APPLICATION OF DEFICIT IRRIGATION STRATEGY FOR BARLEY (*HORDEUM VULGARE* L.) AND WHEAT (*TRITICUM DURUM DESF*.) IN THE REGION OF BISKRA

ABLA KESSAI[1], MAHMOUD DEBABACHE[2], ANDREA PITACCO[3]

[1,2]Laboratory of Civil and Hydraulic Engineering, Sustainable Development and Environment – LARGHYDE

University of Biskra.

[1]Department of Agronomy, University of Biskray.

[3]University of Padova, DAFNAE.

kessaiabla69@gmail.com

ABSTRACT

This study was carried out during the growing season 2013-2014 in order to determine the effect of deficit irrigation on grain and straw yield of barley and wheat, along with irrigation water use efficiency at grain yield (IWUEg) and total biomass (IWUEbio), using flood irrigation for clay loam to slit clay soil texture under the arid climate of Biskra. Three deficit irrigation strategies were applied: T1 (50% of full water supply, from initiation to heading), T2 (50% deficit during grain filling), T3 (alternate deficit during whole season). Different treatments were compared with T0 (full irrigation). The obtained results show that mean grain and straw yield forT1, T2and T3treatments of both crops, were significantly affected by deficit irrigation (P<0.005).The water deficit during grain filling (50% water supply) for both crops had a less impact on grain yield (11% and 15% for barley and wheat, respectively), saving 20.32% of water and improving both IWUEg and IWUEbio, compared to full irrigation supply (T0).The findings of this study support the idea that the most effective strategy of deficit irrigation is to improve IWUE, by reducing the amount of applied water during those growing phases which have less impact on the yield and growth.

KEYWORDS: Barely, wheat, deficit irrigation, yield, irrigation water use efficiency, Biskra.

RESUME

Cette étude a été réalisée pendant la saison agricole 2013-2014 afin de déterminer l'effet de l'irrigation déficitaire sur le rendement en grains et de paille de l'orge et du blé, ainsi que l'efficience de l'utilisation de l'eau d'irrigation sur le rendement en grains (IWUEg) et le rendement de biomasse aérienne (IWUEbio), en utilisant l'irrigation par submersion sous le climat aride de la région de Biskra. Trois stratégies d'irrigation déficitaire ont été adoptées: T1 (50% du total de la quantité d'eau, à partir de la levée jusqu'à la fin du stade de l'épiaison), T2 (déficit de 50% pendant le remplissage du grain), T3 (alterné, pendant tout le cycle de croissance). Ces différents traitements ont été comparés avec T0 (irrigation complète).Les résultats obtenus ont montré que le rendement moyen en grains et le rendement en paille pour les traitements T1, T2 et T3 des deux cultures sont significativement affectés par l'irrigation déficitaire (p<0,005). Le déficit de l'eau appliqué pendant le remplissage des grains (50% du total de la quantité d'eau donnée) pour les deux cultures a eu un impact réduit sur le rendement en grain (11% et 15% respectivement pour l'orge et le blé), permettant une économie d'eau de 27,58% et améliorant l'IWUEg et l'IWUEbio comparativement au traitement T0 (irrigation complète). Les résultats de cette étude soutiennent l'idée que la stratégie la plus efficace de l'irrigation déficitaire est d'améliorer l'IWUE, en réduisant la quantité d'eau appliquée pendant les phases de croissance qui ont le moindre impact sur le rendement et la croissance.

MOTS CLES: Orge, blé, irrigation déficitaire, rendement, efficience de l'utilisation de l'eau d'irrigation, Biskra.

