Al-Qadisiyah Journal For Agriculture Sciences (QJAS)
ISSN : 2618-1479 Vol.13, Issue. 1 ,(2023), pp. 87-95
https://jouagr.qu.edu.iq/

Effect of Supplemental Irrigation on Durum Wheat (*Triticum durum)* Crop and Water use Efficiency under a Saline Environment in the Lower Cheliff Plain

Djamal BELLAGUE[1], Ibrahim YAHIAOUI[2] , Abdelhamid GACEMI[3], Azziz LARICHE[4] , Mohamed RATA[5] and Abdelkrim KHALDI[6]

[1,3,4,6]National Institute of Agronomic Research of Algeria, El Harrach, Algeria.
[2,5]Laboratory of Crop Production and Sustainable Valorization of Natural Resources (PRAVDUR), Faculty of Nature, Life and Earth Sciences, Department of Ecology, University Djilali Bounaama of Khemis Miliana, Algeria.

[1]E-mail: bellague@yahoo.fr
[2]E-mail: i.yahiaoui@univ-dbkm.dz
[3]E-mail: abdelhamid_gacemi@yahoo.fr
[4]E-mail: laricheazziz@yahoo.fr
[5]E-mail: m.rata@univ-dbkm.dz
[6]E-mail: Khaldiabd@gmail.com

Abstract. In Algeria, the launching of projects encouraging the practice of supplemental irrigation on cereals to increase productivity and the sustainability of farms in arid and semi-arid regions is confronted with the problems of water use efficiency and soil quality conservation. The use of poor-quality irrigation water for supplemental irrigation is subject to secondary salinization processes, which become worse over time. The present paper aims to study the impact of supplemental irrigation on the increase of durum wheat yield, water use and soil salinization, a trial was set up in the soil of the HMADNA experimental station (RELIZANE, Lower-Cheliff). The experimental set-up is a randomized block with three replications and five treatments (water regime): T1 rainfed, T2 irrigated at tellering stage (T), T3 irrigated up to booting stage (TB), T4 irrigated up to heading stage (TBH) and T5 irrigated up to grain filling stage (TBHF). The parameters studied were: grain yield (GrYd), water consumption or actual evapotranspiration (AET), water use efficiency (WUE), soil salinity (EC) and water satisfaction rate (Ts). The analysis of the variance of the measured parameters showed significant to highly significant differences. Under the experimental conditions of the study site, the supplemental irrigation corresponding to the T5 water regime with an AET of 543mm, contributed significantly to the increase in grain yield up to 62.64 Qx/ha with a WUE of 11.83 Kg/ha/mm and a Ts of 96.31%. Moreover, an irrigation water quantity of near 113mm at the end of the wheat vegetative cycle (grain filling stage) causes the leaching of salts from the surface layer (H0-20cm) previously acquired during the vegetative cycle of the crop. The behavioural study of the saline profile showed that the salinity of the H20-40cm layers undergoes a secondary salinization process with an increased rate ranging from 100% to 220%. In saline environments, the contribution of supplemental irrigation is very important to ensure sustainable food security within specific phenological stages (end of cycle) according to the prevailing climatic conditions of the area while meeting the water needs of the crop.

Keywords. Supplemental Irrigation, Phenological stages, Grain Yield, Water use efficiency, Saline profile.

1. Introduction

In Agriculture, rainfed crops remain dependent on rainfall and its space-time distribution [1] and the cereal management technique can only be reasoned in terms of risks [2]. With the remarkable climate change and meteorological drought ratesrecorded during the last three decades, durum wheat yields are at an uncompetitive level, according to, is argued that since 1970, durum wheat production has not been able to meet the needs of the local population.

During a year with significant rainfall deficits, terminal water stress is the limiting factor in the yield of the rainfed cereal crop [4]. Furthermore, [5], find that more than 75% of the variation in wheat yield is caused by rainfall variability.

In arid and semi-arid areas, water availability is a limiting factor for agricultural production. The use of irrigation is a strategic choice for the development and maintenance of agricultural activity [6]. However, irrigation water quantity/quality fundamentally affects both soil and crops.

On a global scale, secondary salinization through irrigation practices affects around 20% of irrigated land [7].

Nevertheless, Algerian agricultural authorities have launched keyprojects aiming to encourage the practice of supplemental irrigation on cereal cropping to increase productivity and farming sustainability in arid and semi-arid regions that adhere to it.The main challenge was to confront the problems related to water use efficiency and the conservation of the quality of their soils. The Lower-Cheliff region is, on one hand, characterized by poor groundwater quality [8,9], and is subject to a secondary salinization process which may be the consequence of cumulative supplemental irrigation practices. On the other hand, the surface water coming from the local GARGAR dam with an electrical conductivity of 1.6 dS/m is the only irrigation source widely used by almost all farmers there.

