WATER STRESS ON DIFFERENT GROWING STAGES FOR QUINOA (*Chenopodium quinoa willd*) AND ITS INFLEUNCE ON WATER REQUIRIMENTS AND YIELD

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ABSTRACT

A factorial experiment was conducted within split-split plot design with three replicates. Four genotypes seeds (Regalona, Q-37, KVL-SR2, and Q21) were planted in the sub plots while six water treatments distributed in the main plots. They were ordinary river irrigation (S0), stress at emergence (S1), branching (S2), at ear formation (S3), at flowering (S4), and at maturity (S5). Irrigation water was applied in the normal irrigation when 50-60% of the available water was depleted and one irrigation was omitted from the water stress treatments. Reference and actual evapotranspiration, pan evaporation, yield, crop coefficient, and water use efficiency were calculated. Mean irrigation requirement for the four genotypes based on irrigation scheduling was 230.8 mm, decreased by 14 and 17% under stress conditions of the drought tolerant stages. Grain yield ranged between 3.1 and 5 Mg ha^{-1} for water stress treatments compared to 5.6 and 4.2 mg. ha^{-1} for normal irrigation treatments. Genotype Q21 gave the highest yield and differed significantly from others. Field water use efficiency ranged between 1.6 to 1.1 kg m^{-3} and crop water use efficiency 1.38 to 2.22 kg m^{-3}. KVL-SR2 and Q21 showed the highest efficiency (1.87 kg m^{-3}). Results indicated that the stage of ear formation and flowering are the most tolerant to water stress. On the other hand, the branching, and maturity were critical stages with high reduction in yield under stress conditions.

Key word: irrigation scheduling, genotypes, deficit irrigation

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اثر الشد المائي اثناء مراحل نمو نبات الكينوا (*Chenopodium quinoa*) في الاحتياجات المائية والغلة

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المستخلص

نفذت تجربة عاملية خلال الموسم 2018 في محطة السكران التابعة لدائرة زراعة حديثة، باستعمال تصميم الألواح المنشقة-المنشقة بثلاث مكررات. زرعت بذور أربعة تراكيب وراثية من الكينوا (Regalona وQ-37 وQ-21 وKVL-SR2) في الألواح الثانوية بينما توزعت خمس معاملات للشد المائي مضافا اليها معاملة المقارنة على الألواح الرئيسة: بدون شد و شد مائي في كل من مرحلة البزوغ و التفرعات و الطور العجينيى والنضج على التتابع. يتم الري بعد نفاد50-60% من الماء الجاهز. بلغ متوسط متطلبات الري للتراكيب الوراثية الأربعة بناء على جدولة الري 230.8 مم، انخفضت المتطلبات بمقدار11 و17% تحت ظروف الشد المائي عند المراحل المتحملة للجفاف. بلغ متوسط الاستهلاك المائي الفعلي 2 و 212 مم انخفض بمقدار 17% تحت ظروف الشد المائي عند المراحل المتحملة للجفاف. تراوح حاصل الحبوب للتراكيب الوراثية الأربعة بين 3.1 و 5.0 لمعاملات الشد المائي مقارنة بـ 5.6 و 4.2 طن هكتار$^{-1}$ لمعاملات الري الاعتيادي مع ملاحظة ان التركيب الوراثي Q-21 أعطى أعلى حاصل حبوب. تراوحت كفاءة استعمال الماء الحقلي بين 1.6 و1.1 كغم م$^{-3}$ والمحصولي بين 1.38 و2.22 كغم م$^{-3}$. تشير هذه النتائج الى ان مرحلتي تكوين العرانيص و التزهير من أكثر مراحل نمو النبات تحملاً للشد المائي (نقص الري) في حين يمكن اعتبار مرحلتي التفرعات وامتلاء الحبة مرحلتين حرجتين يؤدي تعرضهما للشد المائي إلى نقصان شديد في حاصل الحبوب.

الكلمات المفتاحية: جدولة ري، تراكيب وراثية، ري ناقص.

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INTRODUCTION

Chenopodium quinoa Willd, which belongs to the amaranthaceae family, is a new crop of most consuming countries. As little information is available about it as in Iraq in terms of the impact of water stress on the water use efficiency, growth and production of this crop. This promising crops known to be resistant to apotic stresses such as drought (26) and salinity (41 and 28). It was found that quinoa plant can grow under high salt conditions similar to those of sea-water crops (10 and 27). It is also found that quinoa grows under a wide range of soil texture ranging from sandy to clay and within the soil pH range from 4.5 to 9. It belongs to a C3 plant (35). The need for this water varies depending on the planting season and the growth period of the plant. It is possible to survive depending on rainwater, but if it is planted during summer, crops need light irrigations, and salt water can be used (23). There have been several attempts by international organizations such as FAO, AOAD and regional organizations such as ICARDA and ICAD to develop solutions to water problems in the Arab region. Following the research, the survey identified three trends to bridge the gap between available water resources and demand: Development of water resources, rationalization of water consumption and hence the search for alternative freshwater resources. Water stress is one of the most important factors in the disruption of biochemical processes (37). where water stress at different stages of plant growth reduces the biological yield of the genotypes that vary in their water stress responses. Drought resistant varieties are described as having a high accumulation of dry matter during vegetative growth (31; 33 and 35). Chenopodium sp. belonged to a complex of two species (C. album and C. quinoa) grown in the Himalayan regions of Punjab, and more precisely at high altitudes (1700–2700 m) in the Ravi River basin, as well as higher up in Kashmir and Ladack. The plant was cultivated for its leaves and used as a pot herb, but these Chenopodium species were mainly grown for their grains, which were considered superior to buckwheat (20 45 and 36).Drought and salinity are common negative environmental factors that affect plant growth and determine the global geographic distribution of vegetation and restrict crop yields in agriculture (22; 18; 29; 30 and 47). Crop production in arid and semi-arid regions, including Iraq, can be improved by diversifying crop production and introducing new strains and varieties with stress tolerance such as *chenopodium quinoa Willd*, a tolerant plant with the potential to become an important crop in the regions And a growing global market (26 and 27). This is one of the major problems in Iraq as large areas are lost due to salinity and drought every year (48 Humphreys and Dawe). The wide variation in salinity tolerance in quinoa provides an excellent source of choice and education for high endurance. In this regard, a number of researchers (25 and 13 Humphreys and Dawe) indicate that the yield or reduction of water used can be increased by many of the means. There has been a major increase in irrigation and water productivity in the quinoa-rice system in Asia and Australia over the past decades as a result of improved varieties and better management of irrigation, nutrients, bush and wafers. In a report by the Food and Agriculture Organization of the United Nations (19), quinoa is considered an annual crop that favors short day and low temperatures. It includes groups of varieties adapted to various agro-ecological systems and climatic conditions, growing at temperatures between 4 ° C and 35 ° C and various altitudes starting at sea level.The aim of the research is to identify:(i) water requirements and water efficiencies of four quinoa genotypes (Regalona, Q-37, KVL-SR2 and Q21) under normal irrigation conditions and (ii) water stress at different stages of plant growth stages.