1 INTRODUCTION

Water has been considered as the most limiting factor in reducing agriculture production in arid and semi-arid zones (Boutraa, 2010; Cattivelli et al., 2008). For this fundamental reason, within these environments, agriculture requires high water use mainly because of the high rate of evapotranspiration. Therefore, and as it has been emphasized by many Authors, irrigation water management in an environment of water scarcity has to be carried out with great deal of efficiency to be able to save water and optimize its productivity (Fereres and Soriano, 2007). Much research on agriculture in arid and semi-arid zones has been carried out to study the relationship between crop yield and water use(Molden et al., 2003; Zwart and Bastiaanssen, 2004 Tabarzad and Ghaemi, 2015). In these conditions of water scarcity, many studies emphasized the Deficit Irrigation (DI) or Regulated Deficit Irrigation (RDI) strategy which, according to its results, could play a major role. It is defined as a water management method in which water will be saved by allowing and accepting a little yield reduction without causing any sever damage to the plant (English, 1990).

This method has been investigated as a valuable and sustainable production strategy appropriate especially for dry regions to maximize water use efficiency (WUE) (English, 1990; Fereres and Soriano, 2007) and therefore reducing water consumption while minimizing adverse effects on yield (Geerts and Raes, 2009). Optimum crop yields under deficit irrigation practices can be obtained by allowing a certain level of yield reduction of a given crop in a particular area in order to divert the saved water to irrigate other areas or crops.

In Algeria, cereals occupy an important place, socially as well economically. The annual production during the year 2012/2013has been estimated around 49millionof quintals. However, the productivity remains low and fluctuates from one season to another depending especially on climate conditions and maintenance factors such as drought and water management. The irrigated area of cereals in the region of Biskra is estimated at 7,509ha (2012/3013) with yield reaching23q/ha. (ITGC, 2013); in this region the irrigation for agricultural production is mainly from groundwater, which is non-renewable: it is the main source of water and irrigation for the local farmers. Moreover, the climatic conditions in these regions make irrigation necessary for agriculture.

This situation shows a need to carry out studies concerned with Deficit Irrigation strategies applied to barley and wheat production in the region of Biskra, which has not known prior studies.

The objective of this study is to determine the effect of deficit irrigation applied in two growth stages: from initiation to heading and during grain filling, on grain and biomass yield, and the evaluation of the efficiency of irrigation water use for growing barley and wheat.

2 MATERIALS AND METHODS

2.1 Study area and Meteorological data

The research was conducted in the south of Algeria, Biskra (34° 51' N, 5° 44' E, 87m above the sea level), in the experimental field of the Department of Agronomy of the University “Mohamed Khider”, between December 2013and May 2014.

The data points for the growing period during the year of experiment tare shown in Table1.During the period December 2013–May 2014, most of rainfall occurred during the growing season with a total of about 43.2mm and maximum value in March (about 16.0 mm). December was the coolest month (7.1C°) and May was the hottest (32.9 C°). Monthly value of evapotranspiration in this period exceeded precipitation, being about 602 mm for the whole growing season.

Table 01: Monthly average of climate data from the period December 2013 to May 2014(ONM, Biskra)

Month	Temperature max (°C)	Temperature min (°C)	Mean Sun Shine (h)	Rainfall (mm)	Relative humidity (%)	Wind speed m/s	ET_0 (mm)
December	18.1	7.1	6.27	15.0	35.32	_	43.99
January	18	7.9	7.18	8 .2	42.06	-	52.55
February	20.4	9.3	8.09	3.2	36.03	-	67.49
March	21.9	10.7	7.61	16.0	35.54	3.37	98.24
April	29.3	16.0	9.97	0.0	21.49	2.99	152.43
May	32.9	20.1	10.88	2.1	21.50	3.07	187.03

2.2 Soil characteristics

Physical and chemical lproprieties of the soil are presented in Table 2.The methods and procedures for the soil analysis concerning our study have been carried out according to ISRIC (L.P,vanReeuwijk, 1995). Soil layers have been defined to compute water budget in relation to rooting depth. The texture of 0-30 cm is clay loam, the 30-60 cm is silt clay and the 60-90 cm has a clay texture. The total available water (TAW) for barley and wheat root extracting at depth of 0.90 m is182 mm. It is calculated from the following equation:

TAW = (FC-WP)*Da*Rd

Where Fc is the water content at filed capacity %, WP is the water content at the wilting point %,

Da is the bulk density (g/cm3) and Rd is the rooting depth of soil (dm)

Table 02: Characteristics of soils in study area

Properties	Soil layer (cm) 0-30	30-60	60-90
Clay (%)	28.55	43.04	48.9
Fine Silt (%)	20.64	18.45	28.88
Coarse silt (%)	12;20	22.72	10.79
Fine Sand %	37.64	15.52	11.28
Coarse sand%	0.97	0.27	0.15
Organic matter (%)	1.43	0.68	0.56
pH (1:2,5soil : water)	7.52	7.27	7.45
CE1:5dS/m at 25°C	1.46	2.85	3.63
Field capacity (%)	20.06	29.68	32.92
Wilting point (%)	10.61	13.86	15.36
Da g/cm^3	1.28	1.42	1.48

2.3 Experiment design and crop management

The experiment was laid out in a total randomized complete block design with three replications and four irrigation treatments. The experimental area was divided into three blocks with four replicate plots per blocks. Individual plot size was 6 m2 (3m× 2m).The sowing was carried out in first week of December at rate of 130kgha-1 for wheat and 120 kg ha-1 for barley. The durum wheat variety was “Waha”, and the 2-row barley variety was “Soufara”.At sowing, 120kgha-1of superphosphate 46% has been incorporated in all plots, then potassium as potassium sulphate (K2O 50%) at 100kgha-1. A total amount of 150kg ha-1of urea (N 40%) was applied at tillering and anthesis stages of both crops. (ITDAS2005).

2.4 Crop water requirement and Scheduling irrigation

The experiment consisted of full irrigation supply treatment during the whole season (T0) and three different deficit treatments:

Treatment T1: 50% of full irrigation supply until heading,

Treatment T2: 50% of full irrigation supply during the late stage (grain filling),

Treatment T3: 50%of full irrigation supply until heading and during grain filling (alternate deficit).

We applied flood irrigation to the experimental plots (basin), and all irrigated plots received water supply with the same frequency.

The reference evapotranspiration ET0 was calculated using a “class A” evaporation pan (Figure 2) applying the following equation:

$$ET_0 = K_{pan} * E_p \qquad \text{Eq 1}$$

Where kpan is the pan coefficient; Ep is the daily evaporation from the pan. In our study we choose the values proposed by Doorenbos and Pruitt (1977).

The ET0from Eq.1 was converted to crop evapotranspiration (ETc):

$$ET_c = ET_0 * k_c \qquad \text{Eq .2}$$

Where: k_c is crop factor.We used kc values according to the local prevailing climatic conditions provided by Doorenbos and Pruitt (1977) for the early (ES), mid (MS) and late (LS) growth stages of barley and wheat: 0.4, 115 and 0.4 respectively.

Figure 01: "Class A" evaporation pan(left) and level gauge (right)

Irrigation scheduling was calculate using the methodology of the water balance, according to (Allen et al., 1998)

$$ETc = I + Pe - D - Ro \pm \Delta S \quad \text{Eq.3}$$

Where is the applied irrigation water (mm), Pe is the effective rainfall (mm); D is drainage (mm); Ro is runoff (mm)and ΔS is the change in water storage in the soil profile (mm). We assumed that runoff was negligible because water application rate was controlled. Also, ground water effect was ignored because the water table was deep:

$$ETC = I + Pe \pm \Delta S \quad \text{Eq. 4}$$

Irrigation Water requirement (IWR) is the net depth water (mm) to be applied to crop, and it was calculated with the following equation:

$$\mathbf{IWR} = \frac{\mathbf{ETc - Pe - \Delta S}}{\mathbf{1 - LR}} \quad \text{Eq. 5}$$

Where: Pe is the effective precipitation, LR is leaching requirement (assuming to be negligible), and ΔS is the change in soil water storage in soil profile (mm). Thus:

$$\mathbf{IWR = (ETc - Pe - \Delta S)} \quad \text{Eq ;6}$$

Irrigation was applied at 55% depletion of available water.