Given Algeria's limited water potential, the use of a rational irrigation technique was necessary and compulsory. Supplemental irrigation is one technique among others that aims at the rational use of water. The timing and quantity of water applied not only allows for water use efficiency but also contribute to the preservation of soil quality. Therefore, it is necessary to know how to manage the little water available in the time dimension through the phenological phases most sensitive to water stress.

For this purpose, an experiment is conducted under the conditions of the Lower-Cheliff plain, on a strategic crop (durum wheat) conducted over several rounds of supplemental irrigation. Thus, we studied the effect of the cumulative water supply on crop behaviour, the efficiency of water use and the contribution to the desalination of the soil’s surface layer. Also, its contribution to rising farmers' awareness about the necessity of supplemental irrigation under water stress conditions.

2. Materials and Methods

2.1. Study Site

Our experiment was conducted at the Relizane research station of the Algerian National Institute of Agronomic Research (INRAA). It is located between 35° 54' N and 0° 47' E at 48m altitudes, in a region belonging to the semi-arid bioclimatic stage (Figure 1).

The physicochemical analysis of the experimental plot soil on a depth of 35 cm, reveals a clay-silt texture (47.19% clay, 42.11% silt and 10.7 sand), pH of 7.95, a low salinity level of 0.42 dS/m for the 0-20cm horizon and 0.59 dS/m for the 20-40cm horizon, with an average bulk density of 1.48 and a moisture content at the field capacity of 35% [10].

2.2. Experimental Plotting

The adopted experimental set-up is a randomized complete block design (R.C.B.D.) with three replications and elementary plots measuring six square meters (3x2 m^2). Five is the number of treatments (water regime), corresponding respectively to T1 rainfed, T2 irrigated at tellering stage (T), T3 irrigated at booting stage (TB), T4 irrigated at heading stage (TBH) and T5 irrigated until grain filling stage (TBHG). The supplementary irrigation applied, aims to bring the soil to the retention capacity.

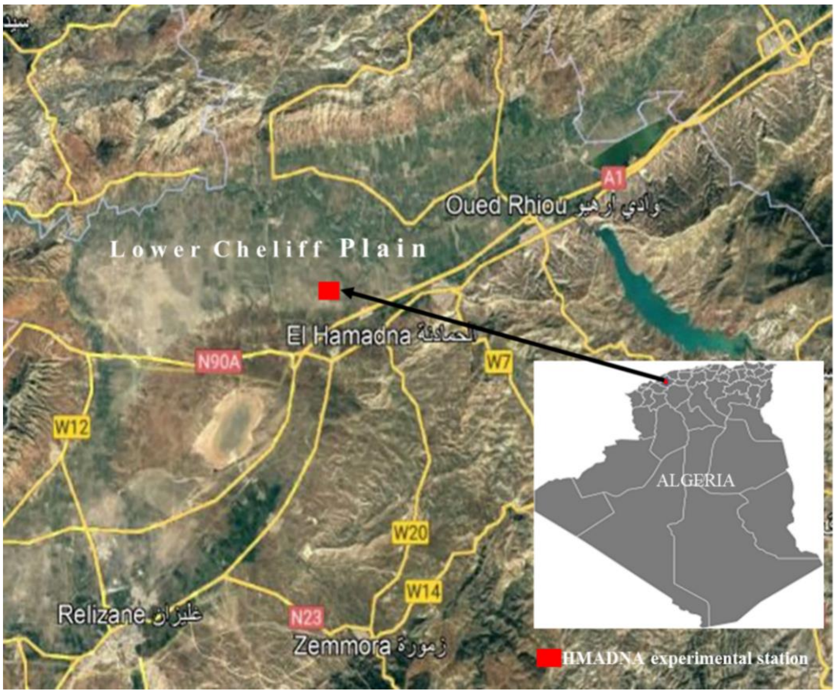

Figure 1. Location of the experimental site.

2.3. Plant Material and Trial Set-Up

The plant material used is durum wheat (*Triticum durum*, variety: Waha). It is a variety originating from Spain, semi-early, better adapted to arid and semi-arid regions with good productivity [2]. It is a cereal that is cropped in our study area. After the preparation of the seedbed, the semi-planting was carried out manually on December 11th, with a dose of 120 kg/ha. A pre-irrigation of 10mm is provided to ensure the start crop germination process. Nitrogen fertilisation was applied with a dose of 80kg/ha (urea 46%).

