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RESEARCH ARTICLE **(Open Access)**

The effect of different levels and stages of low irrigation on some morphological traits of amaranth cv. Koniz (*Amaranthus hypochindriacus* L.× *Amaranthus hybridus* L.)

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Abstract

Drought is one of the most stressful environmental factors that strongly influence the growth and yield of crops. However, the plant's response to this stress differs depending on the stage of its growth. The present study set out to investigate the effect of different levels of low irrigation regimes (irrigation after 50, 80, 110, 140 and 170 mm evaporation from pan A) in different growth stages (plant establishment, branching, flowering and grain filling). The results of the study showed that irrigation after 170 mm evaporation of pan following the plant establishment, branching, flowering and grain filling, caused biomass reduction by 8%, 27%, 43% and 53%, respectively. Irrigation levels after 80, 110, 140 and 170 mm evaporation from pan led to the reduction of yield by 12%, 22%, 33% and 45% compared to the irrigation after 50 mm evaporation from the pan. In case of stress per delay time of irrigation based on evaporation from the evaporation pan, the grain yield decreased by 3.03 units. Results showed that applying low levels of irrigation before pollination leads to further reduction of the yield; so that the stress in the stages of plant establishment, branching, and flowering reduced the yield by 34, 27 and 22% compared to the irrigation after 50 mm evaporation from pan.

Key words: Amaranth, Growth stage, Low irrigation, Morphological traits

1. Introduction

Amaranth is a C_4 plant whose plantation is increasing day by day [11]. Amaranth seeds are brightly colored (Amaranth seeds are light in color), but the pigweed seeds are black. The main seed-producing species of this plant are *Amaranthus hypochon, A. Cruentus* and *A. caudatus*, in which the morphological characteristics of flowers and florets are also distinct [2]. In recent years, Amaranth, due to its high nutritional value, has attracted considerable attention. Proteins of the seed of this plant contain high amounts of essential amino acids, especially lysine, which exists in lower amounts in other plants [6, 24]. Plant growth is controlled by several factors of which water plays an important role. A small decrease in the amount of available water in the plant slows down the photosynthetic and metabolic processes [8].

Due to the high cost of animal proteins, herbal proteins will serve as a good protein source. Legume seeds contain high amounts of protein but low amounts of sulfur containing amino acids. Amaranth seeds are very good sources of such amino acids [30]. Specialists regard this plant as one of the most important plants of the twentieth century, and the US Academy of Sciences has included it among 36 significant herbal species in the world [33, 22]. Depending on the type of crop, the yield reduction under the influence of non-biological stress-causing factors *(abiotic stressful conditions)*, will be between 50 and 80 % [28]. Drought is one of the production limiting factors in dry areas. In fact, many researchers believe that the amount of water used on by plants determines plant growth and development [19]. Drought can lead to a significant reduction or even complete loss in the yield. In addition, it can negatively affect the quality of the products [14]. Drought decreases the availability of water for plants, thus reducing the production potential of crops, forests and prairies. The shortage of rainfall in dry years affects the crop yield in rain fed and dry land situations. Crops in irrigated conditions feel only a relative dryness in some months when the rainfall is below a certain threshold. In dry conditions, in which the plant meets its water need from rainfall, drought can exert a terribly negative effect on crops [29]. Rapid germination of crop seeds is one of the important factors that affect the success of farming under dry conditions. In many crops, germination and

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growth of seedlings are stages sensitive to drought stress. Drought could delay germination and slow down the germination rate. It could also reduce the growth and yield of the crops [27]. Slabbert and Van den Heever [31], in their study on Amaranth's resistance to drought reported different degrees of resistance between amaranth varieties. Plant varieties had different mechanisms at the cellular, developmental, and biochemical levels. Yarnia *et al.* [34] reported that early sowing dates with low density and high irrigation levels increased growth period and reduced competition, so increased production potential of Amaranth.

The present study set out to investigate the effect of different levels of low irrigation regimes in different growth stages of amaranth.