The gross water irrigation (GIR) requirement was calculated with the following equation:

$$\mathbf{GIR} = \frac{\mathbf{NIR}}{\mathbf{EFF}} \quad \text{Eq ;7}$$

Where NIR is the net irrigation, EFF is the efficiency of the irrigation system (0.9 for flood irrigation). Irrigation was applied when the cumulative soil water deficit reached 22.1mm during initiation till heading stage and 40.4 thereafter.

2.5 Plant measurements and Irrigation Water use efficiency

At harvest time for each crop, in each plot sample, areas of 1 m2 were harvested to determine grain yield per unit area, straw, biological yield (q ha-1), harvest index (%) and sub samples of 10 plants were taken from each plot to measure plant height (cm). Irrigation water use efficiency IWUE, defined as the ratio of grain yield or total biomass per hectare to the amount of irrigation water(mm),is calculated using the methodology provided by (Howell, 2006, 2003; Payero et al., 2008; Sinclair et al., 1984).Irrigation Water use efficiency for grain yield (IWUEg) and biomass (IWUEbio) were calculated as follows:

$$IWUE = \frac{Yield(kg)}{Total\ waterapplied[(m]^3)}$$

2.6 Statistical analysis

The statistical analysis was realized according to the method of analysis of variance (ANOVA). This enabled us to evaluate the effect of deficit treatment. As for the means of treatments, they were compared by the Least Significant Difference method (LSD) at 0,005 level of probability. The used software is CoStat version 6.400.

3 RESULTS AND DISCUSSION

3.1 Effect of irrigation regime on plant height and on grain and straw yield

The data concerning the parameters considered in plant height and yield for barley and wheat are presented in Tables 3. The results intable3 indicate that plant height and mean grain and straw yield for various treatments of both barley and wheat was significantly ($P<0.005$) affected by deficit irrigation. These values are comparable with average water use measured by other authors for wheat, cv. Waha (Chenafi et al., 2006) and for barley, cv. Soufara, (Benkherbache et al., 2009)

Table3: Plant height and grain and straw yield of barley and wheat under full and deficit irrigation

Treatments	Plant height (cm)	Plant height (cm)	Grain yield (qha^{-1}) Barely	Grain yield (qha^{-1}) Wheat	Straw (qha^{-1}) Barley	Straw (qha^{-1}) Wheat	Harvest index (%) Barley	Harvest index (%) Wheat
T0	75.64a ±1.75	89.12a ±2.00	44.45a ±0.92	47.12a ±2.88	88.55a ±5.83	96.6 a ±6.57	33.46a ±1.05	32.83a ±2.81
T1	65.62c ±2.00	74.57c ±1.59	28.51c ±1.98	29.40c ±0.85	68.82b ±2.42	73.74 b ±2.78	29.27 b ±0.85	28.51b ±0.35
T2	71.55b ±2.05	83.35b ±1.56	39.64b ±2.54	40.22b ±2.00	84.58a ±1.56	90.16 a ±6.71	31. 89a ±1.21	30.87ab ±0.52
T3	61.03d ±1.62	70.27d ±1.46	22.16d ±2.39	23.78d ±1.63	58.94c ±5.23	68.43 b ±4.41	27.32b ±1.96	25.78c ±0.16
Lsd	3.50	3.13	3.87	3.73	7.85	10.01	2.52	2.71

This result for plant height indicates that application of the deficit irrigation in earlier vegetative stage until heading (T1) or in alternate deficit (T3) significantly reduced plant height respect to the deficit suffered in the other stage (Table 3). Similar result were obtained by other Authors, which confirmed that increasing water deficit induced relative reduction of plant height (Ali et al., 2007; Andarzian et al., 2011; English and Raja, 1996).