MATERIALS AND METHODS

Experimental site and soil characteristics

A field experiment was conducted on loam soil, to cultivate the quinoa crop (*Chenopodium quinoa* Willd) during the 2018 season, located in the research area of field Sakran station / Haditha agricultural station 240 km North West of Baghdad, the site located at latitude 35^{o} 340^{-} north and longitude 420^{o} 22^{-} west and 80 m above sea level. The prevailing soil was a loam texture and the soil was classified as typic turifluvents.The basic characteristics of the soil were determined by taking samples from three sites and the depths 0 - 0.10, 0.10 - 0.20, 0.20 - 0.40 and 0.40 - 0.60 m. Soil characteristics were estimated according to standard methods (4) (Black et al., 1965) (Table 1). soil samples were be used from different depth to determine soil moisture release curve at 0, 33, 100, 500, 1000 and 1500 kPa for samples taken from depths 0.10, 0.20, 0.30, 0.40 and 0.50 M. Soil available water content was calculated from difference in moisture content at 33 and 1500 kPa.

Table1. Some physical and chemical properties of soil

Property	Unit	value
Sand	**gm kg^{-1}**	**428**
Silt	**gm kg^{-1}**	**396**
Clay	**gm kg^{-1}**	**176**
Texture	**Loam**	**-**
Porosity	**51.36**	**cm^{-3}cm^{-3}**
Bulk density	**Mg kg^{-3}**	**1.26**
Particle density	**Mg kg^{-3}**	**2.59**
Organic matter	**gm kg^{-1}**	**14.72**
Electrical conductivity	**dSm^{-1}**	**0.9**
pH	**---**	**7.5**
CEC	**C mole kg^{-1}**	**0.28**
Volumetric moisture content at tensions		
KPa 33	**cm^{3} cm^{-3}**	**0.31**
KPa 100	**cm^{3} cm^{-3}**	**0.23**
KPa 500	**cm^{3} cm^{-3}**	**0.16**
KPa 1000	**cm^{3} cm^{-3}**	**0.12**
KPa 1500	**cm^{3} cm^{-3}**	**0.10**
Volumetric moisture content at %65 - 70depletion	**cm^{3} cm^{-3}**	**0.169**
Volumetric moisture content at %85-90depletion	**cm^{3} cm^{-3}**	**0.128**

Agricultural treatments

The soil was plowed two orthogonal plows with the plow-bearing plow and softening with the disk plough. The experimental layout consisted of a split plot design with three replicates. The first main factor was assigned to irrigation treatments, and the second sub-main factor was assigned to genotypes. The plots (2m x 1.2m each) were isolated by ditches of 1.5 m in width to avoid lateral movement of water. Two seeds were grown planting in holes 25 cm apart within the row. The seeds of four genotypes of Regalona, Q-37, KVL-SR2 and Q21 were planted in sub plots, which included eight lines per 2 m plot in length and 0.15 m between lines, on 2/1/2018. The seed rate was 120 kg ha^{-1}. Seed quantities were adjusted based on the weight of each grain. The urea fertilizer was added by 200 kg N ha^{-1} and with two equal, first time at planting and the second at the branching stage. Triple superphosphate fertilizer was added by 100 kg / p at planting. Weeds removed by hand as need. The plants were harvested on 25-5-2018.

S0: without stress (normal irrigation):
S1: water stress at emergence stage.
S2: water stress at branching stage
S2: water stress at branching stage
S3: water stress at earing stage
S4: water stress at flowering stage
S5: water stress at maturity stage

Irrigation treatments

The experiment included five water stress treatments in addition to (normal irrigation) distributed on the main plots as follows: Irrigation water was applied (Euphrates river water 0.9 dSm^{-1}) through a plastic pipe network connected to an electric pump and water meter to measure the quantities of water applied to each experimental plot, when 50-60% of the available water was depleted based on gravimetric method. A water depth of 73.3 mm was added before planting to create a water balance within the root area of depth 45 cm. A water depth equivalent to 42 mm was added after planting and all treatments for germination based on Equation 1 and soil moisture content.

