CODEN [USA]: IAJPBB ISSN: 2349-7750

INDO AMERICAN JOURNAL OF
PHARMACEUTICAL SCIENCES

http://doi.org/10.5281/zenodo.1218223

Available online at: http://www.iajps.com *Research Article*

CONTROL OF SUPPLEMENTARY IRRIGATION AND WATER REQUIREMENTS FOR DURUM WHEAT IN THE F'KIRINA PLAIN

Sihem Fellah[1,2,*], Abdelkader Khiari[1,2], Mohammed Kribaa[1,2], Abdelkrim Arar[3], Haroun Chenchouni[4]

[1] Department of Natural and Life Sciences, Faculty of Exact Sciences and Natural and Life Sciences, University of Oum-El-Bouaghi, 04000 Oum-El-Bouaghi, Algeria.

[2] Laboratory of Natural Resources and Management of Sensitive Environments 'RNAMS', University of Oum-El-Bouaghi, 04000 Oum-El-Bouaghi, Algeria. Emails: hhkhiari@yahoo.fr; kribaa58@gmail.com

[3] Department of Ecology and Environment, Faculty of Natural and Life Sciences, University of Batna 2, Fesdis 05078, Algeria. Email: bionacer@yahoo.fr

[4] Department of Natural and Life Sciences, Faculty of Exact Sciences and Natural and Life Sciences, University of Tebessa, 12002 Tebessa, Algeria. Email: chenchouni@gmail.com

Abstract:

Two regimes of water, rainfed and irrigated with respect to rainfall and the stages of cultivation were applied on two varieties: Gta-Dur and Vitron. The period (2014-2016) was characterized by a large variability in the distribution of rainfall amounts. Precipitation recorded between December 2014 and May 2015 totaled 232 mm, while precipitation was very low in the second year (2015-2016) when precipitation amounted to 173 mm.

Rainfed grain yields range from 9 quintals per hectare in 2014 to 12 the two varieties are considered less productive in rainfed, their yield remains lower than 20 quintals per hectare but presents a better stability, they are less affected by early drought.

The use of water must be maximized in the form of transpiration optimize production. Therefore, reducing the evaporation and simultaneously improving water storage or holding capacity and also controlling weeds are the key-procedures in order to improve the CWP by the plant. Thus, optimizing the productivity of water in rainfed crops and improving cereal yield in cropping systems with limited water requires the maximization of precipitation for transpiration by reducing losses of soil water.

Keywords: *Durum wheat; supplementary irrigation, varieties; semi-arid, yield components, water productivity.*

Corresponding author:

Fellah, S.,

Department of Natural and Life Sciences,
Faculty of Exact Sciences and Natural and Life Sciences,
University of Oum-El-Bouaghi, 04000 Oum-El-Bouaghi, Algeria.
Email: fellah_sihem@yahoo.fr

QR code

Please cite this article in press Fellah, S et al., ***Control of Supplementary Irrigation and Water Requirements for Durum Wheat in the F'kirina Plain,*** *Indo Am. J. P. Sci, 2018; 05(04).*

INTRODUCTION:

In Algeria, the total area of the national territory is 238 million hectares. 42 million with an agricultural vocation of which 8.4 million hectares are useful. Cereal production in Algeria no longer covers the needs of the population since 1970 [1], wheat hard being the main straw cereal grown on 47% of the cereal sole [2]. In those areas where the average annual rainfall is less than 450 mm, the yield of durum varies between 7 and 10 q / ha and inter-annual variability is high due to an increasingly erratic rainfall distribution [1,3].

In this environment, water stress can occur at any point in the cycle cultural [4]. Once the soil water present at the plantation in November is exhausted, the amount of rain received in the spring will determine the level of yield in the absence of irrigation complement [5]. Thus, if the drought occurs during the two weeks preceding the heading, it can reduce the number of grains per spikelet[6], while the lack water at the end of the cycle reduces the weight of the grain [7]. The number of spikes per m² will be reduced by a drought that begins when wheat is tilled [8].

A relatively small number of durum wheat varieties are grown in Algeria come from local populations or from a fairly recent introduction [9]. Local genotypes are characterized by low yield potential but enough stable. In contrast, introductory genotypes achieve a high potential of production but only in favorable water and thermal conditions. That is why, to develop this potential and stabilize production, the irrigation of durum wheat has been proposed in complement of varietal choice [10]. The overall objective of this study is to determine the water requirements of durum wheat and the control of supplementary irrigation of durum wheat in the semi-arid zone. This requires analysis results of these experiments in terms of the overall response of the crop to irrigation and in terms of water productivity achieved. This contribution systematically returns to a context of regional and national economic profitability. We plan to reach aset of recommendations will be made to advise on better optimization of supplementary irrigation in semi-arid zones.