For both barley and wheat crops, the highest grain yield was found in treatment T0 (Table 3), followed by T2. The lowest grain yield both for barley and wheat was obtained under T3.There was no significant difference of straw yield between T0 andT2, while the deficit by 50% until heading (T1), and deficit alternate (T3) caused a significant reduction of straw yield both for barley and wheat

(Table 3).

The value of harvest index (HI) (%) varied between 27.3% and 33.5% and between 25.8 and 32.8%, for barley and wheat respectively. The highest value was obtained under full irrigation supply, while the deficit irrigation caused reduction in HI in all treatments (Table 3). However, there was no significant difference between T0 and T2. The decreasing values of HI observed in applied of deficit irrigation until heading (T1) and alternate deficit (T3) is likely related to overall reduction in biomass and to the reduced amount of biomass partitioned into the reproductive organs. Our results indicate that deficit irrigation applied during grain filling (T2) had little impact on mean grain and straw yield; compared at different growing stage. These findings agree with (Ali et al., 2007; Zhang et al., 2006),confirming that water deficit during the grain filling period had little effect on grain yield.

3.2 Effect of water irrigation applied on yield and water saving

The amount of irrigation water supply for barley and wheat (Table 4) ranged from 237.4to 436.9mm. In our study, water saving was25.3% (T1), 20.3% (T2) and 45.7% (T3), as compared to full irrigation supply (T0).The highest reduction in average yield was observed in the treatment that experienced the most severe deficit (T3): 50% compared to full irrigation T0. Reduction of yield for treatment T1 was 38% and 36% for barley and wheat, respectively. A lower reduction was observed in treatment T2:11% and 15% compared to full irrigation. Yield reduction by stress during this stage was confirmed with the results observed by Mugabe and Nyakatawa, (2000),who noted that applying 75% and 50% of crop water requirements resulted in a reduction in yield of 12% and 20%.

Table4: Amount of water applied (mm) and water saving under different treatment

Treatment	Irrigation (mm/season)	Rainfall effective (mm)	Relative Yield (%) wheat	Relative yield (%) barely	Water saving (%)
T0	398.95	37.95	100	100	-
T1	288.24	37.95	62.39	64.13	25.3
T2	310.17	37.95	85.36	89.18	20.32
T3	199.47	37.95	50.46	49.85	45.66

3.3 Irrigation Water use efficiency at grain yield and biomass

Irrigation water efficiency for grain yield (IWUEg) and biomass (IWUEbio) were both influenced by deficit irrigation.

- ***Grain yield***

Differences in IWUEg were significant ($P<0.005$); with LSD: 0.13 and 0.11 for barley and wheat, respectively. The data in Figure 3a and 3b show that the mean IWUEg values expressed as the ratio of yield to total water applied in all treatments ranged from 0.87 to 1.14 kg.m-3forbarley and 0.90 to 1.16 kg m-3 for wheat. The highest IWUEg for barley and wheat were registered in treatmentT2 (1.14 and 1.06 kg m-3) followed by T0 (1.1 and 1.02 kg m-3), however without significant difference between them. The lowest IWUEg value was obtained under treatment T1: 0.87 and 0.90 kg m-3for barley and wheat, respectively. We indicate that the water deficit of 50%applied during grain filling can increase IWUEg for both crops, because of the lower reduction in yield (11% and 15% respectively for barley and wheat), with a lower consumption of about 20.32% (table 4). We also noted that decreasing water supply to 50% until heading stage (T1) affects significantly the reduction of IWUEg for both crops, caused by the reduction of grain yield of 36%; and 38% respectively for barley and wheat, with a lower consumption of about 20.32%.

Our findings comply with the results of Tari (2016), which reported that water deficit applied during stem elongation and heading stages can decreased the IWUE values .Also, they confirm earlier studies(Ali et al., 2007; Tari, 2016) which suggested that deficit irrigation should be applied during late stages, in order to minimize yield reduction.