$$d = (\theta_{fc} - \theta_{w})D.......(1)$$

Where d = depth of water applied (mm), θ_{fc} =Volumetric water content at field capacity (cm3 cm-3), θ_{w} = Volumetric water content before irrigation (cm^3 cm^{-3}), D = Soil depth to be wetted at irrigation (0.0-0.30 m). For the water stress treatments (S1-S5), irrigation water is usually applied until the growth stage is reached, in which the plants are exposed to water stress. The stages of plant growth were determined by the scale of (49). When the desired growth stage is reached after 66% of available water was depleted, the treatment is at the beginning of entry into the water-stress status. Monitoring soil moisture depletion and determination of soil water content continued by taking soil samples and at the point where 85-90% of available water depleted water depletion is reached, which corresponds to water stress of about 500 to 600 kPa ,is roughly equal to cutting one irrigation for each growth stage required compared to the S0 treatment (without cutting). The plants are irrigated by adding a quantity of water equal to these quantities of the. Thus, the sequence of the treatments is progressively exposed to stress starting from the branching growth stage (S1) until ripening stage (S5). As shown in table 1. The metrological data for Haditha station were used.

Table6. Metrological data for the experiment site during growth stages of quinoa

month	Air temperature			Relative humidity			Wind speed (Average)	sun radiation
	max	Min	Average	Max	Min	Average		
February	17.3	1.8	9.6	78.1	23.1	50.6	4.89986	15.3
March	23.4	10.09	16.74	84.76	27.05	55.90	5.967871	17.64
April	30.27	13.74	22.00	71.07	19.04	45.05	5.60988	24.34
May	37.59	19.86	28.73	45.55	10.40	27.98	3.274839	26.69

Water consumptive use (evaporation) of the crop was measured using the following water balance equation:

$$(\boldsymbol{I}+\boldsymbol{P}+\boldsymbol{C})-(\boldsymbol{ET_a}+\boldsymbol{D}+\boldsymbol{R}) = \mp\Delta\boldsymbol{s}\ldots\ldots.(\boldsymbol{2})$$

I=irrigation (mm)

P=precipitation (mm)

C= capillaries (mm)
ET_a= actual evapotranspiration (mm)

D= deep percolation (mm)

R=rune off (mm)
ΔS= changes in the water storage during soil profile
R=0 (plain soil)

C=0 (limited contribution , water table depth= 3m)

D=0 (because irrigation is limited to depletion at field capacity)

Equation 2 becomes:

$$I+P-ET_a=\pm\Delta s\ldots\ldots..(3)$$

In this study, the soil water content at the beginning of the study was found to be close to its content at the end of the experiment, ie, D ≈ 0

The water balance equation becomes as follows:

$$I+P=ET_a\ldots\ldots\ldots\ldots\ldots(4)$$

Penman-Monteith equation was used, based on the CROPWAT (45 Smith) software, to estimate ET_o (2 Allen).

$$ET_o=\frac{0.408(R_n-G)+\gamma\frac{900}{T+273}U(e_a-e_d)}{\Delta+\gamma(1+0.34U)}$$

ET_o = \4reference evapotranspiration [mm day^{-1}],

R_n =net radiation at the crop surface [MJ m^{-2} day^{-1}],

G =soil heat flux density [MJ m^{-2} day^{-1}],

T =mean daily air temperature at 2 m height [°C],

u_2 =wind speed at 2 m height [m s^{-1}],

e_s =saturation vapour pressure [kPa],

e_a =actual vapour pressure [kPa],

e_s - e_a =saturation vapour pressure deficit [kPa],

D= slope vapour pressure curve [kPa $°C^{-1}$],

g =psychrometric constant [kPa $°C^{-1}$].

The reference evapotranspiration provides a standard to which:

1. Evapotranspiration at different periods of the year or in other regions can be compared;
2. Evapotranspiration of other crops can be related.

The measured solar radiation values (Rs) should be used if available or local calibration method should be used also to estimate RS. Evaporation from class-A pan was used crop coefficient (K_c) and water use efficiencies (field and crop) were determined (9)(Carcium, and Cracium, 1996):

$$WUE_f = \frac{GY}{WA} \dots\dots\dots\dots(7)$$

Where WUE_f=field water use efficiency, GY= total grain yield (Kg m^{-3}), WA=water applied(m3 ha^{-1}).

$$WUE_C = \frac{GY}{ET_a} \dots\dots..(8)$$

Where WUE_c=crop water use efficiency, ET_a=actual evapotranspiration (mm).

Crop coefficient was determined according the following equation:

$$ET_a = (k_c)(ET_o) \dots.(9)$$

Where: k_c=crop coefficient, ET_o=reference ,evapotranspiration (mm)

Data analysis

Data were statistically analyzed using the Gen-stat software, and the least significant difference (LSD) ($p \leq 0.05$) was used (45) (steel and Torrie 1980).

RESULTS AND DISCUSSION

Actual and reference evapotranspiration, water use efficiency and crop coefficient

Water consumptive use (actual evaporation) of quinoa

The result showed (Table 2) that the highest water consumptive use (ETa) of 397mm was obtained by control treatment (without stress) for Q-37 genotype, while the lowest water consumptive use was for the KVL-SR2 genotype (309 mm) and an increase by 22%. The genotypes gave varying averages for actual water consumptive use values when exposed to water stress in the growth stages corresponding to 347.8, 315.2, 315.2 and 270 mm for Q-37, Regalona, KVL-SR2 and Q21 ', respectively. The variation in the water consumption rates of the genotypes is due to the fact that the quantities of irrigation water added to the control treatment were higher than the treatments exposed to irrigation cuttings and close to the field capacity, the genotype susceptibility and efficiency of extracting higher quantities of groundwater, differences in growth time and dry matter (1); (32) ;(22) ;(26); (27) ;(39). This makes quinoa suitable for growth in arid and semi-arid regions where farmers can rely on monsoon rains (4).