MATERIALS AND METHODS:

Study area

The plain of F'kirina is located in the province of Oum-El-Bouaghi (northeastern Algeria), it is bordered by the Constantinian High Plains, the Mountains of Mellegue, Harectas and Nememchas. Its surface area is about 650 km^2 (Fig. 1). The plain of F'kirina belongs to the sub-watershed of Garaet Tarf (2430 km²), which is a part of the watershed of Hauts-Plateaux Constantinois (9578 km²). Evapotranspiration and infiltration of runoff in this area are dependent of several factors including watershed steep slope, geological nature of outcrops, climate characteristics, and vegetation [11].

The study area is characterized by a semi-arid Mediterranean climate. The coldest moth is January and the hottest month is July. The rainy season occurs between October and March; the rest of the year is considered dry (Fig. 2). During the two study crop years (2014–2015 and 2015–2016), the highest temperature was recorded during May with 26.8 in 2015 and 18.6 °C in 2016. While the coldest month was December with 2.4 °C in 2014 and 1.0 °C in 2015. The rainfall occurred between December 2014 and May 2015 totaled 232 mm, while the rainfall was very low during the 2nd year (2015–2016) where precipitation totaled 173 mm.

Plant material

Two varieties of durum wheat were selected as a test plant in our experiments: the GTA-Dur variety (characterized by a short development cycle of 157 days with a flowering period of 123 days) and the Vitron variety which at the beginning of its life cycle stages, has a slight delay in maturation compared to the GTA-Dur variety. This delay varies between 4 and 49 days with a difference of 7 days at the end of the cycle [12].

Study and experimental design

In order to avoid the effects of the slope in the study plots, the experimental design adopted was the complete random block type for the two tests. The elementary plots were of 6 square meters (2 × 3 m). Sowing was carried out in mid-December each year with a density of 250 grains/m² and 92% of lifting rate. The first experimentation comprised two extreme water regime treatments. The first treatment conducted in maximum evapotranspiration (ETM) during all the vegetative cycle, and the second was carried out under in rain mode (Pluv). The second experimentation consisted of four water treatments (T1, T2, T3 and T4) corresponding to the timing of supplementary irrigations that matched four wheat growth phases: tillering, heading, flowering and grain growth (Table 1). Each treatment was repeated three times (*i.e*. three elementary plots). Irrigation was done by means of watering cans to homogenize the quantity of water over the whole plot. Outside the supplementary irrigation period and with the exception of the ETM treatment, all treatments were conducted under rainfed conditions (without irrigation).

The number of blocks was two for the first test and four blocks for the second test, each block contained three micro-plots corresponding to the two varieties studied. Therefore, with a total of eighteen micro-plots for each varieties thus making 36 elementary plots for the whole device per crop year. The field work carried out consisted of deep plowing in March and September followed by two cover crops with spreading of basic fertilizer: T.S.P. (triple superphosphate 46%) at 1.5 quintal/ha. In March–April, nitrogen fertilizers were applied in the form of urea 46% at a rate of 1.5 quintal/ha. Chemical weed control is carried out, just after nitrogen fertilization, with the GrandStar [Methyl triberunon] at a rate of 12 g/ha.

Estimation of water requirements of durum wheat

The water requirements of a crop represent the height of water needed to ensure the equivalent of maximum evapotranspiration of a crop in good health, under non-limiting water and fertility conditions, thus leading to a potential yield under given climatic conditions [13]. They are expressed by the notion of cultural maximum evapotranspiration (ETM) defined by daily evapotranspiration (in mm per day) of a given crop related to the crop stage, maximum environmental conditions, and cultural practices [14]. The daily quantities of water to be supplied for the ETM plot were determined by calculating the evapotranspiration using the following formula: $ETM=Kc \times ET_0$, whereET_0: reference evapotranspiration, *Kc*: crop coefficient. The coefficient *Kc* varies from 0 to 1.2 and depends on the growing stage of the culture. A set of *Kc* values allows the evaluation of water requirements of cereals according to the different stages of growth [15]. Moreover, ET_0 was calculated using the software CROPWAT version 8.0 (www.fao.org/land water/databases-and-software/cropwat/en/), which is a computer program that allows calculating the water requirements of crops per decade and day based on updated algorithms which include the adjustment of the values of the culture coefficients using the Penman-Monteith equation.

Data collection, ratings and measurements

Ratings and measurements of growth traits and yield components were based on the determination of the duration of the vegetative phase counted in number of calendar days from 1 January to the date of removal of 50% of the barbs from the sheath of the standard leaf [16].

Measured characters

Determination of crop water productivity

The agricultural sector faces the challenge to produce more food with less water by increasing Crop Water Productivity (CWP) [17]. A higher CWP results in either the same production from less water resources, or a higher production from the same water resources, so this is of direct benefit for other water users. In this study CWP (kgm^{-3}), which is originally referred to in literature as ‘water use efficiency’, is defined as the marketable crop yield over actual evapotranspiration:

$$CWP = Y \div P+I \ (kgm^{-3})$$

Y being the yield of grains, (P) and (I) are cumulative

Rainfall and irrigation respectively

Production components

Grain yield and yield components were determined at plant maturity from the packs harvested on a segment of rank one millimeter long.