2.4. Determination of the Water Supply

The amount of irrigation water to be applied for each treatment is calculated using a simplified water balance carried out with an agronomic auger. For the latter, a water profile is necessary (current moisture in percentage, Ha) to a depth corresponding to the rooting depth of the crop (0-20cm, during the vegetative period and 0-40cm for the reproductive period). The irrigation rate consists of bringing the actual moisture to the field capacity [11]. This method allows the yield components to develop under good water conditions [12,13].

Thus, the following formula is applied:

$$\text{Dose(mm)} = \text{da} * \text{p} * \frac{H_{cc} - H_a}{100}$$

Where:

Dose (mm), the amount of irrigation water to be applied in millimetres

p, depth of soil explored by the roots (millimetre)

Hcc: Weight moisture at field capacity (percent)

Ha: Current weight moisture (percent)

The irrigation water used is classified as C3S1 with an electrical conductivity of 1.68 dS/m and a SAR of 2.61. It is poor water [14,15]. Used for most field crops, but can cause secondary salinization if leaching and drainage are not adequate.

For all treatments, a pre-irrigation of 10mm is ensured for crop germination. Irrigation is carried out with a showering device, to homogenize the quantity of water brought on the whole elementary plot. Figure (2) below shows the distribution of rainfall and the amount of irrigation water applied for each treatment.

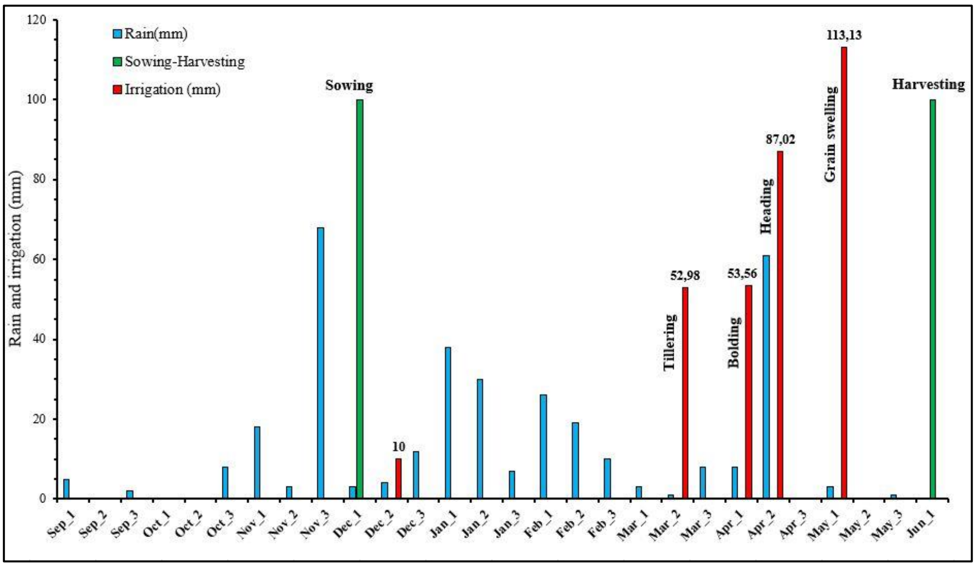

Figure2. Distribution of rainfall and irrigation over the crop cycle.

2.5. Grain Yield and Water use Efficiency

Through our experiment, we estimated the grain yield at the end of the physiological maturity (harvest), by the production of the middle square meter of each elementary plot. The water consumption for each treatment is estimated through a simplified water balance. For this purpose, a water profile is made over a depth of 60cm with 20cm steps. The consumption formula is as follows:

$$AET(mm) = P + I \pm \Delta S$$

AET, Actual Evapotranspiration (water consumption, mm)
P, cumulative rainfall over the crop cycle (mm)
I, irrigation provided over the cycle (mm)
ΔS, the difference in water stock in the water profile between the beginning and end of the crop cycle (mm)
Thus, water use efficiency (WUE) is calculated as the ratio of yield to the corresponding water consumption [16,17,18]. It is calculated as follows:

$$WUE(Kg.ha^{-1}.mm^{-1}) = \frac{\text{Grain Yield }(\frac{Kg}{ha})}{AET(mm)}$$

2.6. Electrical Conductivity and Saline Profile

After harvesting, a salt profile is carried out to a depth of 60cm with a 20cm step. The soil samples obtained are dried in the open air, crushed and sieved to 2mm. The electrical conductivity of the diluted extract (soil/water ratio: 1:5) is measured with a conductivity meter. The values obtained are classified according to the [19] method.