2. Material and Methods

A Split plot experiment based on randomized complete block design with three replications was conducted during the growing season of 2010-2011 at the Agricultural Research Station of the Islamic Azad University, Tabriz Branch located at 38° 3′ N and 46° 27′ E, 1360 meters altitude in North West of Iran with amaranth cv. Koniz (*Amaranthus hypochindriacus* L.× *Amaranthus hybridus* L.). Variables included irrigation levels (after 50, 80, 110, 140 and 170 mm evaporation from class A pan) and different growth stages (establishment, branching, flowering and grain filling), respectively. Distance of sub plots was two no planting row and distance of main plots was three no planting rows and distance of replication was two meters. This study had 45 plots and each plot had five rows with 50 cm distance. Annual rainfall and temperature and maximum temperature were 8.1mm, 11.1^{oC}, 41.2 ^{oC}, respectively. To determine available soil nutrients, samples were taken from 0- 30 cm depth. Based on the results of soil analysis, 300 kg/ha urea, 100 kg/ha triple super phosphate and 150 kg/ha potassium sulfate were applied to soil as the starter fertilizer prior to planting. Soil pH is poor alkaline and with no salinity risk (Table 1).

Table 1: Physicochemical analysis for soil in 0-30 cm depth

Soil texture	clay	silt	sand	Absorptive potassium (P.P.M)	Absorptive phosphor (P.P.M)	Total nitrogen (%T.N)	(%) O.C	TNV (%)	pH	Electrical Conductivity EC*10^3
Sandy lomy	12%	21%	67%	194	53.22	0.215	0.94	17.25	7.87	1.84

When the plants were at 2-4 and 6-8 leaf stages, thinning and nitrogen top dressing were performed. No pesticide accomplished for nonexistence of pests and specific disease in field. Weeding and weed control accomplished in equal manner duration growth season. Irrigation accomplished basis on evaporation of class A pan [13]. First, farm irrigation times required to canopy growth applied based on regional climate conditions without water stress, but after shoot growth beginning irrigation treatments were applied. After ripening by mid November, an area of 2.5 m^2 from middle line of plot area was separately harvested and height, leaf number, shoot number, panicle number, panicle length, stem and leaf dry weight, biomass, grain number per plant and yield were evaluated. MSTAT-C and EXCEL were used to data normal test, analyze the data and draw graphs, respectively. Duncan multi range comparison test in p<5% probability used for comparing means.

3. Results and Discussion

ANOVA analysis showed that different levels of irrigation had a significant effect on all the traits except the plant height at 1% probability level. The Effect of irrigation stage on all the traits was also significant at 1% probability level. The Effect of irrigation levels*stages on leaf number, panicle number, and biomass was significant at 1% probability level (Table 2).

Plant height

The results showed that the stress time had a significant effect on Amaranth plant's height. The most reduction in plant height was observed after drought stress application at plant establishment (Table 3). Germination is a major stage involved in the process of the plant establishment [32]. Plants experience high levels of risk during the seedling phase. This is why this stage is critical to the development of the plant's reproductive phase [3]. Considering the importance of this stage in the plant yield, any factor distorting the plant growth at this stage will have a major impact on the development traits. Since seedlings that are weak at the early stages of growth lose the chance of competing or the ability to tap resources [5].

Leaf number

The results showed that irrigation after 50 and 80 mm evaporation from the evaporation pan did not have a significant effect on the leaf number. But with the increasing severity of water stress, the number of leaves significantly reduced. In irrigation following 110 mm from evaporation pan, only exerting stress after seedling establishment produced a significant effect on the number of leaves, causing a 16% decrease in the number of leaves compared to the irrigation after 50 mm evaporation from pan. Irrigation after 140 mm evaporation from the basin following the plant establishment and branching brought about a reduction in the leaf number by 31 and 37% respectively compared to the irrigation after 50 mm evaporation from pan. Irrigation after 170 mm evaporation from pan in the plant establishment, outset of branching and flowering gave rise to a decrease in the leaf number by 32, 46 and 59 percent respectively compared to the irrigation after 50 mm evaporation from pan. Thus, the exertion of low-irrigation stress following the evaporation from 50 to 170 mm in the grain filling stage did not have a significant effect on leaf number. However, drought stress at other growth stages resulted in a significant reduction in the number of leaves. A simple linear regression equation showed that per delay time based on the increase per mm of irrigation based on evaporation from evaporation pan, the stress caused reduction in the leaf number by 0.093 units in the plant establishment phase, 0.069 units in the branching stage, and in the flowering stage 0.05 units in the flowering stage (**Figure 1**).