- ***Growth and biomass***

Figures 3a and 3b show the effect of deficit irrigation treatment on IWUEbio with significant differences ($P<0.005$) and LSD of 0.34 and 0.35, respectively for barley and wheat. The highest value of IWUEbio was measured both for barley and wheat in T2 (3.57 and 3.75 kg m-3 respectively), followed by T3 (3.42 and 3.88 kg m-3, without no significant differences). The lowest value of IWUEbio for barley and wheat was found in treatment T0.The biomass during grain filling generally increased as irrigation frequency increased. In addition, the biomass increased more in the treatments that received irrigation between anthesis and the middle of grain filling (Xue et al., 2006). From previous results, the improvement of IWUEg and IWUEbio in T2 can be explaining buy the lesser water applied and less reduction in grain yield and biomass

(Table 4)

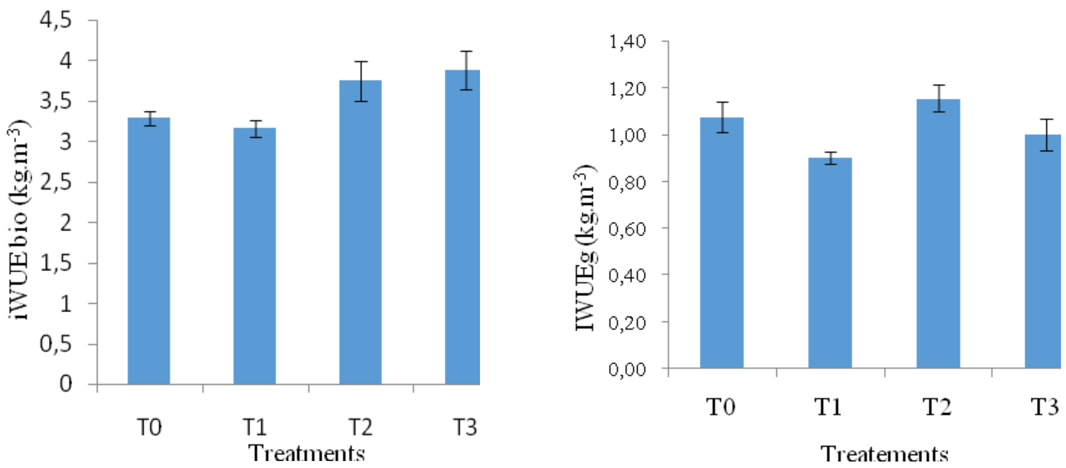

Figure 3a: Irrigation water use efficiency (IWUE) at grain yield and biomass under full and deficit irrigation treatment for Barley

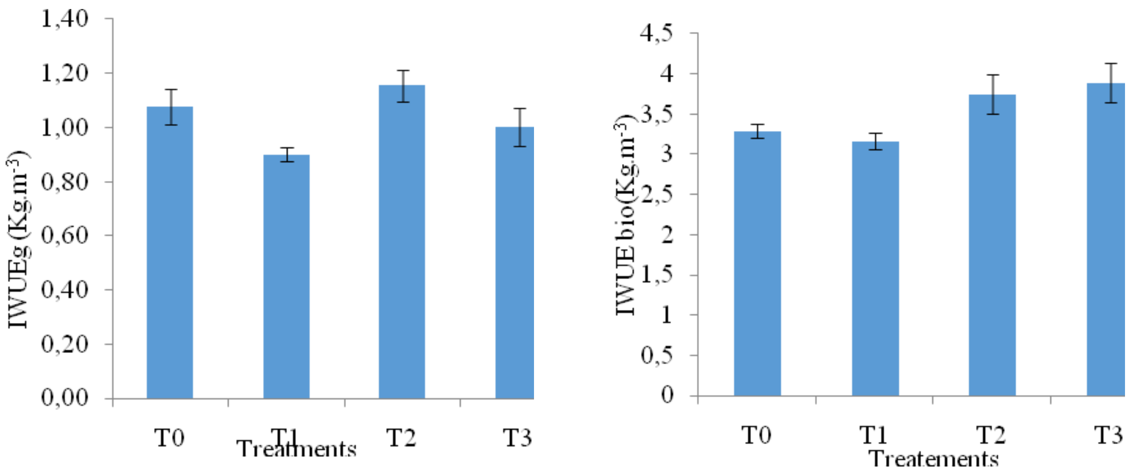

Figure 3b: Irrigation water use efficiency (IWUE) at grain yield and biomass under full and deficit irrigation treatment for wheat