Table2. Actual water consumption (ETa) and added irrigation quantities for quinoa as influenced by water stresses.

	Actual evapotranspiration and irrigation water applied(mm)						
	Water stress treatments						
genotypes	S0	S1	S2	S3	S4	S5	average
	ETa(irrigation water + precipitation)						
Regalona	353	315	304	295	304	320	315.2
Q-37	397	349	341	324	331	345	347.8
KVL-SR2	309	273	267	254	253	267	270.5
Q21	353	315	304	295	304	320	315.2
average	353	313	304	292	298	313	312.2
	irrigation water						
Regalona	258	242	224	217	220	242	233.8
Q-37	274	257	265	256	264	272	264.5
KVL-SR2	222	204	183	171	180	190	191.3
Q21	258	242	224	217	220	241	233.7
Mean	253	236	224	215	221	236	230.8

(42 Siddique ; 17 Ehdaie) pointed a positive correlation between total water used and total dry matter with the number of days required to mature under normal irrigation conditions. Water stress at various stages of growth reduced the amount of water added and actual water consumption (ET_a) for quinoa genotypes compared to the S0 treatment (without stress). The actual water consumptive use reduction percentage for water stress treatments ranged from 11 to 17% for the control treatment. Actual plant consumptive use of water

increased as growth progressed under normal irrigation conditions (S0) (Table 3 and 4). The water consumption values were very low at the beginning of the growth stage (from emergence to the beginning of the branching) due to the lack of plant need for water because of the low growth rates in these stages, the small size of the plant, limited surface area and low evaporation rates due to low temperatures and high humidity due to rain. Water consumption increased gradually in the branching stage (S2), and ear stage (S3) as the temperature started to rise and the effective growth of the plants began to increase, the growth and expansion of leaves and stems, increasing depth of roots throughout the soil and the accumulation of dry matter (50 and 51). The highest water consumption of the crop is achieved at ear stage due to the arrival of the plants to the maximum surface area and the increased need of the plant to build more nutrients to meet the requirements of flowering, seeds formation and transporting the carbohydrates towards the grain (8 and 38).

Table 3. Actual and reference evapotranspiration for quinoa under water stress

irrigation number	Date of irrigation	irrigation interval	irrigation water	ETa I + P (mm)	ETa day (mm)	ETo (PM) (mm)	E_{pan} (mm)	ET(Doorenbos and pruitt) (mm)	$Kc_{(PM)}$	Kc_{pan}
Comparative treatment Without stress (S0)										
1	2-1	20	8	16	0.8	2.04	2.30	2.1	0.39	0.35
2	22-1	39	19	40	1.03	1.51	2.67	2.47	0.68	0.39
3	2-3	31	33.0	50	1.60	2.19	3.13	3.63	0.73	0.51
4	21-3	19	55.3	61	3.21	3.73	5.61	3.75	0.86	0.57
5	5-4	15	49.6	55	3.70	3.74	6.31	5.75	0.99	0.59
6	17-4	12	36.0	40	3.3	4.24	6.61	6.7	0.78	0.50
7	4-5	17	21.2	53	3.12	4.81	7.36	6.05	0.65	0.42
8	1-6	28	30.5	38	1.36	6.32	9.41	8.81	0.22	0.14
Water stress at emergence stage(S1)										
1	2-1	59	8.5	16	0.27	1.48	2.54	0.79	0.18	0.11
2	2-3	31	19.3	50	1.6	2.19	3.13	0.78	0.73	0.51
3	21-3	19	61.3	61	3.2	3.73	5.61	1.29	0.86	0.57
4	5-4	15	49.6	55	3.7	3.74	6.31	1.54	0.99	0.59
5	17-4	12	38.0	40	3.3	4.24	6.61	1.77	0.78	0.50
6	5-4	17	23.3	53	3.12	4.81	7.36	2.05	0.65	0.42
7	1-6	28	36.3	38	1.38	6.32	9.41	2.81	0.22	0.15
Water stress at branching stage (S2)										
1	2-1	20	8.5	16	0.8	1.43	2.30	0.89	0.56	0.35
2	22-1	70	7.3	41	0.59	1.81	2.88	0.73	0.68	0.20
3	21-3	19	61.3	61	3.2	3.73	5.61	1.29	0.35	0.57
4	5-4	15	49.6	55	3.7	3.74	6.31	1.54	0.99	0.59
5	17-4	12	38.0	40	3.3	4.24	6.61	1.77	0.78	0.50
6	4-5	17	23.3	53	3.12	4.81	7.36	2.05	0.65	0.42
7	1-6	28	36.3	38	1.36	6.32	9.41	2.81	0.22	0.14
Water stress at earing stage (S3)										
1	2-1	20	8.7	16	0.8	1.43	2.30	0.89	0.56	0.35
2	22-1	39	21.8	40	1.03	1.51	2.67	0.70	0.68	0.39
3	2-3	50	37.8	50	1	2.66	4.07	1.04	0.38	0.25
4	5-4	15	49.6	55	3.7	3.74	6.31	1.54	0.99	0.59
5	17-4	12	38.0	40	3.3	4.24	6.61	1.77	0.78	0.50
6	4-5	17	23.3	53	3.12	4.81	7.36	2.05	0.65	0.42
7	1-6	28	36.3	38	1.36	6.32	9.41	2.81	0.22	0.14
Water stress at flowering stage (S4)										
1	2-1	20	8.5	16	0.8	1.43	2.30	0.89	0.56	0.35
2	22-1	39	21.8	40	1.03	1.51	2.67	0.70	0.68	0.39
3	2-3	31	38.5	50	1.61	2.19	3.13	0.78	0.74	0.25
4	21-3	34	54.9	61	1.8	3.79	6.17	1.41	0.47	0.59
5	17-4	12	38.0	40	3.3	4.24	6.61	1.77	0.78	0.50
6	4-5	17	23.3	53	3.12	4.81	7.36	2.05	0.65	0.42
7	1-6	28	36.3	38	1.36	6.32	9.41	2.81	0.22	0.14
Water stress at maturity stage (S5)										
1	2-1	20	8.5	16	0.8	1.43	2.30	0.89	0.56	0.35
2	22-1	39	21.8	40	1.03	1.51	2.67	0.70	0.68	0.39
3	2-3	31	38.5	50	1.61	2.19	3.13	0.78	0.74	0.51
4	21-3	19	61.3	61	3.21	3.73	5.61	1.29	0.86	0.57
5	5-4	27	46.6	55	2.04	4.81	7.06	1.65	0.42	0.29
6	4-5	17	23.3	53	3.12	4.81	7.36	2.05	0.65	0.42
7	1-6	28	36.3	38	1.35	6.32	9.41	2.81	0.21	0.14