Table 2: Analysis of variance of different treatments of Amaranth

S.o.V	*Df*	*MS*										
		Plant height	**Leaf number**	**branch number**	**Panicle number**	**Panicle length**	**Stem dry weight**	**Leaf dry weight**	**Panicle dry weight**	**Biomass**	**Grain number**	**Grain yield**
Replication	2	34.98^{ns}	2.81^{ns}	1.33 ^{ns}	0.08 ^{ns}	1.30 ^{ns}	5.9 ^{ns}	1.87 ^{ns}	3.05 ns	1.12 ^{ns}	549012 ^{ns}	4.7 ^{ns}
Irrig level	4	435.39 ^{ns}	89.35**	2.66**	12.59**	581.1**	184.6**	173.01**	173.01**	1429.2**	23818525^{ns}	277**
Error A	8	136.85	2.18	0.52	0.04	29.21	10.45	10.71	10.71	8.7	3022031	24
Irrig stage	3	406.83**	72.81**	3.38**	5.79**	326.6**	105.8**	78.84**	78.84**	767.9**	13631444**	134**
Irri × stage	12	139.61^{ns}	10.01**	0.95 ^{ns}	0.83**	43.89 ^{ns}	25.53 ^{ns}	11.44 ^{ns}	11.44 ns	134.11**	2034094 ^{ns}	140**
Error	30	118.03	2.89	0.68	0.018	68.81	19.78	7.80	7.80	2.27	3263552	22
CV%		13.86	10.61	23.24	3.95	18.58	11.85	15.74	15.74	2.19	22.43	**22.58**

ns: non significant   * : P<0.05   ** : P<0.01

Researchers reported that drought could reduce leaf meristema activity, and reduction of the leaf meristema activity will result in the reduction of the number of leaves [**25**]. Drought stress could reduce the number of leaves at the beginning stages of growth by affecting the emergence of leaves. Drought can also reduce the number of leaves through accelerating the aging and falling of leaves [**14**].

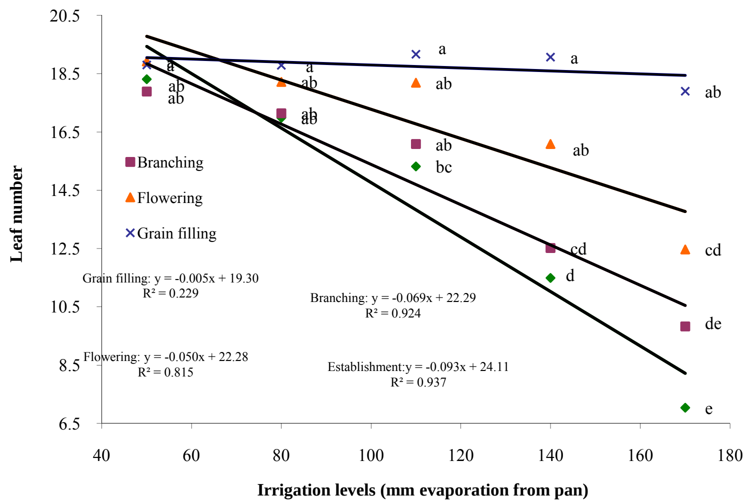

Figure 1: Effect of irrigation levels in different growth stages of amaranth on leaf number

Branch number

The number of branches was reduced as a result of the level of irrigation after 170 mm evaporation from the evaporation pan. Irrigation after 170 mm evaporation from evaporation pan reduced the number of branches by 30 percent compared to the level of irrigation after 50 mm evaporation from pan. Simple linear regression showed that in case of exerting stress per delay time of irrigation based on the increase of every mm of evaporation from pan, the number of branches will be reduced by 0.009 units (**Figure 2**).