4 CONCLUSIONS

The results of this research trial indicate that barley and wheat show similar responses to deficit irrigation (50%water supply)for T1 (early vegetative stage to heading), T2 (late reproductive stage, filling and maturity), andT3 (alternate deficit from tillering to heading and late reproductive stage) for clay loam to slit clay soil texture. The data show that applying 50% of water supply during last stage for both crops had a lower impact on grain yield (11% and 15%) compared to full irrigation supply, with a reduction of water consumption of 20.32% compared to full irrigation. The highest IWUEg and IWUEbio were obtained in deficit irrigation treatment, applied during grain filling. The findings of this study support the idea that the main objective of an effective deficit irrigation strategy is to improve IWUE grain yield and total biomass by reducing amount of irrigation when stress has the lowest impact to the yield and biomass. Considering the growth stage of the two crops, the water deficit applied in early vegetative growth until heading resulted in a significant reduction of IWUE, both for grain yield and biomass. Therefore, during the stage of grain filling, the irrigation water use for grain yield for both wheat and barley is not significantly different compared to full irrigation. However, the highest irrigation water use of the biomass was found in treatment that received deficit irrigation during grain filling, as compared to the full irrigation.

In conclusion, in water-limited conditions, water deficit should be better shifted to the grain filling stage, in order to minimize the reduction in yield. While the reduction of grain yield cannot be completely avoided, benefits related to water saving for irrigation could well compensate it.

REFERENCES

[1] Ali, M.H., Hoque, M.R., Hassan, A.A., Khair, A., 2007. Effects of deficit irrigation on yield, water productivity, and economic returns of wheat. Agric. Water Manag. 92, 151–161.

[2] Allen, R.G., Pereira, L.S., Raes, D., Smith, M., 1998. Crop evapotranspiration: Guidelines for computing crop requirements. Irrig. Drain. Pap. No. 56, FAO 300.

[3] Amini, A.R.A., Soleymani, A., 2013. Deficits irrigation Effects on Seed Yield and Yield Components of Barley Cultivars. Int. J. Agric. Crop Sci. 5, 782–784.

[4] Andarzian, B., Bannayan, M., Steduto, P., Mazraeh, H., Barati, M.E., Barati, M.A., Rahnama, A., 2011. Validation and testing of the AquaCrop model under full and deficit irrigated wheat production in Iran. Agric. Water Manag. 100, 1–8.

[5] Benkherbache, N., Hassous, K., Mahani, T., Bouazza, D., Djakoun, A., 2009. Which Genotype of Barley (Hordeum Vulgare L .) Can Be Selected in the Algerian Semi-Arid Region ? Res. J. Agric. Biol. Sci. 5, 932–939.

[6] Bouazzama, B., Xanthoulis, D., Bouaziz, A., Ruelle, P., Mailhol, J., 2012. Effect of water stress on growth, water consumption and yield of silage maize under flood irrigation in a semi-arid climate of Tadla (Morocco). Biotechnol. Agron. Soc. Environ. 16, 468–477.

[7] Boutraa, T., 2010. Improvement of Water Use Efficiency in Irrigated Agriculture: A Review. J. Agron. 9, 1–8.

[8] Cattivelli, L., Rizza, F., Badeck, F.W., Mazzucotelli, E., Mastrangelo, A.M., Francia, E., Marè, C., Tondelli, A., Stanca, A.M., 2008. Drought tolerance improvement in crop plants: An integrated view from breeding to genomics. F. Crop. Res. 105, 1–14.