The increase in temperature, increasing evaporation rates, hot winds and low humidity in the atmosphere all contribute to increasing the water consumption of the crop as it progresses towards maturity as well as increase the water availability in the root zone of the quinoa plant, which is reflected in the water absorption rates from the root area.

Evaporation rates from soil surface. These results are in harmony with what (32 Jensen) , who noted that the availability of soil water depends on the type of soil, the amount of water available and the requirements of daily evaporation or evaporation effort, which controls the maximum rate of water extraction. Consumptive use values was decreased from flowering stage to maturity stage because of the low demand for water by the plant for the completion of the tissue and decreasing of green surface area and dry a high proportion of the parts of the plant and accelerate towards full maturity, full coverage of the soil surface by the crop reduces the evaporation rates and decreases the water requirement of the crop in late stages The water consumption of Quinoa was reduced during exposure to water stress at various stages of growth due to the decrease in soil moisture and the lowering of available water for the plant (Table 2 and 3). The length of time required to reach the required stress level is determined as the plant progresses in the growth stages. This depends on the moisture depletion of the soil associated with the water consumption of the crop, which depends on the characteristics of growth and climatic conditions. This explains the increased demand for Water in the advanced stages of plant life, which are critical stages that cause damage to the crop when exposed to water stress for a long time (40; 46; 48).

Comparison of actual evapotranspiration reference and evaporation from class-A pan

Figure 1 shows that evaporation values from the class-A pan (EP) are significantly higher than the actual evapotranspiration values (ETa), reference evaporation (ET_o) and evapotranspiration calculated by (14 and 15), with a difference in primary values. This difference increases as the growth stage progresses. The values for no without stress treatment were 5.43 mm for E_{pan}, 3.57 mm ET_o and 4.91 mm, respectively. The high values of Ep are due to the calculated values of the metrological data that the evaporation process can occur without interruption during daylight hours and night due to the effects of weather condition like solar radiation, which equip the water molecules with the energy needed to convert the liquid to vapor and wind, which removes the saturated layer and replace dry layer. As well as sensitive heat, relative humidity and heat transfer across the sides of the pan that affect the energy balance (12 and 42). The values of ETD and ET_o are related to temperature as well as light hours as the process of transpiration during daylight hours is under the influence of solar radiation. at night, the stomata of the plant are closed, reducing water consumption or stopping it. The ET_o values of the Penman-Montieth equation have similarly to the actual evapotranspiration values of the quinoa yield, although they were slightly higher than the actual evaporation values (Fig. 1). ET_o increased with the growth stages and approached to ETa at flowering and maturity stages was higher in the early stages. This may be due to the low values of aerodynamic resistance (ra) and rc resistance values during these stages in the modified Penman-Montieth equation (2 and 3 Allen). The values of evapotranspiration were estimated by (15). The results showed the similarly trend to the ETa values of the increase in the progress of the growing stages but were generally lower and the differences remained clear between them.

Grain yield and crop and field water use efficiency:

The results showed that the grain yield ranged from 3.1 to 5.0 for the four genotypes and for water stress treatments compared with 5.6 and 5.1 ton ha^{-1} for normal irrigation treatments, noting that Q21 gave the highest grain yield and was significantly different from other varieties under normal irrigation conditions (Table 4).