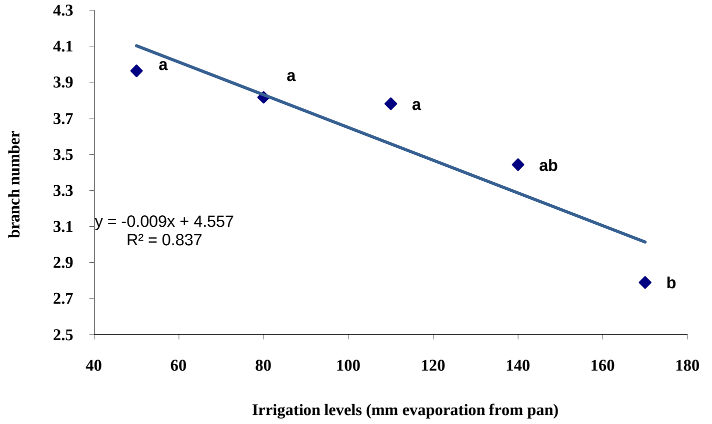

Figure 2: Effect of irrigation levels on leaf number of amaranth

At the early stages of the growth of crops, due to the strong effect of Auxin hormone of the terminal bud, the growth of the main stem is more than that of lateral shoots. However, due to the increase of cytokinin with age, the effect of auxin hormone wears off and the lateral buds begin to become active [**4**]. Thus, cytokinin has an important role in the formation of side branches, The tissues with high amounts of cytokinin are good sources for getting assimilates which promote more growth and development [**20**]. Research has shown that the amount and activity of this hormone decreases by drought [**7**]. Asch et al. [**1**] reported that brancing depends on the presence of assimilates, and drought reduces the amount of assimilates.The result showed that of different times of stress, only the stress after the plant establishment led to the reduction of the number of branches (Table 3), because it is at the early stages of crops' growth that it becomes possible to specify the number of branches [**4**].

Number of panicle

All the irrigation levels led to a significant reduction in the number of panicles. The most reduction in the number panicles belongs to the level of irrigation after 170 mm evaporation from pan. At this level of irrigation, stress in the plant establishment and branching stages resulted in 71% and 83% decrease in the number of panicles respectively. Simple linear regression showed that per delay time of irrigation based on the increase of each mm of evaporation from the evaporation pan, the number of panicles was cut by 0.967 units at the plant establishment phase and 0.0.845 units at the branching phase (**Figure 3**). There are reports that shortage of nitrogen due to drought might restrict the transfer of carbon and nitrogen compounds to buds [**17**]. Consequently, shortage of nitrogen and carbon compounds could halt the growth of new panicles and lead to the reduction in the number of panicles [**12**]. Pantuwan et al. [**23**] reported that in different cultivars of rice, drought before flowering delayed flowering, and delayed flowering had a nehative relationship with the percentage of fertile panilcles.

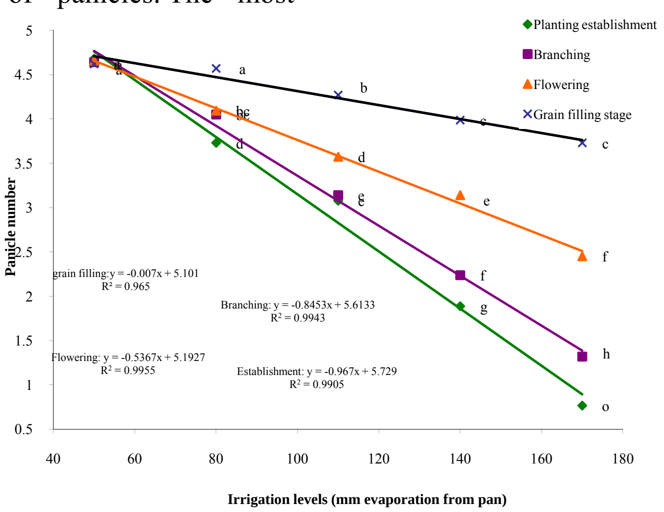

Figure 3: Effect of irrigation levels in different growth stages of amaranth on panicle number

