Using deficit irrigation to improve crop water productivity of sweet corn, chickpea, faba bean and quinoa: a synthesis of several field trials

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Abstract

Several experiments were conducted in the south of Morocco (IAV-CHA, Agadir) during two seasons 2010 and 2011 in order to evaluate the effect of deficit irrigation with treated wastewater on several crops (quinoa, sweet corn, faba bean and chickpeas). During the first season (2010) three crops were tested, quinoa, chickpeas and sweet corn applying 6 deficit irrigation treatments during all crop stages alternating 100% of full irrigation as non-stress condition and 50% of full irrigation as water deficit condition applied during vegetative growth, flowering and grain filling stage. For all crops, the highest water productivity and yield were obtained when deficit irrigation was applied during the vegetative growth stage. During the second season (2011) two cultivars of quinoa, faba bean and sweet corn have been cultivated applying 6 deficit irrigation treatments (rainfed, 0, 25, 50, 75 and 100% of full irrigation) only during the vegetative growth stage, while in the rest of crop cycle full irrigation was provided except for rainfed treatment. For quinoa and faba bean, treatment receiving 50% of full irrigation during vegetative growth stage recorded the highest yield and water productivity, while for sweet corn applying 75% of full irrigation was the optimal treatment in terms of yield and water productivity.

Keywords: water stress, water productivity, evapotranspiration, yield, crop stage.

Résumé

Plusieurs essais ont été conduits dans le sud du Maroc (IAV-CHA, Agadir) durant deux saisons 2010 et 2011 dont le but d'évaluer l'effet de l'irrigation déficitaire par les eaux usées traitées sur plusieurs cultures (quinoa, maïs doux, fève et pois chiche). Durant la première saison (2010) trois cultures ont été testées, quinoa, maïs doux et pois chiche en appliquant 6 traitements d'irrigation déficitaire durant tout les stades culturaux en alternant 100% d'ETm comme condition de confort hydrique et 50% d'ETm comme conditions de stress durant le stade de croissance végétative, floraison et remplissage des grains. Pour toutes les cultures, le rendement et la productivité d'eau les plus élevés ont été obtenus lorsque l'irrigation déficitaire a été appliquée durant le stade de croissance végétative. Pendant la deuxième saison (2011) deux lignés du quinoa, la fève et le maïs doux ont été cultivées en adoptant 6 traitements d'irrigation déficitaire (bour, 0, 25, 50, 75 et 100 d'ETm) appliqués juste pendant le stade de croissance végétative, tandis que durant le reste du cycle cultural les cultures ont reçues une irrigation complète sauf pour le traitement bour. Pour le quinoa et la fève, appliquant 50% d'ETm durant le stade végétatif a permis d'obtenir le rendement et la productivité d'eau les plus élevés, tandis que pour le maïs doux le traitement optimal qui a enregistré le rendement et la productivité d'eau les plus élevés est celui qui a reçu 75% d'ETm.

INTRODUCTION

Recently, water crisis has become one of the most significant problems in the world especially in the Mediterranean region (Rabi *et al*., 2012), water scarcity exacerbated by climate change is expected to define food production in the coming decades (Schaffnit-Chatterjee, 2009; Abbassian *et al.*, 2010). Thus, as countries confront the water crisis situation, there will no doubt be increasing pressure to allocate water away from agricultural to industrial and municipal uses as well as to increase water efficiency within the agricultural sector (Safwat, 2011). Treated and reused sewage water is becoming a common source for additional water especially in agriculture (Qadir *et al.*, 2010). Morocco has implemented several strategies to improve water resource management by increasing irrigation efficiency, prevent water pollution, and reuse wastewater. The quantity of wastewater in Morocco was about 600 Mm^3 in 2008, and this quantity is estimated about 900 Mm^3 in 2020 (Choukr-Allah *et al.,* 2010). Deficit irrigation (DI) is now widely been investigated as one of the solutions to save water (Pereira *et al.*, 2002). This practice of deficit irrigation aims at obtaining maximum water use efficiency and at stabilizing yields (Geerts & Raes, 2009).