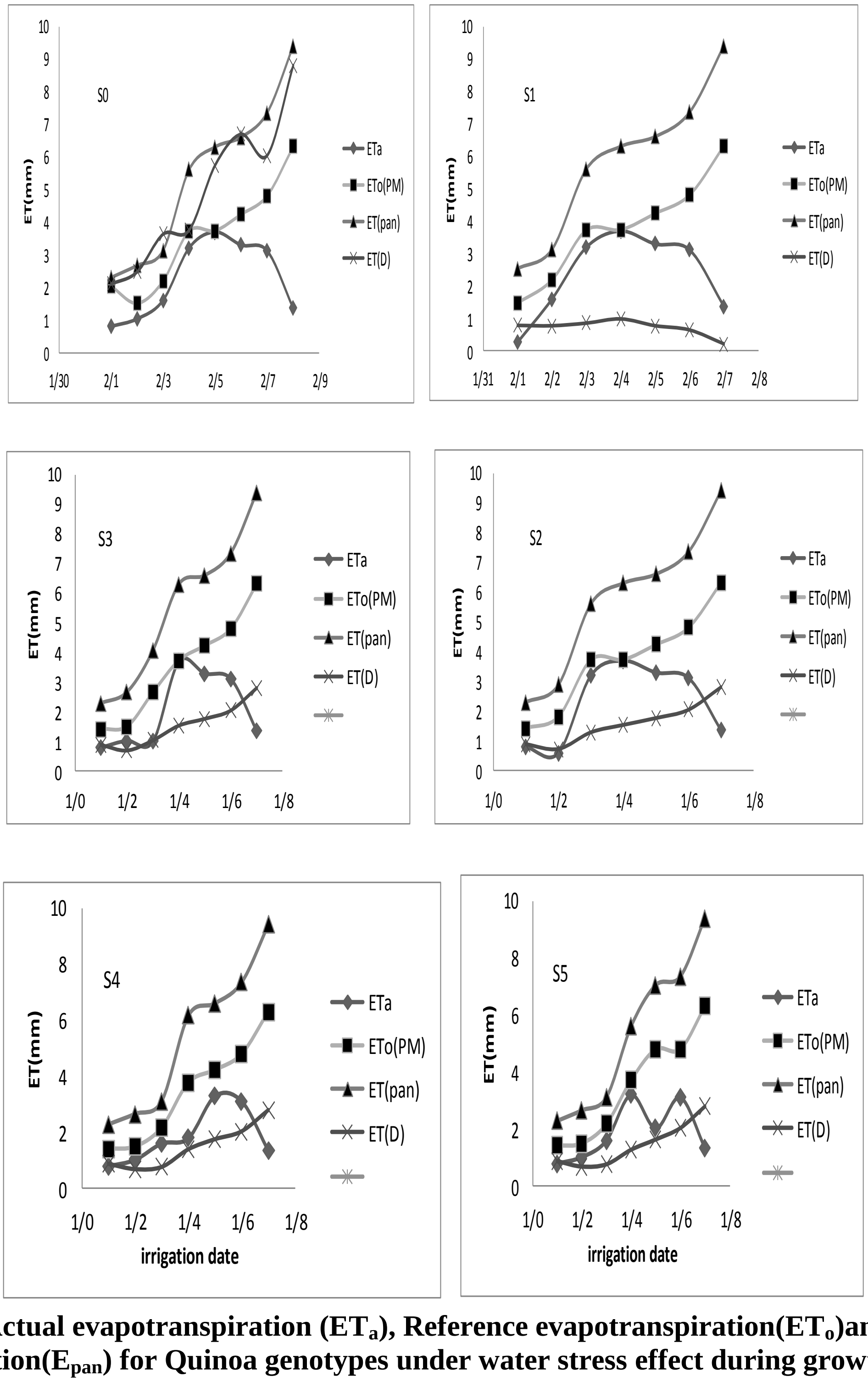

Fig1.Actual evapotranspiration (ET_a), Reference evapotranspiration(ET_o)and Pan evaporation(E_{pan}) for Quinoa genotypes under water stress effect during growth stages

Table4. Grain yield, field water use efficiency and crop water use efficiency for quinoa genotypes under water stress

genotype	Grain yield and water use efficiency						
	Water stress treatments						
	S0	S1	S2	S3	S4	S5	Average
	Grain yield (t ha^{-1})						
REGALONA	4.2	3.1	3.0	3.99	4.0	3.4	3.62
Q-37	4.4	3.5	3.3	3.6	3.99	3.1	3.65
KVL-SRA2	5.1	4.1	3.8	4.3	4.4	3.8	4.25
Q21	5.6	4.7	4.2	4.7	5.0	3.7	4.65
Average	4.8	3.85	3.85	4.15	4.35	3.5	4.04
$LSD_{0.05}$	genotype (0.3) ‹water stress (0.3) ‹genotype × water stress (0.8)						
	field water use efficiency (kg m^{-3} water)						
REGALONA	1.33	1.01	1.02	1.31	1.25	1.1	1.17
Q-37	1.26	1.03	1.02	1.09	1.16	0.9	1.1
KVL-SRA2	1.87	1.54	1.50	1.70	1.65	1.4	1.6
Q52	1.87	1.55	1.42	1.55	1.65	1.16	1.5
Average	1.56	1.28	1.24	1.41	1.14	1.14	1.3
$LSD_{0.05}$	genotype (0.06) ‹water stress (0.07) ‹genotype × water stress (0.22)						
	Crop water use efficiency (kg m^{-3} water)						
REGALONA	1.63	1.28	1.34	1.84	1.40	1.55	1.55
Q-37	1.61	1.36	1.25	1.51	1.14	1.38	1.38
KVL-SRA2	1.65	2.01	2.08	2.44	2.0	2.22	2.22
Q21	1.58	1.94	1.88	2.27	1.54	1.99	1.99
Average	1.61	165	1.63	2.01	1.52	1.79	179
$LSD_{0.05}$	genotype (0.02) ‹water stress (0.04) ‹genotype × water stress (0.19)						