Panicle length

The irrigation levels after 110, 140 and 170 mm evaporation from the evaporation pan reduced the Panicle length by 12%, 22% and 33%. The Regression equation showed that in case of stress per delay time of irrigation based on the increase of each mm of evaporation from the evaporation pan, the panicle length decreased by 0.145 units (**Figure 4**).

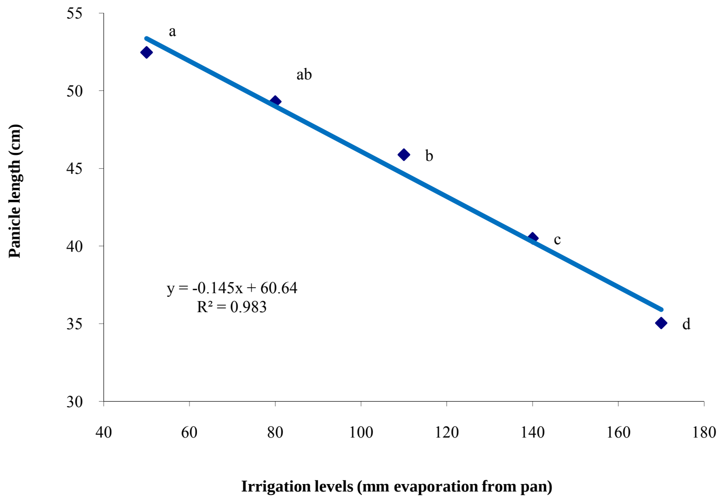

Figure 4: Effect of irrigation levels on panicle length of amaranth

Kgang et al. [**16**] also reported the reduction of panicle length because of drought. Physiologically, water shortage cuts cell division and elongation at all dimensions since firstly the hydraulic force of water which is effective in cell growth lessens and secondly cell walls get thicker [**18**]. Stress at the outset branching and after the plant establishment showed a significant reduction compared to that of the grain-filling stage. Implementing low irrigation at the outset of branching and after crop establishment caused a 23% reduction compared to the emergence of stress from the stage of grain filling (Table 3).

Dry weight

Low levels of irrigation led to a significant reduction in dry weight of all the components of Amaranth. Irrigation level after 140 mm and 170 mm evaporation from the evaporation pan caused 14% and 24% decrease in the dry weight of stem respectively. The linear regression equation showed that in case of stress per delay time of irrigation based on the increase of every mm of evaporation from pan, the stem loses 0.078 units of its dry weight. The exertion of stress at the outset of branching and after crop establishment brought about reduction in the shoot's dry weight by 12% and 15%, respectively compared to exertion of stress at the beginning of the grain filling stage (**Figure 5**).