According to Schultheis (1996) field corn was grown in North America before 200 B.C. Field corn is produced primarily for animal feed and industrial uses such as ethanol, cooking oil, etc. In contrast, sweet corn is produced

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for human consumption as either a fresh or processed product. The specific time when sweet corn originated cannot be pin-pointed; however, sweet corn was grown by the American Indian and first collected by European settlers in the 1770's. The first variety, Papoon, was acquired from the Iroquois Indians in 1779. Sweet corn is available as yellow, white, or bicolored ear types. Cultivars vary in their days to maturity; they are classified as early, mid-, and late season. Late season cultivars generally are the best quality. Many of the new cultivars are higher in sugar content and retain their sweetness longer (Lerner & Dana, 1998).

Chickpea (*Cicer arietinum* L.) is the third most important food legume grown in the world; 12 million ha are cultivated, producing a total grain yield of 11 million ton. Chickpea is grown in over 45 countries (FAOSTAT, 2010). In the Mediterranean countries, chickpea is one of the favourite legumes and an essential part of the diet in some countries such as Morocco, Tunisia, Lebanon and Syria. Because of its importance, it has received the attention of many researchers not only for being one of the primary legume crops but also due to its relatively high protein content (Chang *et al*., 2011, Hirich *et al*, 2011).

The production of quinoa (*Chenopodium quinoa* Willd.) could contribute to food security, and has a great potential to increase food security in the Mediterranean region and in other parts of the developing world (Hirich *et al*., 2012 a and b, 2013; Jacobsen *et al*., 2012). Quinoa has been selected as one of the crops to secure food in the 21st century (FAOSTAT, 2010). The year 2013 has been declared "The International Year of the Quinoa" (IYQ), recognizing the Andean indigenous peoples, who have maintained, controlled, protected and preserved quinoa as food for present and future generations (FAO, 2012). Quinoa is an Andean seed crop well adapted to poor soils and unfavourable climatic conditions (Garcia *et al.*, 2003; Geerts *et al.*, 2006; González *et al*., 2009).

Faba bean (*Vicia faba* L., broad bean, horse bean) is grown worldwide in cropping systems as a grain (pulse) and green-manure legume (Jensen *et al*., 2009). According to Sakr (1991) faba bean is the most important food legume crop in Morocco, the cultivated area of faba bean in Morocco is about 186,000 ha, 118,000 Tons was the harvested production (FAOSTAT, 2010).

MATERIALS AND METHODS

The research has been conducted in the experimental field of the Agronomic and Veterinary Medicine Hassan II Institute, Complex of Horticulture in Agadir in the south of Morocco. The climate is arid, characterized by low precipitation (250 mm), rainfall is occurred from November to Marsh. Sunshine is more than 300 days a year and average temperature is variable form 14 to 16 °C in January and from 19 to 22°C in July.

Soil type was loamy with pH equal to 8.13 and EC 0.27 dS/m. The soil was moderately rich in organic matter (1.6%), field capacity humidity (FC_{RH}) was 30%, and the permanent wilting point humidity (PWP_{RH}) 15%.

Table 1: Irrigation treatments applied during first season 2010 for sweet corn, chickpeas and quinoa

Treatment	Germination	Vegetative growth	Flowering	Grain filling	Senescence
T1 (Control)	100	100	100	100	0
T2	100	50	50	50	0
T3	100	100	50	100	0
T4	100	100	100	50	0
T5	100	50	100	100	0
T6	100	50	50	100	0

Table 2: Irrigation treatments applied during the 2nd season 2011 for sweet corn and faba bean (% of full irrigation)

Treatment	Germination	Vegetative growth	Flowering	Seed filling	Senescence
T0 (Rainfed)	100	0	0	0	0
T1	100	100	100	100	0
T2	100	75	100	100	0
T3	100	50	100	100	0
T4	100	25	100	100	0
T5	100	0	100	100	0

Table 3: Irrigation applied during the 2nd season for 2 cultivars of quinoa (% of full irrigation)