Table 1. Salinity classes according to electrical conductivity classification [18].

Salinity class EC ($dS.m^{-1}$)	**0-0.6**	**0.6-1**	**1-2**	**2-4**	**>4**
Level	Non-saline	Slightly saline	Moderately Saline	Highly saline	Extremely saline

2.7. Statistical Analysis

We applied the analysis of variance (ANOVA) at the NEWMAN-KEULSclassification criterion, using the XLSTAT software 2014. The obtained results for (GrYd,WUE, and AET) are at a significance level of 5%. On the other hand, theelectrical conductivity EC was studied for comparison with the literature-predefined salinity classes.

DOI: 10.33794/qjas.2023.136405.1092

3. Results and Discussion

3.1. Effect of Supplemental Irrigation on Grain Yield

The obtainedyields are proportional to the amount of water consumed. Grain yields varied from a minimum of 15.19 Qx/ha for the rainfed treatment to a maximum of 62.64 Qx/ha for the T5 treatment (Figure 3). The average yield value obtained was 34.32 Qx/ha. [2], on the same wheat variety and under the same climatic conditions and water regime, found a maximum yield of 62.47 Qx/ha under a permanent water regime from emergence to physiological maturity.

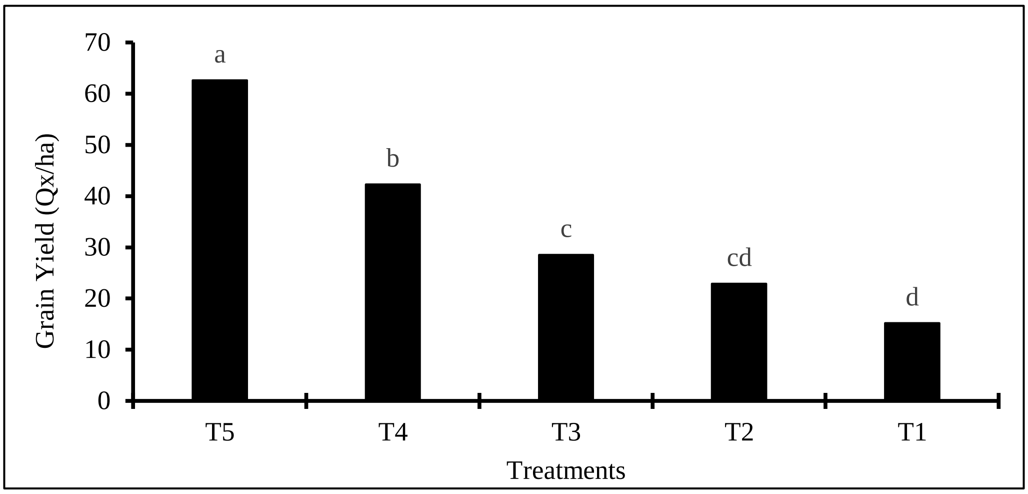

Figure 3. Evolution of grain yield as a function of water regime.

From the study of the analysis of variance, we found a highly significant difference. The improvement in grain yield of the crop was around 50.82%, 88.02%, 178.47% and 312.38%, for the T2, T3, T4 and T5 water regimesrespectively compared to the T1 rainfed control. The rate of improvement found is confirmed by the work of [20] on the application of supplemental irrigation on soft wheat in Tunisia. Indeed, he found a rate of improvement of 308% between the rainfed and irrigated regimes.

The rate of improvement became very important startingfrom theirrigation stageat the grain earing to the grain enlargement stage. During this phase, in addition to the irrigation provided, there was a significant rainfall of about 60mm in the second ten days of April. [21], argue that supplemental irrigation at the end of the cycle is necessary from April onwards, as a water deficit during this period penalizes wheat yields. A study carried out on irrigated wheat under the climatic conditions of the Middle Cheliff showed that irrigation during the heading-flowering phase improved the index of satisfaction of the crop's water needs [22].

3.2. Water Consumption (AET) and Water use Efficiency (WUE)

The WUE varies from a minimum of 6.52 kg/ha/mm for the rainfed regime to a maximum of 11.83 Kg/ha/mm for the T5 treatment. The mean value of the experiment is 8.93 Kg/ha/mm. The analysis of variance at the 5% significance level showed a solid difference. The maximum value is very close to the one found by [23]. [24], on three years of experimentation on durum wheat including Waha, conducted under irrigation, found an average efficiency of 10.03 Kg/ha/mm with average water consumption of 543mm (406.33mm rainfall and 136.67mm irrigation).