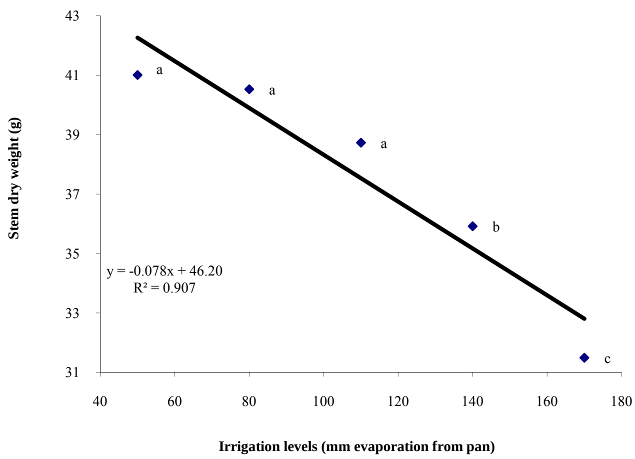

Figure 5: Effect of irrigation levels on stem dry weight of amaranth

Also, the increase of the dehydration stress at every stage of the growth of Amaranth reduced the dry weight of the leaves. This reduction was significant at all stages except the outset of the grain filling stage. At the irrigation level following 110 mm evaporation from pan, exerting stress after the establishment of the seedlings and growth of the stem had a significant effect on the number of leaves. These treatments led to the reduction of the leaves' dry weight by 28% and 29%, respectively compared with the irrigation level after 50 mm evaporation from pan. Irrigation after 140 mm evaporation from the evaporation pan following the plant establishment, branching and flowering reduced the dry weight of the leaves by 28%, 45% and 51%, respectively in comparison with the irrigation after 50 mm evaporation from the evaporation pan. In the irrigation after 170 mm evaporation from the basin, the start of stress at the plant establishment stage and the outset of branching and flowering brought about reduction in the number of leaves by 38%, 63%, and 73%, respectively compared to the irrigation after 50 mm evaporation basin. Linear regression showed that in case of stress per delay time of irrigation based on the increase of each mm evaporation from the evaporation pan, the leaves lost its dry weight by 0.109 units at the stage of plant establishment, 0.086 units at the branching stage, and 0.058 units at the flowering stage (**Figure 6**).

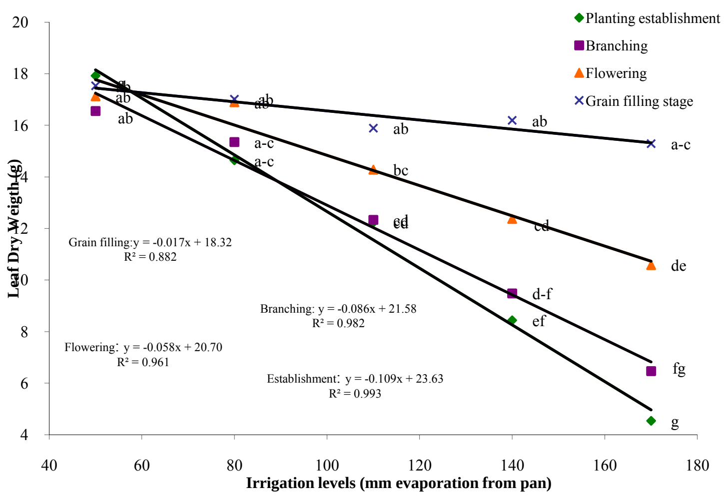

Figure 6: Effect of irrigation levels in different growth stages of amaranth on leaf dry weight

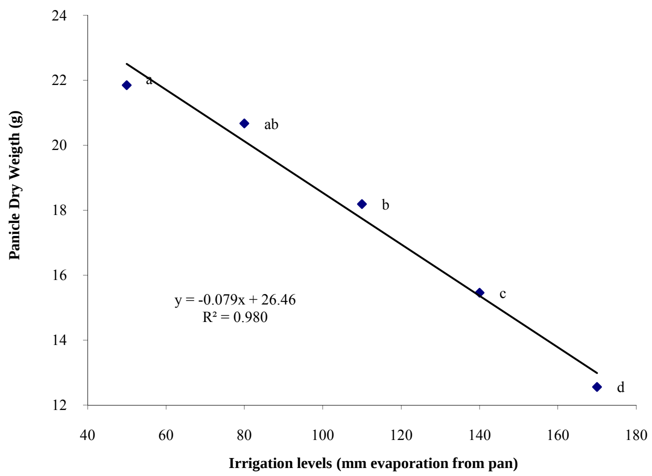

Figure 7: Effect of irrigation levels on panicle dry weight of amaranth

Researchers have reported that drought can contribute to the reduction of the number and growth of leaves, since plants with fewer and smaller leaves and with a greater ratio of root to shoot are more resistant to drought [**26**]. The irrigation levels after 110, 140 and 170 mm evaporation from pan brought about the reduction of Panicles dry weight by 16, 36, and 42 percent. The linear regression equation showed that in case of stress per delay time lag of irrigation based on the increase of each mm. of evaporation from the evaporation pan, the panicles lost their dry weight by 0.079 units. Exerting stress at the outset of branching stage and after the plant establishment led to a reduction by 26 and 29 percent compared with the start of stress from the grain filling stage (**Figure 7**).