Cultivar	Treatment	Vegetative growth	Flowering	Seed filling
DO708 **QM1113**	T1	**100**	100	100
	T2	**50**	100	100
	T3	**25**	100	100

The irrigation water used was domestic wastewater treated by aerobic lagoon (sheafer system) at the treatment plant of the institute, very rich in nitrogen and organic matter, with EC equal to 1.31 dS/m and pH 7.6. According to the nutrient content in this water, most of the fertilizer requirements of the crop can be covered since 1000 m^3 can provide 22 kg of Nitrogen, 15 kg of Phosphorus and 19 kg of Potassium. In terms of microbiological analysis, the irrigation water remains within the standards of the World Health Organization (WHO, 2006).

Experimental units (18 m^2) were organized in a completely randomized design with 24 plots. Inside plot there were 5 sowing lines, a distance of 50 cm between lines and 40 cm between sowing holes has been adopted. All treatments have received the same quantity of water during the initial stage (20 days after sowing), this irrigation supply during this stage was necessary for crop to start its growth and to be able after to resist to deficit irrigation supply.

In the first season (2010), the objective was to test different irrigation strategies applied during several crop stage, the applied treatments for the 3 crops are shown in table 1.

In the second season 2011, the objective was to test several water stress degree during the vegetative growth stage which was the most resistant crop stage to water stress according to first season results, Table 2 shows the different applied treatments for sweet corn and faba bean and table 3 shows the deficit irrigation treatments applied for 2 cultivars of quinoa.

Four replications for each treatment have been adopted. Differences between response variables to deficit irrigation treatments were assessed with a general linear model in the StatSoft STATISTICA 8.0.550. All statistical differences were significant at $\alpha = 0.05$ or lower. Tukey HSD test was used to reveal homogeneous groups.

RESULTS

Deficit irrigation applied during different crop stages

Chickpea

Table 4 shows the chickpea yield, total dry matter, harvest index (HI), Root to shoot ratio, water supply and crop water productivity (CWP) obtained for each deficit irrigation strategy. Statistical analysis carried out on yield in response to water stress applied during different crop stages revealed a highly significant difference ($p< 0.001$). Applying water stress during flowering (T3) and grain filling stage (T4) led to reduction in yield by 26 and 38% compared to full irrigation. 33 and 43% of yield reduction has been occurred when plant was stressed during both vegetative and flowering stage (T6) and during the whole growing period (T2) respectively. While stressing the crop during vegetative growth stage resulted in improvement of yield evaluated by 34% compared to fully irrigated treatment (T1).

Total dry matter showed the same tendency as yield with the highest dry matter production has been harvested when chickpea was stressed during vegetative growth stage. Harvest index seems to be not affected by deficit irrigation since all investigated treatments showed statistically the same value of HI. The lowest HI was recorded when crop was subjected to water stress during flowering stage (T3) and during grain filling stage (T4). The root to shoot ratio has been also affected negatively by deficit irrigation where water stress applied during vegetative growth stage increased significantly this ratio indicating that water deficit applied early during growing period has induced root growth and development where stress application either during the whole growing period, flowering or grain filling stage has affected negatively root growth.

Applying stress during vegetative growth stage improved yield and consequently increased significantly CWP due to reduced amount of supplied water (16%), the lowest CWP was obtained when crop was stressed during grain filling stage (T4) for which yield has been greatly affected. Presented results indicate that both flowering and grain filling stage were the most sensitive to deficit irrigation and vegetative growth stage was the most resistant to water deficit.

Sweet corn

Sweet corn responded similarly to deficit irrigation applied during different crop stages as chickpea (Table 5). Highest fresh ear yield has been obtained when applying deficit irrigation during vegetative growth stage (T5) with an increasing of 28% compared to fully irrigated treatment (T1). While water stress affected negatively sweet corn yield with a reduction of 34, 12, 17 and 29% when crop was subjected to water stress during the whole growing period (T2), flowering (T3), grain filling (T4) and during both vegetative growth and flowering (T6) respectively. Total fresh matter was affected by deficit irrigation and showed the same tendency as yield. Statistical analysis has not revealed any significant difference between HI. While significant difference was obtained in terms of the root to shoot ratio with the highest value has been recorded under water stress applied during vegetative growth stage (T5) and during flowering (T3). Applying deficit irrigation during vegetative growth stage allowed water saving of 23% and maximisation of CWP (6.48 kg m^{-3}) compared to other deficit irrigation strategies.

