه المستخدمة في الري واستهلاك النبات وإنتاجية المحصول مدار اهتمام الباحثين، خصوصاً في المناطق الجافة كالمملكة العربية السعودية حيث محدودية الموارد المائية. في هذه الدراسة تم إجراء تجارب حقلية لإيجاد العلاقة بين كمية المياه المستهلكة في عمليات الري لنبات البرسيم الحجازي (صنف حساوي) والإنتاجية الرطبة والجافة، وكذلك كفاءة الاستخدام لهذه المياه خلال موسمين مختلفين متتاليين، صيف عام ١٩٩٧م وشتاء عام ١٩٩٨م. ولتحقيق ذلك فقد استخدمت أربعة معاملات ري مختلفة بنسب استنزاف للمحتوى الرطوبي للتربة (٩٪، ١٨٪، ٣٦٪ و ٥٥٪ على التوالي) مع جدولة كمية المياه لكل معاملة من المعاملات المستخدمة لفترات ري (١، ٢، ٤، و ٦ أيام على التوالي) مع حساب كمية المياه المستخدمة لكل معاملة. خلال الموسم الزراعي تم أخذ سبعة عشر حشة، حيث تم إدراج هذه الحشات في التحاليل الإحصائية كعامل مؤثر في البخر–نتح و الإنتاجية للمحصول. أُجريت التحاليل الإحصائية وذلك باعتبار معاملات الري المختلفة وعدد الحشات كمؤثران أساسيان، بينما استخدم كمية البخر–نتح، وإنتاجية النبات (الرطب والجاف)، وكفاءة استخدام المياه كمتغيرات للدراسة. وقد بينت الدراسة وجود علاقة رياضية خطية قوية تربط بين إنتاجية المحصول الجاف وكمية المياه المستخدمة خلال موسم الصيف، بينما كانت هذه العلاقة ضعيفة نسبياً خلال موسم الشتاء. كما استنتجت الدراسة وجود علاقة رياضية خطية ضعيفة نسبيا خلال موسم الصيفً تربط بين الإنتاج الرطب للنبات و كمية المياه المستخدمة

بينما كانت هذه العلاقة متعددة الحدود من الدرجة الثانية ومنخفضة نسبياً في موسم الشتاء. كما بينت النتائج لموسم الصيف وجود تأثير معنوي لعدد الحشات على مقدار البخر-نتح ,وكمية المياه المستخدمة ,وكفاءة استخدام المياه، بينما في موسم الشتاء كان التأثير المعنوي قاصراً على مقدار البخر-نتح. من ناحية أخرى أظهرت التحليلات الإحصائية أن هناك تأثيراً معنوياً لعدد الحشات على كل المتغيرات، بينما معاملات الري كان لها تأثير معنوي على كمية المياه المستخدمة وكفاءة الري فقط.