Biomass

The results showed that increase in the intensity of the dehydration stress at all the stages of growth led to a significant reduction of the biomass of Amaranth. Irrigation after 80 mm evaporation from pan caused a significant decrease in the biomass. At the irrigation level following 80 mm evaporation from the evaporation pan, exerting stress after the plant establishment and the outset of branching caused reduction by 4 and 7 percent respectively. In the irrigation after 110 mm evaporation from the evaporation pan, exerting stress after the plant establishment and at the beginning of branching and flowering resulted in a reduction by 8, 16, and 18 percent respectively. In the irrigation after 140 mm evaporation from pan, exerting stress after the plant establishment and at the outset of flowering and branching led to a reduction by 16, 30 and 33 percent respectively. In the irrigation after 170 mm evaporation from pan, exerting stress after the plant settlement and at the outset of flowering and branching, and the grain filing stage gave rise to a reduction in biomass by 8, 27, 43, and 53 percent respectively compared to the irrigation after 50 mm. evaporation from pan (Figure 8). Therefore, at low intensity levels of dehydration, the stress affects the biomass only at the early stages of growth, but at high intensity levels of low irrigation, the stress could affect the final stages of growth and development, too. This is probably because roots are of lesser depth and cover a lesser area of soil at the early stages of growth [**21**]. Another reason is that the plants were greatly affected by the stress to which they had been exposed a long time since its beginning. The linear regression equation indicated that in case of dehydration stress per delay time of irrigation based on the increase of each mm. evaporation from the evaporation pan, the amount of biomass decreased by 0.37 units at the stage of plant establishment, 0.294 units at the branching stage, 0.19 units at the flowering stage, and 0.05 units at the time of grain filling (**Figure 8**). Stress exerted at the stages prior to flowering will greatly affect the dry weight of the crop components. An analysis of the changes of the dry weight of the components of this plant showed that delaying the start of stress can reduce its effect on the dry matter accumulation in Amaranth.

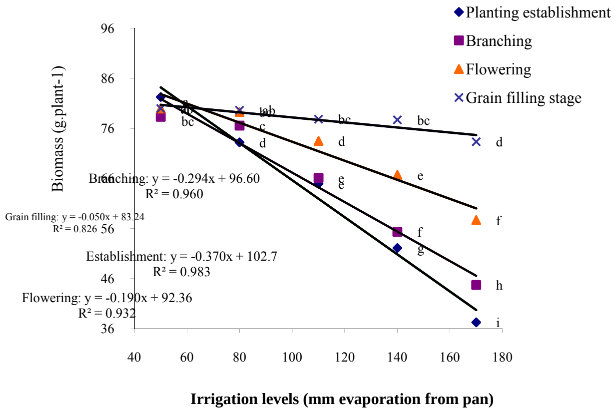

Figure 8: Effect of irrigation levels in different growth stages of amaranth on biomass

Grain number

The increase of the stress intensity to any extent significantly reduced the grain producing ability of Amaranth. Irrigation levels after 80, 110, 140 and 170 mm evaporation from pan reduced the number of grains by 10%, 16%, 27% and 36% respectively compared to the control. The Regression equation also showed that in case of stress per delay time of irrigation based on the increase of each mm. of evaporation from the evaporation pan, the number of seeds will decrease by 889.2 units. Drought and the reduction of nitrogen uptake lead to the reduction of crops' reproductive parts as well as the number of seeds [**9**]. Stress in the plant settlement and the outset of branching and flowering caused a significant decrease in the number of grains by 27%, 22%, and 14%, respectively (Table 3).