Quinoa

Contrarily to chickpea and sweet corn quinoa seed yield was not maximized under deficit irrigation applied during vegetative growth stage (T5) but it was stabilized compared to control conditions (Table 6). The highest dry matter accumulation was obtained under full irrigation (T1) conditions and the highest HI was recorded when quinoa was subjected to water stress during vegetative growth stage (T5). The other treatments showed statistically an equal value of HI.

Applying water deficit during vegetative growth stage (T5) resulted in increase of root to shoot ratio indicating that early water deficit induced root development. CWP has been also maximized under deficit irrigation during vegetative growth stage allowing water saving of 19% of full irrigation.

Table 4: chickpea yield, total dry matter, harvest index (HI), Root to shoot ratio, water supply and crop water productivity (CWP) obtained for each deficit irrigation strategy.

Deficit irrigation strategies	Grain Yield g $plant^{-1}$	Total dry matter g $plant^{-1}$	Harvest Index	Root to shoot Ratio	Water supply mm	CWP kg m^{-3}
T1 (100% of FI during the whole growing period)	48.7 ab	217.9 ab	0.22	0.034 a	278.22	0.88 b
T2 (50% of FI during the whole growing period)	27.4 b	118.4 c	0.23	0.028 b	139.11	0.98 ab
T3 (50% of FI during flowering, 100% of FI during the rest of growing period)	36.0 b	216.3 ab	0.17	0.026 b	235.80	0.76 b
T4 (50% of FI during grain filling, 100% of FI during the rest of growing period)	30.2 b	181.8 b	0.17	0.022 b	225.72	0.67 b

Table 5: Sweet corn fresh ear yield, total dry matter, harvest index (HI), root to shoot ratio, water supply and crop water productivity (CWP) obtained for each deficit irrigation strategy

Deficit irrigation strategies	Fresh ear yield g $plant^{-1}$	Total fresh matter g $plant^{-1}$	Harvest Index	Root to shoot Ratio	Water supply mm	CWP kg m^{-3}
T1 (Fully irrigated, 100% of FI during the whole growing period)	365.9 b	1726.1 a	0.21	0.052 b	469.3	3.90 b
T2 (Fully stressed, 50% of FI during the whole growing period)	238.6 d	833.1c	0.29	0.055 b	237.1	5.03 ab
T3 (50% of FI during flowering, 100% of FI during the rest of growing period)	322.3 bc	1164.4 b	0.28	0.062 a	421.5	3.82 b
T4 (50% of FI during grain filling, 100% of FI during the rest of growing period)	301.3 bcd	1044.1 b	0.29	0.050 bc	393.1	3.83 b
T5 (50% of FI during vegetative growth, 100% of FI during the rest of growing period)	469.1 a	1913.2 a	0.25	0.067 a	361.9	6.48 a
T6 (50% during vegetative growth and Flowering, 50% of FI, 100% of FI during the rest of growing period)	258.8 cd	885.1 c	0.29	0.046 c	313.8	4.12 b

Table 6: Quinoa seed yield, total dry matter, harvest index (HI), Root to shoot ratio, water supply and crop water productivity (CWP) obtained for each deficit irrigation strategy