- **Number of spikes per m² (NS/m²):** was determined by counting all spikes from the same boot.
- **Number of grains per spike (NGS):** We counted the grains from the spikes of the sample that were used to determine the previous parameters.
- **Weight of 1000 grains (WTG):** The weight of 1000 grains was determined, according to the weight of the counts of 4 times 250 seeds.
- **Total yield:** was determined as; Yield = NS/m² × NGS × WTG, results were converted to quintals/ha.

Statistical analysis

For each growth or yield parameter, the collected data from the two experiments were analyzed using three-way analysis of variance (ANOVA) of randomized complete blocks (RCB) design. The factors considered were 'Year' with two levels (2014–2015 and 2015–2016), 'Variety' with two levels (GTA-Dur and Vitron) and 'Treatment' with six levels (T1, T2, T3, T4, ETM, Pluv). All possible interactions between these three factors were included in the model. In order to compare results between varieties within each treatment and between treatments, Tukey's post-hoc test were conducted when ANOVA showed significant effects (*i.e.* $P<0.05$). Results of the multiple comparisons of averages (homogeneous groups) were associated with graphs displayed in the form of boxplots. Besides the statistics represented in each boxplot, the average (of three repetitions) was also included.

Next to that, the relationship between yield component and CWP for the six irrigation treatments and wheat cultivars was modelled using generalized linear models (GLM). Irrigation treatments wereimplemented in the GLM as explanatory variable to test whether this relationship ‘yield vs. CWP’ differed between treatments for both wheat cultivars and for each cultivar separately. The interactionbetween treatments and CWP was included in the model GLM. The variation of the total yield was fitted to a Gaussian distribution error with identity link, then the effects of explanatory variables were summarized using *type-IIIF*-test.

Moreover, the relationships between the measured and/or calculated variables were studied by Pearson correlation tests at $P<0.05$. All statistical analyzes were carried out with the software R version 3.3.2. (R Core Team, 2016) using the following libraries {ggplot2}, {corrplot}, {Rcmdr}, {splines}, {car} and {sandwich}.

RESULTS AND DISCUSSION:

Table 1: Timing and irrigation volume of the treatments following the vegetative phases of the durum wheat cultivated in the region of Oum-El-Bouaghi, northeastern Algeria

Treatments	Vegetative stage	Irrigation timing	Irrigation volume (mm)
First irrigation for the treatments T1, T2, T3 and T4	Tillering	Early February	20
Second irrigation for the treatments T2, T3 and T4	Heading	Late March	40
Third irrigation for the treatments T3 and T4	Flowering	Mid-April	40
Fourth irrigation for the treatments T4	Grain growth	EarlyMay	40

Table 2: Analyses of variance testing the variation of production and yield components (NP/m², NS/m², NGS, WTG, yield) of two varieties of durum wheat cultivated under semi-arid conditions of Algeria (*Df*: degrees of freedom, *SS*: sum squares, *MS*: mean squares, *F*: *F*-statistics, *P*: *P*-value, *Sig.*: statistical significance,*: *P*<0.001, **: *P* <0.01, *: *P* <0.05, ns: *P* >0.05)**

Variables	*Df*	*MS*	*F*	*P*	*Sig.*	*MS*	*F*	*P*	Sig.
		Weight of 1000 grains							
Year (Y)	1	180.4	26.69	<0.001	***				
Variety (V)	1	455.5	67.40	<0.001	***				
Treatment (T)	5	909.3	134.56	<0.001	***				
Y × V	1	95.8	14.18	<0.001	***				
Y × T	5	25.9	3.83	0.006	**				
V × T	5	100.8	14.92	<0.001	***				
Y × V × T	5	44.6	6.60	<0.001	***				
Block	2				15.6				
Residuals	46				6.8				
		Number of spikes per m²				Total yield			
Year (Y)	1	81608	5.74	0.021	*	44	2.27	0.139	ns
Variety (V)	1	381064	26.82	<0.001	***	404	20.76	<0.001	***
Treatment (T)	5	18477336	1300.27	<0.001	***	6573	337.46	<0.001	***
Y × V	1	35289	2.48	0.122	ns	9	0.45	0.506	ns
Y × T	5	59131	4.16	0.003	**	6	0.29	0.916	ns
V × T	5	192203	13.53	<0.001	***	118	6.06	<0.001	***
Y × V × T	5	45113	3.18	0.015	*	14	0.74	0.600	ns
Block	2	11799				181			
Residuals	46	14210				19			
		Number of grains per spike							
Year (Y)	1	40.5	4.01	0.051	ns				
Variety (V)	1	338.0	33.43	<0.001	***				
Treatment (T)	5	2259.6	223.46	<0.001	***				
Y × V	1	18.0	1.78	0.189	ns				
Y × T	5	41.3	4.08	0.004	**				
V × T	5	45.6	4.51	0.002	**				
Y × V × T	5	14.5	1.43	0.230	ns				
Block	2	139.4							
Residuals	46	10.1							