The results also indicate that water stress caused a significant decrease in grain yield and in all growth stages ranged from 9 to 27%. The lowest average grain yield was 3.5 t ha^{-1} for the water-stress treatment at the grain filling stage (S5) and 3.85 T. ha^{-1} for water stress treatment in both S1 and S2. The lowest effect of water stress which was imposed at flowering stage (S4). This treatment showed clear tolerance of water stress (irrigation cut) compared to other treatments. On the other hand the treatment (S5) showed the lowest yield of 3.5 t ha^{-1}. The decrease is due to the fact that water stress has affected one or more of the components of the crop, depending on the stage of growth. The water stress reduced the number of inflorescences and the expansion of the total vegetative, which led to the lack of light exposure, reduce the rate of photosynthesis and thus decrease the amount of accumulated dry matter. A significant interaction was found between quinoa genotypes and water stress treatments (Table 4). Regalona and Q-37 were found to be the lowest in grain yield production for the most water stress treatments. The largest decrease was observed by 18-21% with the two genotypes at both S2 and S5 stages. On the other hand, KVL-SR2 and Q21 gave the largest decrease by 20 and 21% respectively at S2 stage, and 22, 28% at S5 stage. Significant interaction was found between quinoa genotypes and water stress treatments (Table 4). Regalona and Q-37 gave the lowest seed yield at most of water stress treatments. The largest decrease by 18-21% was observed with the two genotypes at S2 and S5 stages. On the other hand, the largest decrease of KVL-SR2 and Q21 yield by 20 and 21% at S2, 22 respectively was observed. The results indicated a significant difference between quinoa genotypes and field water use efficiency (WUE) and crop water use efficiency (WUEc). WUEF ranged between 1.87 and 0.9 kg m^{-3} and WUEc between 1.14 and 2.44 kg m^{-3} (Table 4). The difference in the efficiency of the genotypes in both of water use efficiency is due to differences in the duration of growth, amount of water used by the plants, amount of dry matter produced and the transfer of part of the total dry matter in plants towards grains, which is directly associated with water use efficiency (1 and 17). (11 Cooper) and (21 French) note that 30-60% of the water supplied to soil in dry areas is lost by evaporation and that the efficiency of water intake is defined as the plant's total ability to absorb water from the soil to reduce evaporation. Roots, early growth and plant shading (plant cover) are worthy of consideration as values of adaptation in arid and semi-arid regions. The less evaporation from the soil, the greater the water is readies for the plant and the more efficient the transpiration, which increases the rate of net representation to the water lost from the plant (37). Significant differences were observed between the quinoa genotypes in field water use efficiency under normal irrigation as well as under water stress treatments (Table 4). KVL-SR2 and Q21 showed the highest efficiency (1.87 t ha^{-1}) under normal irrigation followed by Regalona and Q-37. At the same time, KVL-SR2 showed the highest efficiency under water stress compared to the other genotypes until reached 1.70 t ha^{-1} at (S3) stage. It is appropriate to note here that water stress reduced the efficiency of half of the water stressors while it was raised in the other half or was equal to it. There was an increase in the efficiency of the Regalona genotype or maintained the same values at S2, S3 and S4 stages , and for Q21 genotype at S4 stage and for KVL-SR2 at S2, S3 and S4 stages and for Q21 at S3 and S4 . These results indicated that the ear stage formation (S3) and Flowering stages (S4) , the most advanced stages of plant growth are tolerant to water stress (lack of irrigation) in the crop water use efficiency and this was reflected in the increase in the efficiency of water use, by 2.01 and 2.22 kg -3, respectively. This attributed to that the all yield components treatments were not affected by the water stress , so that the compensation situation did not lead to a significant reduction in the grain quantity in relation to the amount of water used, WUE consider substantial factor for return under stress circumstances and even a component of drought tolerance for crops. It is used to denote the plant’s production that grow under rain conditions and can be increased by the water unit used, resulting in "more crops per drop” (6; 7 and 16). Field water efficiency values were generally similar to field water efficiency values, both for genotypes and stress treatments, but less in quantity because they represent the ratio of yield to actual evapotranspiration. Field water efficiency values were generally similar to field water use efficiency values, both for genotypes and stress treatments, but less in quantity because they represent the percentage of yield to actual evapotranspiration.

Crop coefficient

The high crop coefficient (Kc) was observed with the development of the stages of growth to maturity calculated according to the modified Penman Montieth equation and evaporation from the class pan-A (Table 3 and Figure 2). There was a reduction in crop coefficient values in the latter stages of the plant life cycle due to the completion of its growth and maturity. Water stress has also reduced crop coefficient values. It is noted that the crop coefficient decreases more when plants are exposed to water stress and as the stages of growth progress. The highest decrease in crop coefficient was obtained when the plants were exposed to water stress at flowering stage (S4). This confirms the increase in the actual water consumptive use values in these stages (34). A difference was observed in the trend of the These values are consistent with the values found by (15 Doorenbos and Kassam) and (42 Siddique), who stated that the Kc is low in the first stages of growth and gradually increases until it reaches the maximum in the intermediate stages of crop life and then decreases as the crop approaches maturity.