Grain Yield

All levels of low-irrigation stress led to a significant decrease in the grain yield of Amaranth so that the irrigation levels after 80, 110, 140 and 170 mm evaporation from pan caused a reduction by 12, 22, 33 and 45 percent in the yield compared to the irrigation after 50 mm evaporation from pan.

Accordingly, based on Regression equation, in case of stress per delay time of irrigation based the increase of each mm of evaporation from pan, 2.006 units of grain yield was reduced per unit of area at the stage of plant establishment, 2.099 units at the branching stage, 1.524 units at the flowering stage, and 1.105 units at the time of grain filling (**Figure 9**). Photosynthesis rate is considerably reduced during drought. In the field conditions, the decrease of stomata conduction is the most important contributor to this reduction [**10**]. Low irrigation levels before pollination caused more reduction in the yield so that the exertion of stress after the plant establishment, branching and flowering reduced the yield by 34%, 27% and 22% compared to the stress at the grain filling stage (**Figure 9**). Jørgensena *et al*. [**15**] refer to crops' reproductive stage as the most critical period in their response to the drought stress.

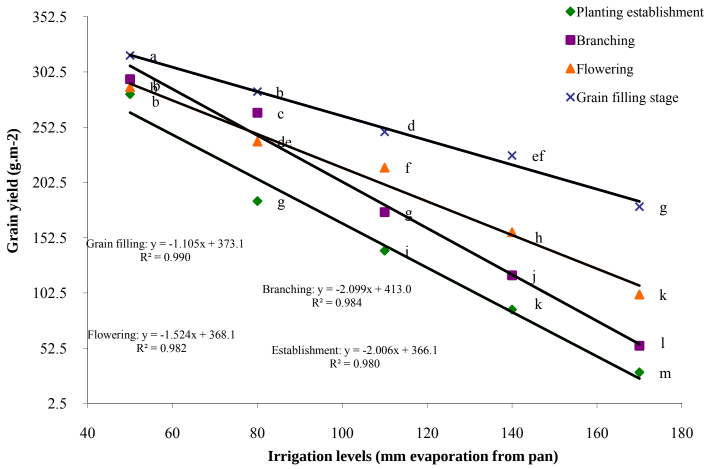

Figure 9: Effect of irrigation levels in different growth stages of amaranth on grain yield

Table 3: Effect of low irrigation stages on amaranth morphological traites

Treatment	*Plant Height (cm)*	*Branch number*	*Panicle length (cm)*	*Stem dry weight (g)*	*Panicle dry weight (g)*	**Grain number**
Planting establishment	71.19b	2.889b	40.79b	34.74b	15.68 b	7135b
Branching	78.09ab	3.57ab	40.98b	36.1b	16.1 b	7610b
Flowering	81.13a	3.821a	46.26ab	38.56ab	18.63 a	8122ab
grain filling stage	83.08a	3.956a	50.51a	40.47a	20.58 a	9350a

4. Discussion

The results showed that Amaranth as a high-yield crop (with a yield of around 5 tons per hectare) could have a high production capability if it is not affected by low irrigation stress at any stage of development. Although, irrigation after 80mm compared to irrigation after 50 mm evaporation from pan A led to a decrease in the number and kernel yield by 10% and 12%, respectively, the amount of water used by the plant dropped by about 60 percent. Considering the fact that water is extremely important in arid and semiarid areas, irrigation after 80 mm evaporation from the basin is much more valuable economic than irrigation after 50 mm of irrigation for the growers. The results showed that Amaranth is a plant whose yield can be better than other small-grain crops in low irrigation conditions. Because, when the amount of irrigation water after 50 to 170 mm evaporation from the basin (i.e. more than 300 percent) decreased, the plant yield was cut only by 45%. This means that the crop, have tolerance to the most severe dehydration stress. After 170 mm of evaporation from the pan at the plant establishment stage, it could produce over 15 g of grain per plant and 3 tons per hectare.

5. Acknowledgments

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