The obtainedresults showed that supplemental irrigation is considered a technique that improves water use efficiency. In contrast, treatments T2, T3, T4 and T5 generated, respectively, an increase of 22.70%, 29.45%, 51.53% and 81.44% compared to the rainfed control (Figure 4)

The water consumption (AET) increased from 233.68mm in the rainfall regime (T1) to 529.71mm in the water regime T5, with an overall mean value of 363.07mm. This important difference was also detected using the analysis of variance at the 5% level. The water requirement of cereals is between 450mm and 650mm, the average value is 550mm/year [25]. Of these, we can say that the water satisfaction rate (Ts) is 42.49%, 51.97%, 61.51%, 77.78% and 96.31%, respectively for treatments T1, T2, T3, T4 and T5, with an average value of 66.01%.

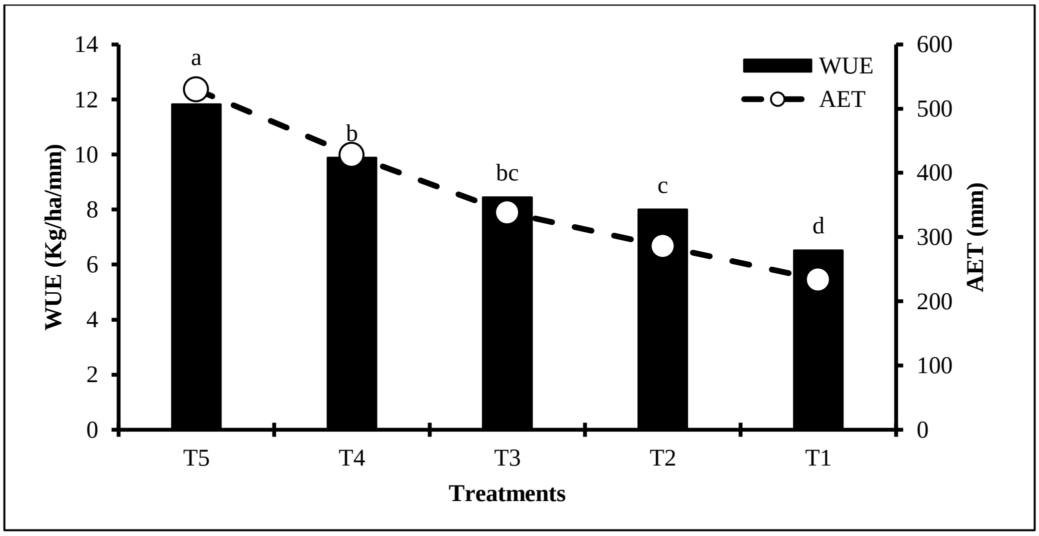

Figure 4. Variation of WUE and AET according to the water regime.

3.3. Effect of Supplemental Irrigation on the Evolution of the Saline Profile

Figure 5 displays anascendinggeneral pattern of the resulting salinity profiles. This means that for all the appliedwater regimes, salinity from lower layers remains higher than those of the upper layers, this indicates a desalination phenomenon per layer. Indeed, the loss of salinity of the upper layer is recovered by the lower layer and so on until the H40-60cm layer.

The evolution of the electrical conductivity of the H0-20cm horizon is inversely proportional to the treatment applied. The regression of salinity increased by 18.33%, 19.62% and 22.70% compared to the control (T1) for water regimes T2, T3, and T4 respectively, reaching a rate of 64.22% for water regime T5. The salinity went from the lower saline class (T1) to slightly saline for treatments T2, T3, and T4 and to the non-saline class for treatment T5.

For the horizon H20-40cm, the regression is 7.35% on average for treatments T2 and T3 and 34.80% for treatments T4 and T5. The salinity remains in the saline class at different salinity levels. The values are decreasing from regime T1 to T5, with maximum values of 1.89 $dS.m^{-1}$and a minimum value of 1.24 $dS.m^{-1}$

For the H40-60 horizon, soil salinity is remarkably high for the T1 and T2 water regimes. Then the EC regresses to the saline class without exceeding the value of 1.47 $dS.m^{-1}$.