[9] Chenafi, H., A Aidaoui, H, B., A, S., 2006. Yield response of Durum Wheat (Triticum durum Desf.) Cultivar Waha to deficit Irrigation Under semi-Arid Growth Conditions. Asian J. Plant Sci. 5(5).

[10] Doorenbos, J., Pruitt, W.O., 1977. Guidelines for predicting crop water requirements. FAO Irrig. Drain. Pap. 24, 144.

[11] English, M., 1990. Deficit Irrigation. I: Analytical Framework. Irrig. Drain. 116, 399–412.

[12] English, M., Raja, S.N., 1996. Perspectives on deficit irrigation. Agric. Water Manag. doi:10.1016/S0378-3774(96)01255-3

[13] Fereres, E., Soriano, M.A., 2007. Deficit irrigation for reducing agricultural water use. J. Exp. Bot. 58, 147–159.

[14] Geerts, S., Raes, D., 2009. Deficit irrigation as an on-farm strategy to maximize crop water productivity in dry areas. Agric. Water Manag. 96, 1275–1284.

[15] Howell, T.A., 2006. Challenges in increasing water use efficiency in irrigated agriculture, in: International Symposium on Water and Land Management for Sustainable Irrigated Agriculture. p. 11.

[16] Howell, T.A., 2003. Irrigation Efficiency. Encycl. Water Sci. 61, 122. doi:10.1081/E-EWS

[17] ITDAS, 2005., Receuil des Fiches Techniques ITDAS, p160, ITDAS, Biskra

[18] [18] ITGC, 2013. Compagne céréalière 2013-2013. Bull. des Gd. Cult. 8.

[19] Molden, D., Murray-rust, H., Sakthivadivel, R., Makin, I., 2003. A Water-productivity Framework for Understanding and Action. Water 1–18.

[20] Mugabe, F.T., Nyakatawa, E.Z., 2000. Effect of deficit irrigation on wheat and opportunities of growing wheat on residual soil moisture in southeast Zimbabwe. Agric. Water Manag. 46, 111–119.

[21] Oktem, a., Simsek, M., Oktem, A.G., 2003. Deficit irrigation effects on sweet corn (Zea mays saccharata Sturt) with drip irrigation system in a semi-arid region I. water -yield relationship. Agric. Water Manag. 61, 63–74.

[22] Payero, J.O., Tarkalson, D.D., Irmak, S., Davison, D., Petersen, J.L., 2008. Effect of irrigation amounts applied with subsurface drip irrigation on corn evapotranspiration, yield, water use efficiency, and dry matter production in a semiarid climate. Agric. Water Manag. 95, 895–908.

[23] Reeuwijk, van, L.P; 1995. Procedures for soil analysis,Technical Paper 9, 5th edition, International Soil Reference and Information Center, FAO.

[24] Sinclair, T.R., Tanner, C.B., Bennett, J.M., 1984. Water-Use Efficiency in Crop Production. Source Biosci. 34, 36–40.

[25] [Tabarzad, A., Ghaemi, A.A., 2015. Deficit irrigation and sowing date as strategies to maximize water use efficiency and crop water productivity in semi-arid region 7, 30–42.

[26] Tari, A.F., 2016. The effects of different deficit irrigation strategies on yield, quality, and water-use efficiencies of wheat under semi-arid conditions. Agric. Water Manag. 167, 1–10.

[27] Xue, Q., Zhu, Z., Musick, J.T., Stewart, B.A., Dusek, D.A., 2006. Physiological mechanisms contributing to the increased water-use efficiency in winter wheat under deficit irrigation. J. Plant Physiol. 163, 154–164.

[28] Zhang, B., Li, F.M., Huang, G., Cheng, Z.Y., Zhang, Y., 2006. Yield performance of spring wheat improved by regulated deficit irrigation in an arid area. Agric. Water Manag. 79, 28–42.

[29] Zwart, S.J., Bastiaanssen, W.G.M., 2004. Review of measured crop water productivity values for irrigated wheat, rice, cotton and maize. Agric. Water Manag. 69, 115–133.