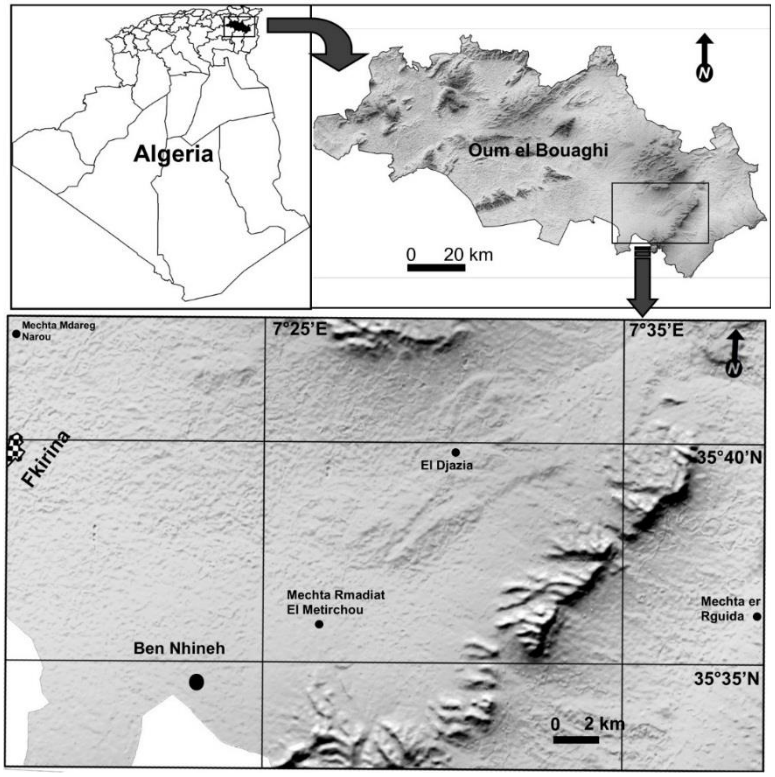

Fig. 1: Location of the experimental site 'plain of F'kirina' in the Wilaya (province) of Oum-El-Bouaghi, northeastern Algeria

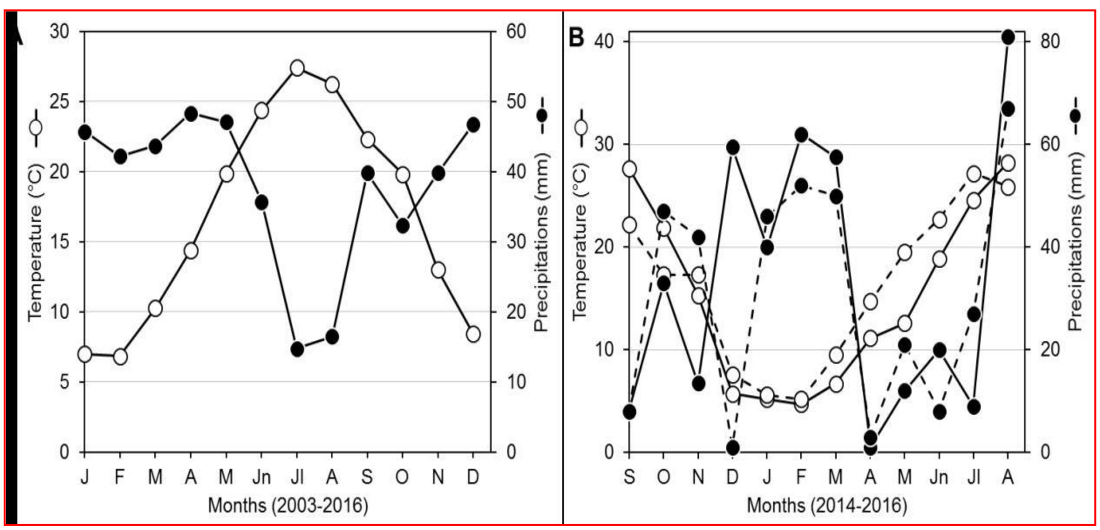

Fig.2: Gaussen's ombrothermal diagrams of the region of Oum-El-Bouaghi (northeastern Algeria), (A) for the period 2003–2016, and (B) for the two agricultural seasons 2014–2015 (continuous lines) and 2015–2016 (dotted line)