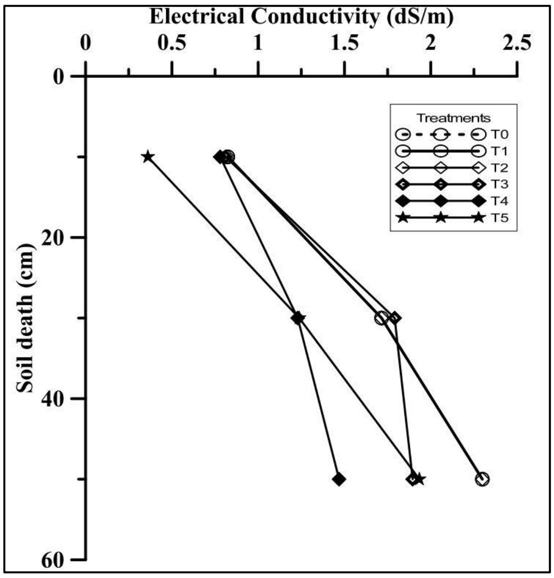

Figure 5. Evolution of the saline profile as a function of the water regime.

Depending on the testedinitial EC value of 0.42 dS/m from the H0-20cm soil horizon, a secondary salinization process was detected for the T1, T2, T3 and even T4 water regimes, with respective growth rates of 140.24%, 96.19%, 93.10% 85.71%. On the other hand, the T5 regime contributed to significant desalination. The water level brought in during the grain growth phase (113.3mm), eliminated the salinity acquired previously.
Depending on the EC value (H20-40), secondary salinisation is present with growth rates varying from 100% to over 200%.

3.4. Selection of the Best Water Regime

The selection of the best treatment (water regime) is based on the hierarchical ascending classification (HAC) of the studied parameters (GrYd, WUE, EC and Ts). Only the H0-20cm horizon was considered, where the soil is the first to be exposed to climatic conditions and water inputs (Figure 6).
This analysis reveals the classification of treatments into three distinct classes (Figure 6). Each class is represented by a central element. Overall, from Table (2), it appears that the T5 treatment is the treatment that gave good results. Indeed, this treatment corresponds to a water regime during the vegetative cycle. Irrigation at the beginning of the cycle allows early soil coverage, decreases soil evaporation and increases WUE [26]. A good water regime from the three-node phase to grain enlargement allows compensating the loss of ear stand by a fertility of the upper ears, which leads to a good yield [27]. Supplemental irrigation during growth and flowering significantly improves water satisfaction in wheat crops [22]. Post-grain heading water use increases grain yield, which is positively correlated with the amount of water applied [28]. In the Mediterranean environment, good climatic conditions during the grain-filling period are important for better grain quality [29].

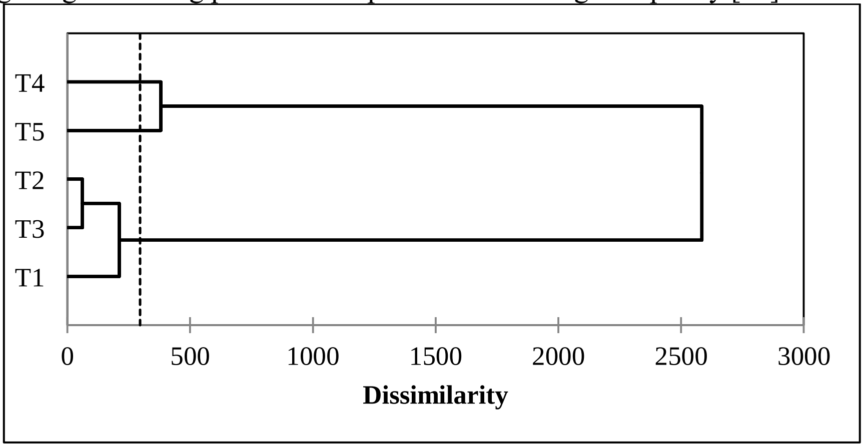

Figure 6. Hierarchical Ascending classification (HAC).

Table 2. Characterization of the central elements of the HAC classes.

Class	Gr_Yd	WUE	EC	Ts%
1 (T5)	62,64	11,83	0,36	96,31
2 (T4)	42,30	9,88	0,78	77,78
3 (T2)	22,91	8,00	0,82	51,97

The T5 water regime seems to be the best treatment. Indeed, it gave the highest grain yield, the best WUE, with a very high satisfaction rate and itbrings the EC of the surface soil layer to its initial state (T0) and regresses it compared to the control (T1).