Deficit irrigation strategies	Seed yield g $plant^{-1}$	Total dry matter g $plant^{-1}$	Harvest Index	Root to shoot Ratio	Water supply mm	CWP kg m^{-3}
T1 (Fully irrigated, 100% of FI during the whole growing period)	74.3 a	270.9 a	0.27 b	0.059 b	356.93	1.04 ab
T2 (Fully stressed, 50% of FI during the whole growing period)	37.0 c	142.0 b	0.26 b	0.072 ab	178.48	1.04 ab
T3 (50% of FI during flowering, 100% of FI during the rest of growing period)	50.3 b	185.9 b	0.27 b	0.084 a	325.33	0.77 b
T4 (50% of FI during grain filling, 100% of FI during the rest of growing period)	46.7 bc	193.0 b	0.24 b	0.064 b	279.09	0.84 b
T5 (50% of FI during vegetative growth, 100% of FI during the rest of growing period)	72.1 a	182.9 b	0.39 a	0.096 a	287.97	1.25 a
T6 (50% during vegetative growth and Flowering, 50% of FI, 100% of FI during the rest of growing period)	40.2 bc	165.4 b	0.24 b	0.062 b	256.34	0.78 b

Table 7: Yield, yield components, root to shoot ration, water supply and CWP at faba bean harvest

Deficit irrigation strategies	Dry grain yield g plant^{-1}	Fresh yield g plant^{-1}	Number of Grains/ pod	Number of pods / plant	1000 grains weight g	Total dry matter g	HI %	Root to shoot ratio	Irrigation supply + rain mm	CWP Kg m^{-3}
T0 (Rainfed)	44.4 c	290.1	4.9	08.7 c	1022.9 c	71.9 b	61.7	0.061 a	105	4.2 a
T1 (FI)	101.6 a	339.4	4.8	14.7 ab	1455.7 a	179.5 a	56.6	0.052 b	354	2.9 b
T2 (75% during V.G and FI during the rest of growing period	101.8 a	316.3	4.9	14.6 ab	1338.2 ab	176.5 a	57.7	0.054 ab	324	3.1 ab
T3 (50% during V.G and FI during the rest of growing period)	105.7 a	342.6	4.7	15.2 a	1462.7 a	182.2 a	58.0	0.057 a	294	3.6 ab
T4 (25% during V.G and FI during the rest of growing period)	86.6 ab	272.4	4.8	13.3 abc	1393.2 ab	146.4 ab	59.1	0.054 ab	264	3.3 ab
T5 (0% during V.G and FI during the rest of growing period)	66.6 bc	316.4	4.9	10.5 bc	1280.6 b	109.2 ab	61.0	0.040 c	233	2.9 b

Deficit irrigation degrees applied during vegetative growth stage

Faba bean

Two kinds of yield were measured, marketable fresh pod yield and dry grain yield. Number of pods per plant, number of grains per pod and 1000 grains weight were measured at final harvest as grain yield components. There were significant differences in dry grain yield, number of pods, and plant and seed weight, but not in fresh pod yield and number of grains per pod (Table 7).

While for grain yield, number of pods per plant and 1000 grains weight, there was a very highly significant difference. Applying 50 of FI during vegetative growth stage (T3) resulted in the highest dry grain yield, number of pods per plant and the 1000 grains weight. The rainfed treatment (T0) recorded the lowest value of all measured parameters. Treatment fully irrigated (T1) showed statistically dry grain yield and 1000 grains weight equal to treatment receiving half of full irrigation (T3) during vegetative growth stage. While for number of pods per plant, treatment T1 produced less pods per plant compared to treatment T3, with no significant difference between T1 and T3 in terms of grain yield, this can be explained by the difference in number of grain per pod in where T1 produced 4.8 and T3 4.7 grains per pod.

The highest dry matter accumulation was obtained when applying water stress degree up to 50% of FI during vegetative growth stage. While the lowest dry matter yield has been recorded under rainfed conditions. Applying 0% during vegetative growth stage (T5) affected greatly root to shoot ratio while under rainfed conditions (T0) this parameter was maximized due to reduced shoot production compared to root. Water stress degree up to 25% of FI applied during vegetative growth stage (T2, T3 and T4) resulted in highest root to shoot ration even more that when full irrigation was provided (T1).