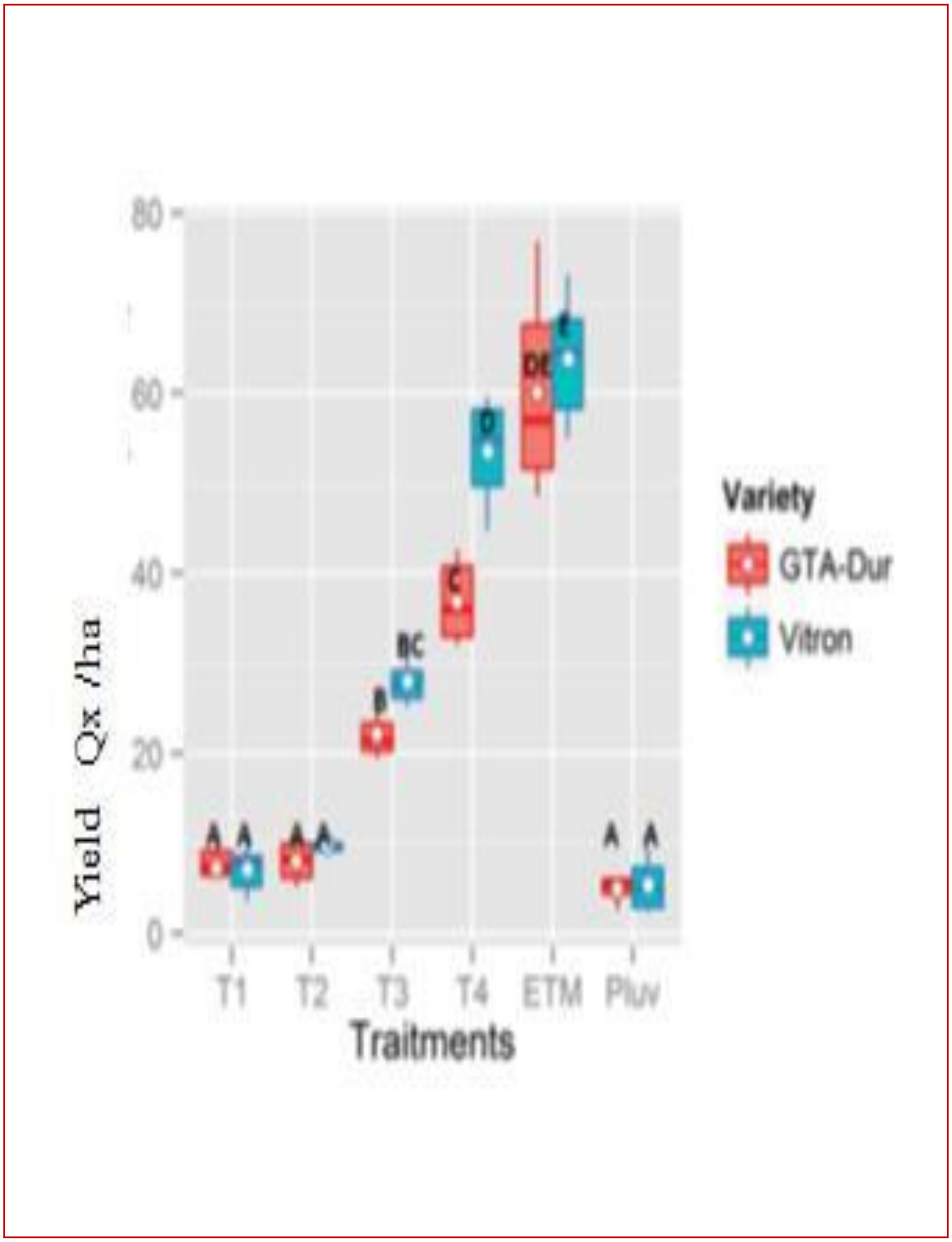

Fig.3: Variation of grain yield and its components in the Durum Wheat (*Triticum durum*) grown in northeastern Algeria following different water regimes including supplementary irrigations. The same letters associated with average values (white circles) are significantly not different following Tukey's post-hoc test