Conclusion

The obtained grain yields for durum wheat are proportional to the consumedamount of water. They ranged from 15.19 for treatment T1 to 62.64 Qx/ha for treatment T5. The ANOVA showed a highly significant difference among applied treatments. The yield improvement reached a rate of 312.38% for the full irrigation regime (T5) compared to the rainfed regime (T1). This improvement was caused by the late irrigation and the 60mm of rainfall during the month of April.

DOI: 10.33794/qjas.2023.136405.1092

The WUE varied from a minimum of 6.52 (T1) and 11.83 Kg/ha/mm for the T5 treatment, with an overall average of 8.93 Kg/ha/mm. These significant variations came from the appliedANOVA, at the 5% threshold.

Supplemental irrigation improved the WUE of the applied regimes compared to the rainfed regime, with rates ranging from 22.70% to 81.44%. Water consumption (AET) increased from 233.68mm in the rainfed regime (T1) to 529.71mm in the T5 regime. The latter remains within the standards of water requirements for wheat cropping (450-650mm).

The general gradient of the analysed saline profiles is ascending. The evolution of the electrical conductivity of the 0-20cm horizon is inversely proportional to the treatment applied. The salinity regression increases progressively by 18.33%, 19.62% and 22.70% compared to the control (T1) for the T2, T3 and T4 water regimes respectively, to reach an exponential rate of 64.22% for the T5 water regime. The salinity went from the lower saline class (T1) to slightly saline for treatments T2, T3, and T4 and to the non-saline class for treatment T5.

For the horizon 20-40cm, the salinity remains in the moderate saline class at different salinity levels. The salinity values decrease from 1.89 dS/m (T1) to 1.24 dS/m (T5). For the 40-60 cm horizon, the soil is very saline for the T1 and T2 water regimes. Then the EC decreases to the moderate saline class without exceeding the value of 1.47 dS/m.

We selected the best treatment (water regime) using the hierarchical ascending classification (HAC) of the studied parameters (GrYd, WUE, EC at 0-20cm and Ts). Herein, only the 0-20cm horizon was considered due to the direct exposition of soil to climatic conditions and water inputs.

Overall, it appears that T5 is the treatment that gave good results. Indeed, it gave the highest grain yield, the best WUE, with a very high satisfaction rate and it returned the EC of the H0-20cm soil layer to its initial state (T0) and regressed it compared to the control (T1).

References

[1] D. Smadhi, Mouhouche B, Mohammed M, Semiani M (2002). Bilan hydrique et besoin d’irrigation de la céréaliculture en zone semi-aride. Revue H.T.E., 124, 53-56.

[2] Bouthiba, Optimisation de l’irrigation de complément du blé dans la région de Chlef (Thèse de doctorat, université Hassiba Benbouali, Chlef, 2007).

[3] D. Smadhi, Zella L (2009). Céréaliculture en sec et précipitations annuelle : le cas du Nord del’Algérie. Revue Secheresse,20, 2, 2009, 199-203.

[4] ITGC,L’irrigation d’appoint des céréales d’hiver (Institut Technique des Grandes Cultures, Fiche technique, 1997).

[5] Blum, Pnuel Y (1990). Physiological attributes associated with drought resistance of wheat cultivars in a Mediterranean environment. Australian Journal of Agricultural Research, 41, 5, 799-810.

[6] J.J. Musa, Mustapha I.A, Yerima I.Y, Kuti I.A, Abogunrin M.E (2016). Evaluation of irrigation application efficiency: case study of chanchaga irrigation scheme. Arid Zone Journal of Engineering, Technology and Environment, 12, 58-64.

[7] S. Wood, Sebastian K, Scherr S.J (2000). Soil resource condition. In: Wood S, Sebastian K, Scherr S.J (Eds.), Pilot Analysis of Global Ecosystems. IFPRI and World Resources Institute, Washington, DC., 108p.

[8] Douaoui, Hartani T, Lakehal M (2006). La salinisation dans la plaine du Bas-Cheliff: acquis et perspectives. Economies d'eau en Systèmes IRrigués au Maghreb. Deuxième atelier régional du projet SIRMA.

[9] Bradai, Douaoui A, Hartani T (2012). Some Problems of Irrigation Water Management in Lower Cheliff Plain (Algeria). Journal of Environmental Science and Engineering A1, 3, 271-278.

[10] Bellague, Mhammedi-Bouzina M, Abdelguerfi A (2016). Measuring the performance of perennial alfalfa with drought tolerance indices. Chilean Journal of Agricultural Research, 76, 3, 273-284.

[11] A.S. Ati, Dawod S.S, Abdeljabbar I.A (2013). Effect of pulverization tools and deficit irrigation treatment on water use efficiency and yield of barley. Al Qadisiay Journal for Agriculture Sciences, 3, 1, 134-141.