Crop water productivity (CWP) was calculated by dividing the dry grain yield with the consumed water quantity. Cultivating faba bean under rainfed conditions (T0) led to the highest CWP and this was due to less water consumption, followed by treatment receiving 50% of FI during vegetative growth stage (T3). Applying full irrigation (T1) or 25% of FI during vegetative growth stage (T5) decreased greatly CWP (2.9 kg m^{-3}). For T1 mainly was due to higher consumed water quantity (354 mm consumed by T1 compared to 233 consumed by T5) and for T5 mainly was due to low obtained yield (66.6 g plant^{-1} for T5 compared to 101.6 g plant^{-1} for T1). Applying deficit irrigation using 50% of full irrigation during vegetative growth stage (T3), 17% of water quantity could be saved compared to full irrigation, that is 600 m^{3} ha^{-1}. Statistical analysis has not revealed any significant difference between tested water stress degrees in terms of HI.

Sweet corn

Sweet corn is a horticultural crop, where the fresh ears are consumed and marketable. Two kinds of yield have been measured: fresh ear yield and dry grain yield, number of ears per plant and 1000 grains weight has also been recorded as yield components (Table 8).

There was a significant difference in terms of fresh ear weight, dry grain yield and 1000 grains weight (Table 6) in terms of the effect of several water stress degree applied during vegetative growth stage. For number of ears per plant there was no difference between treatments. For fresh ears yield applying 75% of FI (T2) resulted in the highest yield. While under rainfed conditions (T0) the crop harvested the lowest fresh ears yield with a reduction of about 50% compared to fully irrigation (T1). For dry grain yield all deficit irrigation strategies except rainfed treatment (T0) recorded statistically an equal dry grain yields, where a reduction of 40% compared to treatment control (T1) was recorded for rainfed treatment (T0). The same was the case for 1000 grain weight where rainfed

Table 8: Sweet corn yield, yield components, root to shoot ratio, water supply and CWP

Treatments	Fresh ears yield g plant^{-1}	Dry grain yield g plant^{-1}	Number of ears/plant	1000 grains weight g	Total dry matter g	HI %	Root to shoot ratio	Water supply + rain mm	CWP Kg m^{-3}
T0 (Rainfed)	285.7 c	95.6 b	1.7	91.7 b	565.5 b	55.4	0.086	217.1	6.6
T1 (FI)	556.1 ab	159.6 a	1.9	122.3 a	911.9 a	56.4	0.092	492.9	5.6
T2 (75% during V.G and FI during the rest of growing period	664.8 a	174.3 a	2.1	136.4 a	978.2 a	62.3	0.097	456.1	7.3
T3 (50% during V.G and FI during the rest of growing period)	544.4 b	163.7 a	2	131.1 a	962.2 a	53.6	0.100	419.2	6.5
T4 (25% during V.G and FI during the rest of growing period)	538.4 b	162.9 a	1.7	130.9 a	892.1 a	56.8	0.128	382.3	7.0
T5 (0% during V.G and FI during the rest of growing period)	519.7 b	146.8 a	1.9	146.0 a	914.4 a	54.8	0.099	345.5	7.5

Table 9: Seed yield, total dry matter, HI, Root to shoot ration, water supply and CWP of quinoa

Cultivar	Treatments	Seed yield per plant g plant^{-1}	Total dry matter g plant^{-1}	HI %	Root to shoot ratio	Water supply + rain mm	CWP Kg m^{-3}
DO708	T1 (FI)	61.8 b	143.3	43.1	0.108	348	0.89
	T2 (50% during V.G and FI during the rest of growing period)	68.9a	137.7	50.1	0.122	323	1.07
	T3 (25% during V.G and FI during the rest of growing period)	42.1 c	82.2	51.2	0.094	273	0.77
QM1113	T1 (FI)	52.7 ab	104.5	50.4	0.100	348	0.76
	T2 (50% during V.G and FI during the rest of growing period)	56.2 ab	108.9	51.6	0.102	323	0.87
	T3 (25% during V.G and FI during the rest of growing period)	32.9 d	91.8	35.9	0.087	273	0.60

treatment (T0) showed a reduction of 25% compared to control treatment (T1). Total dry matter followed the same tendency as dry grain yield where sweet corn accumulated the lowest dry matter under rainfed conditions. Deficit irrigation applied during vegetative growth stage has not affected the HI and the root to shoot ratio.