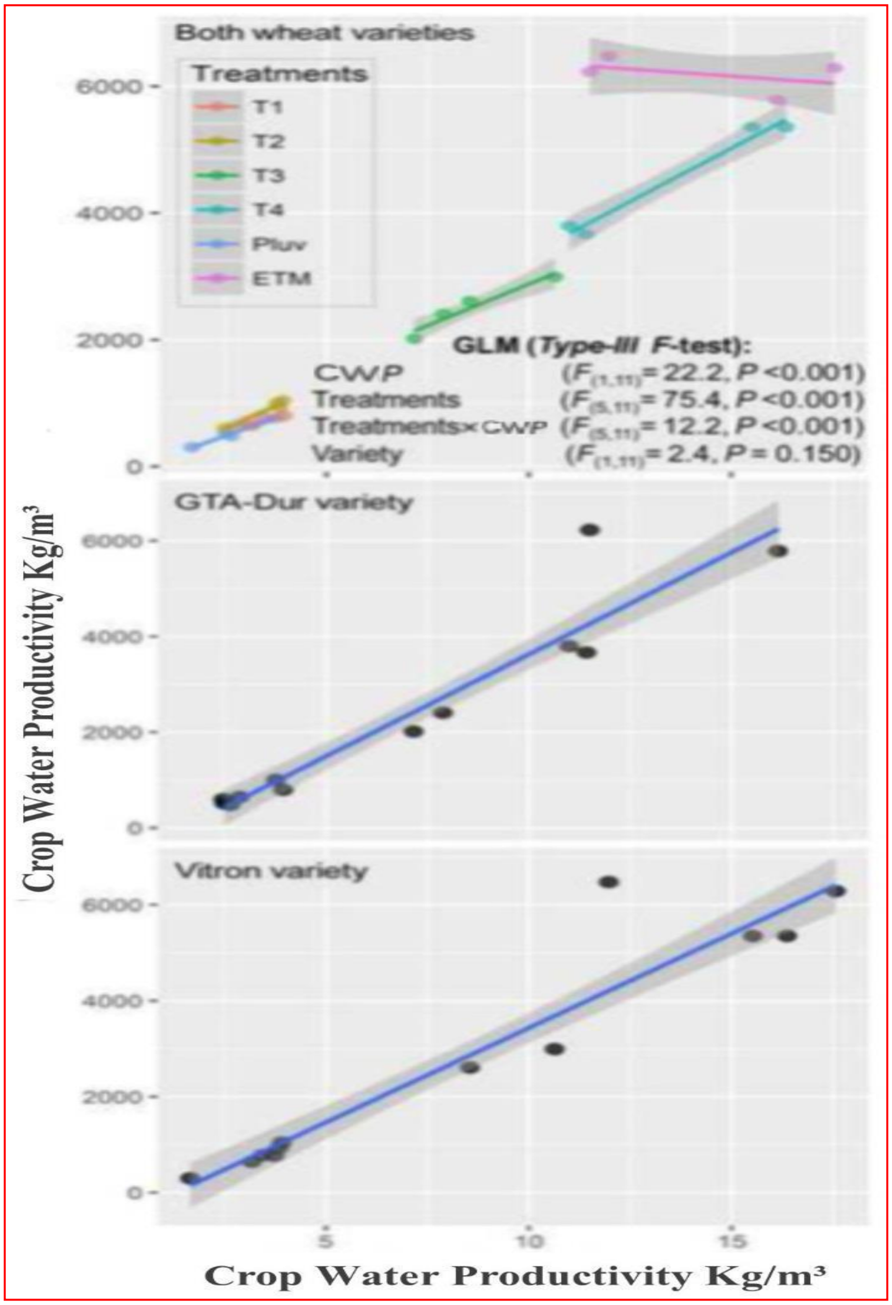

Fig.4: Effects of crop water productivity (CWP) on the grain yield of durum wheat at different irrigation treatments under field conditions in northeastern Algeria. The lines represent a linear regression with a GLM (generalized linear model) fit with 95% confidence regions in light grey. *F* and *P* values are statistics of the GLM

Effect of supplementary irrigation on grain yield

Statistical analysis revealed a very highly significant effect (P<0.001) of the water regime on yield (Table 3).The yield of the durum wheat crop improved by 15.8%, 71.3%, 125.3% and 229.5%, for the irrigation conditions T1, T2, T3 and T4, respectively, with respect to the control condition (Pluv). Thus, the grain yield increased from 4.97 quintals/ha in the GTA-Dur (Pluv) to 60.05 quintals/ha in the irrigated control (ETM) treatment, an increase of 1108% (Figure 3); and a gain of 1094% from 5.34 quintals/ha in rainfed to 63.8 quintals/ha for the variety Vitron under ETM.

These results confirm those obtained by Mengistu *et al.*, (2015) . The series of field trials showed the predominant role of irrigation in improving and stabilizing grain yield. Taking into account the results obtained in this study, the contribution of supplementary irrigation to the improvement of yields is indisputable. Supplementary irrigation significantly improved grain yield at any stage of water supply. The increase of yield in GTA-Dur, compared to rainfed condition, was 45.3%, 61.0%, 344.5%, 640.6% and 1108% for T1, T2, T3, T4 and ETM treatments, respectively. Whereas in Vitron, irrigation treatments T1, T2, T3, T4 and ETM induced an upsurge of33%, 84.3%, 423. 8%, 902% and 1094.7%, respectively (Figure 3). The development of abundant yield depends not only on the timing of water supply but also on the irrigation dose because the latter changes following the water needs of each phase during the breeding period.

For example, irrigation during the flowering stage improved the efficiency and effectiveness of water use (CWP) and allowed the conservation of 34% of the irrigation water compared to the ETM (Figure 4). Controlled supplementary irrigation strategy contributes to water rationalization and sustainability. The results of Figure 4 indicate also that irrigation treatment T4 clearly highlight that Vitron was much more tolerant to drought than GTA-Dur. This suggests that when farmers have little and/or less access to irrigation water, they should use Vitron instead of GTA-Dur.

The results of this study showed that supplemental irrigation is effective in improving and stabilizing yields in arid and semi-arid areas where water is a limiting factor of production. This irrigation leads to additional costs and its profitability depends on the balance between the yield gain and the expenses incurred to obtain it. An economic study on the different irrigation systems is therefore necessary to further justify this technique and its cost-effectiveness.