[12] Soomro, Mirjat M.S, Oad F.C, Soomro H, Samo M.A, Oad N.L (2001). Effect of irrigation intervals on soil salinity and cotton yield. Journal of Biological Sciences, 1, 6, 472-474.

[13] M. Mouhouche, Bourahla A (2007). Optimisation de l’irrigation d’appoint apportée à différentes phases phénologiques d’une culture de blé dur (Triticum durum). Revue Sciences et Technologie/C, Biotechnologie, 25, 53-58.

[14] L.A. Richards, Diagnosis and improvement of saline and alkali soils (Agriculture Handbook n°60, USSL, Washington, 1954).
[15] R.S. Ayers, Westcot D.W (1985). Water quality foragriculture. FAO Irrigation and drainage paper,nr29, Rev.1, Rome, Italy, 186 p.
[16] P.J.M. Cooper, Gregory J, Tully D, Harris H.C (1987). Improving water use efficiencyof annual crops in the rainfed farming systems of West Asia and North Africa.Experimental Agriculture, 23, 2, 113-158.
[17] S.J. Zwart, Bastiaanssen W.G.M (2004). Review of measured crop water productivity values for irrigated wheat, rice, cotton and maize. Agricultural Water Management, 69, 2, 115-133.
[18] Q.P. Sun, Kröbel R, Müller T, Römheld V, Cui Z.L, Zhang F.S, Chen X.P (2011). Optimization of yield and water-use of different cropping systems for sustainable groundwater use in North China Plain. Agricultural Water Management, 98, 808-814.
[19] Mathieu, Pieltain F, Analyse chimiques des sols: Méthodes choisies (Editions TEC and TOC, Londres, Paris, Nez York, 2001)
[20] Daroui, Boukroute A, Kajeiou M, Kouddane N, Berrichi A (2011). Effet de l'irrigation d'appoint sur le rendement d'une culture de blé tendre (Triticum aestivum L.) (Variété Rajae) au Maroc Oriental. Nature et Technologie, 5, 80-86.
[21] N.V. Duivenbooden, Pala M, Studer C, Bielders C.L (1999). Efficient soil water use: The Key to sustainable crop production in the dry areas of west Asia and North and sub-Saharan Africa. In: Proceedings of the Workshops organized by the optimizing Soil Water Use Consortium. Niamey. Niger, 26-30 April 1998 and Amman. Jordan. 9-13 May 1999. International Center for Agric. Res. in the Dry Areas (ICARDA). Aleppo, Syria, p490.
[22] B. Merabet, Bouthiba A (2006). Etude du comportement de la variété de blé dur améliorée Tassili conduite en sec et en irrigué vis-à-vis de la variabilité de la pluviométrie interannuelle et de l'efficience d'utilisation de l'eau. Annales de l'Institut National d'Agronomie, 27, 1-2, 107-118.
[23] Bouthiba, Debaeke P, Hamoudi S.A (2008). Varietal differences in the response of durum wheat (Triticum turgidum L. var. durum) to irrigation strategies in a semi-arid region of Algeria. Irrigation Science, 26, 3, 239-251.
[24] Merouche, Debaeke P, Messahel M, Kelkouli M (2014). Response od durun xheat varieties to water in semi-arid Algeria. African Journal of Agricultural Research, 9, 38, 2880-2893.
[25] Brouwer, Herbloem M (1986). Irrigation water management : irrigation water needs, training manual nr3, FAO, 102p.
[26] M. Rezgui, Zairi A, Bizid E, Benmechlia N (2005). Consommation et efficacité d'utilisation de l'eau chez le blé dur (Triticum Durum Desf.) cultivé en conditions pluviales et irriguées en Tunisie. Cahier Agriculture, 14, 4, 391-397.
[27] Bouthier, Deumier J.M, Bonnifel J.P (2000). Management of water resources : To optimize irrigation of cereal crops. Perspectives Agricoles, 256, 79-84.
[28] K.H.M. Siddique,Regan K.L, Tennant D, Thomson B.D (2001). Water use and water use efficiency of cool season grain legumes in low rainfall Mediterranean-type environments. European Journal of Agronomy, 15, 4, 267-280.
[29] Y. Rharrabti, Royo C, Villegas D, Aparicio N, Garcia del Moral L.F (2003). Durum wheat quality in Mediterranean environments : I. Quality expression under different zones, latitudes and water regimes across Spain. Field Crops Research, 80, 2, 123-131.