There was no significant difference in terms of the effect of deficit irrigation applied during vegetative growth stage on sweet corn water productivity. The highest CWP has been recorded under deficit irrigation applying 0% during vegetative growth stage and this was due to high grain yield, statistically similar to control treatment (T1).

Quinoa

Statistical analysis carried out on the seed yield of quinoa in response to several water stress degrees applied during vegetative growth stage revealed very highly significant difference (Table 9). Cultivar DO708 showed the highest productivity in terms of seed yield comparing to cultivar QM1113. Applying 50% of FI during vegetative growth stage (T2) allowed obtaining the highest seed yield inside each cultivar, while applying 25% of FI (T3) led to the lowest seed yield. Table 7 shows also that quantity of about 250 m^3/ha could be saved when applying 50% of FI during vegetative growth stage and obtaining the highest yield even more than when full irrigation was provided (T1).

DISCUSSION

Several studies showed that corn yield has been affected negatively by water deficit (Oktem, 2008; Garcia *et al*., 2003; Geerts *et al*., 2005; Sharma *et al*., 2007; Labidi *et al*., 2009; Ricciardi *et al*., 2001; Oweis *et al*., 2005). Applying water stress during the vegetative growth stage and supplying full irrigation in the rest of growing period allowed the root system to develop and non-stress conditions during the rest of growing period allowed the plant to be able to cover its needs for water and nutrient supply and optimize its photosynthesis and carbon translocation, therefore increase its productivity. This result was revealed by Oktem (2008) who reported that root dry matter values increased with water shortage, furthermore Kang *et al*. (2000) obtained that soil drying at vegetative stage promotes a larger and deeper root system. Several researches showed therefore that deficit irrigation application during vegetative growth stage induced root system growth and development for quinoa (Geerts *et al*., 2005; Jensen *et al*., 2000; Jacobsen *et al*., 2009), chickpeas (Benjamin & Nielsen, 2006), sweet corn (Çakir, 2004; Oktem, 2008) and faba bean (De Costa *et al*., 1997; Amede *et al.,* 1999; Ricciardi *et al*., 2001; Oweis *et al*., 2005; Khan *et al*., 2010; Hirich *et al*, 2013). Full irrigation supply during the rest of crop cycle accelerated plant growth and development and improved yield and productivity. Applying half required water supply for crop has improved crop productivity by inducing its root system development, full irrigation during flowering and grain filling gave chance to plat to uptake more water and nutrients through its developed root system, as result crop produced more shoots and flowers intercepting more radiations by its large leaf area and producing higher yield (Hirich *et al*, 2012c).

According to our results treatments stressed during the grain filling stage recorded the lowest biological and commercial yields compared to other treatments stressed during vegetative growth and flowering stage for quinoa (Geerts & Raes, 2009), chickpeas (Shamsi *et al*., 2010), and sweet corn (Çakir, 2004). This result indicates that the grain filling stage is the most sensitive crop stage to water deficit. Presented results indicated that throw deficit irrigation strategy using a water stress of 50% of full irrigation during vegetative growth stage can lead to double benefice, in terms of water saving and in terms of marketable yield.

CONCLUSION

This work mainly was focusing on bringing a reasonable answer to the question: can we have satisfactory yield production with less water following the deficit irrigation techniques? The finding of the research evidently indicates that under deficit irrigation we can have a yield production more or less equal (quinoa and faba bean) or even higher than where full irrigation is provided (chickpeas: + 34%, sweet corn: +28%).

The vegetative growth stage for the investigated crops is one among the others growth stages being the most resistant to water stress conditions. Flowering and grain filling stages are both the most sensitive to water stress, so it's important to avoid that both stages to be subjected to any water stress.

Generally the observations recorded during the running of the experiment indicated that putting the vegetative growth under water stress conditions, the consequences are: a reduction in the vegetative growth, less water consumption beside shortening the vegetative growth period, and entering earlier in the flowering stage and lowering the maturity and harvesting time.

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