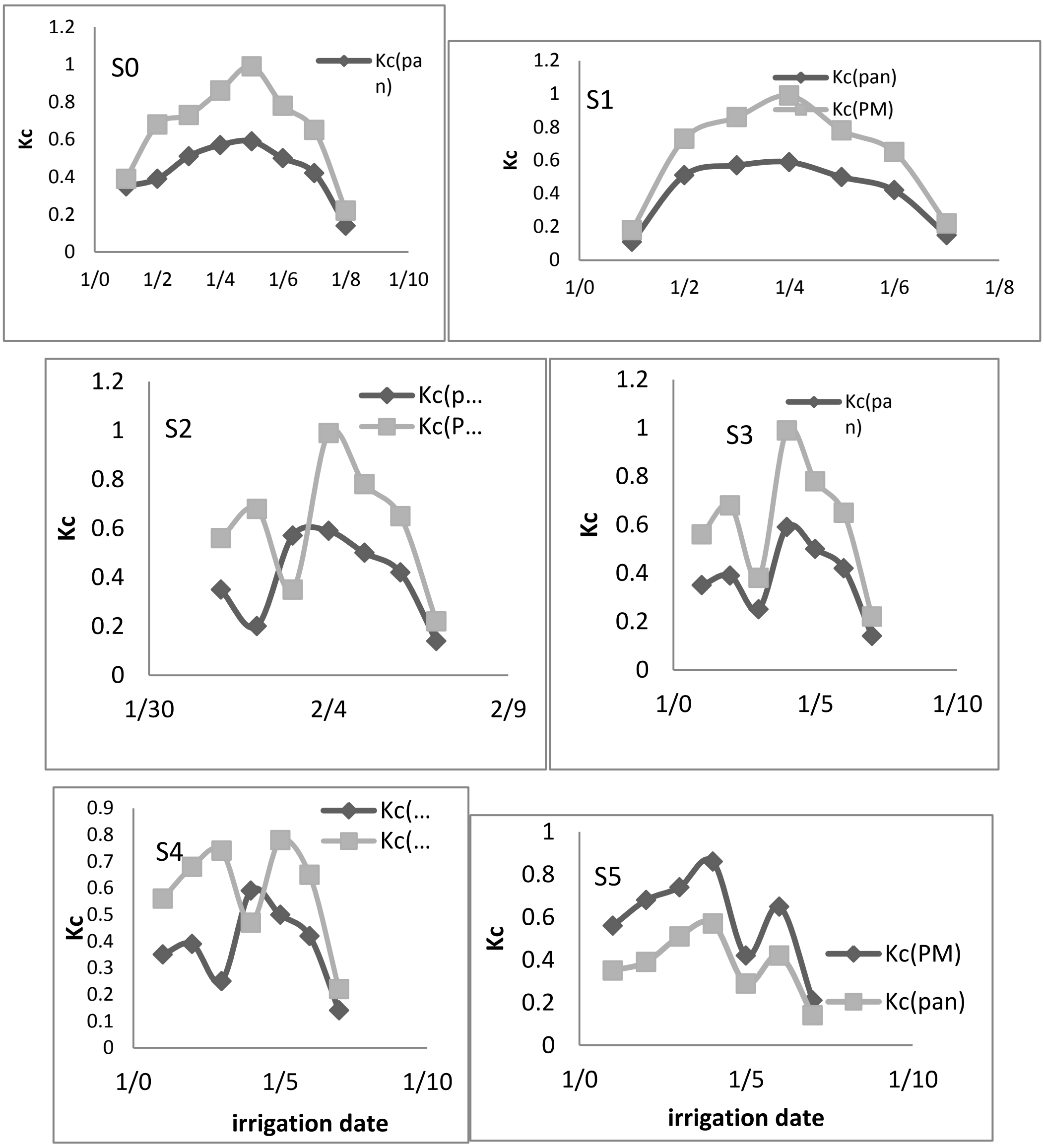

Fig2.Quinoa crop coefficient under water stress treatments during growth stages

(15 Doorenbos and Pruitt) noted that the values of the yield coefficient Kc were related to crop evapotranspiration of disease-free and growing in large fields under soil moisture conditions and optimum fertilization status and gave full production in the conditions of the growth environment. The results shown in Table 5 show the comparison between the reference evapotranspiration (ET_O) and the estimated three different methods compared to the actual ETa estimated by the water balance method during the quinoa growth season.

Table5. Comparison between ET_o and ET estimated by other methods

ET	ET , mm day^{-1}	ET_o \ ET_a
ET_a	**2.27**	**----**
ET estimated by evaporation pan	**5.43**	**2.39**
ET estimated by(15)	**4.91**	**2.16**
ET estimated by(43)	**3.57**	**1.57**

The same table shows that the daily reference evaporation values which estimated by, (15 Doorenbos and Pruitt) (1971) and (14 FAO Penman-montith methods) were 5.43, 4.91 and 3.57 mm day^{-1}, respectively. The estimated value by (44 FAO Penman-montith) (3.57 mm day^{-1}) was closest to daily evaporation (2.27 mm day^{-1})$^{)}$. However, the lowest (ETo / Eta) (1.57 mm day^{-1}) was obtained when evaporation was estimated by (43). We conclude that this method is the most efficient way to schedule the irrigation of the quinoa crop under the conditions of the planting area. These results are consistent with the results obtained by al-Hadithi (2002). These results indicate the validity of the (43 modified Penman-Montieth equation) in estimating the water requirements of quinoa genotypes under the western region of Iraq. For example, (24 GuoDong) found that the Penman-Monteith equation is the best of eight equations that have been tested to determine the water requirements of many Agricultural crops

Conclusions :

1. The average irrigation requirements was 295mm for the four genotypes (Regalona, Q-37, KVL-SR2 and Q21) based on irrigation scheduling of 295 mm, decreased by 11 and 17% under water stress conditions at drought-tolerant stages. While the average actual water consumption was 253 mm decreased by 17% under water stress conditions at the drought tolerant stages 2. The number of irrigations approached to eight in complete irrigation treatment (no stress), and was reduced to seven regard to the water stress treatments

3. The quinoa growing stages (branching, ear formation and maturity stages) were affected by different degrees under water stress condition. The two branching (S2) and maturity stages (S5) can be considered as two critical stages, whose exposure to the water stress causes a severe decrease in grain yield

4. The ear formation (S3) and the flowering (S4) stages were considered of the two tolerant stages of water stress (lack of irrigation). Quinoa genotypes showed clear differences in water requirements, water use efficiency and water stress response. KVL-SR2 is the most efficient genotype of water use, but it is sensitive to water stress in the maturity stage and to some extent in the branching

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