Effects of supplemental irrigation and CWP on yield

The GLM revealed the existence of a very highly significant effect ($P<0.001$) of the CWP at different levels of irrigation 'treatments' as well as their interaction (treatments*CWP) on the variation of grain yield values of both varieties (Figure 4). Supplementary irrigation improved crop water productivity and consequently increased grain yield, however, the model revealed that no difference between study cultivars ($P=0.150$). The results obtained showed that a water supply at the beginning of the breeding period (T1, T2 and T3) did not have a large positive effect on the improvement of CWP (values ranging from 2.88 to 8.55 kg/m^3) compared to the rainfed crop (Figure4). It is concluded that strong climatic demands, especially during the first cycle, cause rapid drying out of the surface horizons associated with the inability of the crop to exploit water from deep horizons. Water supply at the end of the reproductive period (T4) with 140 mm of water distributed over the stages: tillering, heading, flowering and grain growth has resulted in an improvement of CWP with a maximum value of 15.5 kg/m^3 and an increase of yield. These results are consistent with those of Karrou (2013) [18].

CWP increases when the uses of rainwater and irrigation inputs are reasonable [19]. Under regular irrigation (ETM), the test leads to better use of CWP water (up to 17.5 kg/m^3) and therefore a better grain yield with about 63 kg/ha. Although the variety Vitron showed a bit higher productivity and used more efficiently water under the ETM treatment, but the GLM demonstrated that the variation pattern of yield *vs*. CWP in this variety is as similar as that of GTA-Dur (Fig. 4). Supplementary irrigation significantly increases the water use efficiency compared to the treatment with rainfed conditions and reduces its inter-annual variation. For the improvement of irrigated CWP in wheat crop under arid and semi-arid conditions of North Africa, it is proposed to (i) apply 3 to 4 irrigations at the appropriate time of the growth season, (ii) control weeds, and (iii) apply suitable doses of fertilizer. In that context, biofertilizer are demonstrated to offer better yields and resilient adaptation to plants grown under water and salinity stresses compared to mineral fertilizer [20,21]. Nakhforoosh *et al.* (2016) [22] consider that CWP is a component of crop resistance to water stress which determines the yield. Indeed, the yield of a crop mirrors the product of the water used by the plant and how efficiently water is used [23]. In addition, Khila *et al.* (2015) [24], find that improved CWP in modern cultivars is associated with rapid development, early flowering, good vegetation cover structure, and a high harvest index.

CONCLUSION:

Irrigation and varietal improvement serve two main purposes: increased yields and stability of durum wheat production (*Triticum durum*.Desf.) in the semi-arid Mediterranean regions.

Rainfed grain yields range from 9 quintals per hectare in 2014 to 12 the two varieties are considered less productive in rainfed, their yield remains lower than 20 quintals per hectare but presents a better stability, they are less affected by early drought.

However, the new variety introduced in the study area: Vitron is very unstable in rainfed conditions and should be systematically irrigated. Indeed, according to Bouthiba (2007), in the case where irrigation is fully available, Vitron would be a good choice if the potential of the crop is achievable.Vitron is the only variety with good yield potential and tolerance to drought. It could maximize the productivity of irrigation water applied especially between the heading and the grain stage. The grain yield in the Vitron variety exceeds 30-40 quintals per hectare.

In rainfed, the number of spikes m-² (NE) and the number of grain per spike (NGE) constitute the most critical components in the development of the final performance while under the number of grain per spike (NGE) and the weight of one thousand grains (PMG) are the most determinants.

The use of water must be maximized in the form of transpiration optimize production. Therefore, reducing the evaporation and simultaneously improving water storage or holding capacity and also controlling weeds are the key-procedures in order to improve the CWP by the plant. Thus, optimizing the productivity of water in rainfed crops and improving cereal yield in cropping systems with limited water requires the maximization of precipitation for transpiration by reducing losses of soil water.

REFERENCES:

1. Sahnoune F, Belhamel M, Zelmat M, Kerbachi R (2013). Climate change in Algeria:
2. Haddouche L, Mekliche L (2008) Etude comparative de quelques populations de blé dur (Triticum durum Desf) et leur parents. Céréaliculture-ITGC, Algérie 50 : 10-15
3. Feliachi K, Amroun R, Khaldoun A (2001) Impact de la sécheresse sur la production des céréales cultivées dans le nord de l'Algerie. Céréaliculture-ITGC, Algérie, 35: 28-34
4. Baldy C (1993) Effets du climat sur la croissance et le stress hydrique des blés en Méditerranéeoccidentale. In : Monneveux P, Ben Salem M, eds. Tolérance à la sécheresse des céréales enzone méditerranéenne. Diversité génétique et amélioration variétale. Paris : INRA, 64 : 83-100.
5. Chennafi H, Aïdaoui A, Bouzerzour H, Saci A (2006). Yield response of durum wheat (Triticumdurum Desf.) cultivar Waha to déficit irrigation under semi-arid growth conditions. Asian j.Plant Sci. 5:854-860.
6. Fisher RA (1973) The effect of water stress at various stages of development in yield processesin wheat. In ; Plant response to climatic factors. Proc Uppsala Symp. Paris : Unesco. Ecologyand conservation 5:233-241
7. Kobata T, Palta JA, Turner NC (1992). Rate of development of post-anthesis water deficit and grain filling of spring wheat. Crop Sci 32 : 1238-1242.
8. Assem N, El Hafid L, Haloui B, El Atmani K, (2006) Effets du stress hydrique appliqué au stadetrois feuilles sur le rendement en grains de dix variétés de blé cultivées au Maroc oriental.Sécheresse 17: 499-505.
9. Benbelkacem A, Kellou K. (2001). Évaluation du progrès génétique chez quelques variétés deblé dur (Triticum turgidum L. var. durum) cultivées en Algérie. Options Méditerranéennes 6 :105-10.
10. Bouthiba (2007) Optimisation de l'irrigation de complément du blé dans la region de chéliffthése de Doctorat d'état INA, El-Hrrach (Alger), 120p
11. Aliat, T., Kaabeche, M., Khomri, H., Nouri, L., Neffar, S., Chenchouni, H. (2016). A pedological characterisation of some inland wetlands and Ramsar sites in Algeria. *Land Degradation & Development*, 27(3), 693-705. DOI: 10.1002/ldr.2467
12. Adu-Gyamfi, P., Mahmood, T., Trethowan, R. (2015). Can wheat varietal mixtures buffer the impacts of water deficit?.*Crop and Pasture Science*, 66(8), 757–769.
13. Ferrant, S., Bustillo, V., Burel, E., Salmon-Monviola, J., Claverie, M., Jarosz, N., et al. (2016). Extracting Soil Water Holding Capacity Parameters of a Distributed Agro-Hydrological Model from High Resolution Optical Satellite Observations Series. Remote Sensing, 8(2), 154. DOI: 10.3390/rs8020154
14. Chourghal, N., Lhomme, J. P., Huard, F., Aidaoui, A. (2016). Climate change in Algeria and its impact on durum wheat. Regional Environmental Change, 16(6), 1623–1634.
15. Tafteh, A., Babazadeh, H., EbrahimiPak, N. A., Kaveh, F. (2013). Evaluation and improvement of crop production functions for simulation winter wheat yields with two types of yield response factors. Journal of Agricultural Science, 5(3), 111.
16. Haddad, L., Bouzerzour, H., Benmahammed, A., Zerargui, H., Hannachi, A., Bachir, A., et al. (2016). Analysis of the phenotypic variability of some varieties of durum wheat (Triticum durum Desf.) to improve the efficiency of performance under the constraining conditions of semi-arid environments. Journal of Fundamental and Applied Sciences, 8(3), 1021–1036.
17. 17. Kijne, J.W., Barker, R., Molden, D., 2003. Water Productivity in Agriculture: Limits and Opportunities for Improvement. CAB International, Wallingford, UK.
18. Karrou, M. (2013). Combined effect of tillage system, supplemental irrigation and genotype on bread wheat yield and water use in the dry Mediterranean region. African Journal of Agricultural Research, 8(44), 5398–5404.
19. Daroui, E.A., Boukroute, A., Kajeiou, M., Kouddane, N.E., 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. Revue Nature & Technologie, 5: 80-86.

20. Boudjabi, S., Kribaa, M., Chenchouni, H. (2015). Growth, physiology and yield of durum wheat (Triticum durum) treated with sewage sludge under water stress conditions. EXCLI journal, 14, 320-334.
21. Oustani M., Halilat, M. T., & Chenchouni, H. (2015). Effect of poultry manure on the yield and nutriments uptake of potato under saline conditions of arid regions. Emirates Journal of Food and Agriculture, 27(1), 106-120.
22. Nakhforoosh, A., Bodewein, T., Fiorani, F., Bodner, G. (2016). Identification of water use strategies at early growth stages in durum wheat from shoot phenotyping and physiological measurements. Frontiers in Plant Science, 7: 1155.
23. Lauri, P. É., Losciale, P., Zibordi, M., Manfrini, L., Corelli-Grappadelli, L., Regnard, J. L., Costes, E. (2014, August). Responses of young apple trees to soil water restriction: combining shoot morphology and leaf functioning over a range of genotypes. In: XXIX International Horticultural Congress on Horticulture: Sustaining Lives, Livelihoods and Landscapes (IHC2014): 1130, pp. 473–478.
24. Khila, S.B., Douh, B., Mguidiche, A., Boujelben, A. (2015). Effets de la contrainte hydrique et des changements climatiques sur la productivité du blé dur en conditions climatiques semi arides de Tunisie. LARHYSS Journal, 23, 69–85.

Abbreviations

ETM: maximum cultural evapotranspiration.
ET_0: reference evapotranspiration.
Kc: crop coefficient.
Pluv: rain mode.
T1: irrigation treatment during the tillering stage.
T2: irrigation treatment during the Heading stage.
T3: irrigation treatment during the Flowering stage.
T4: irrigation treatment during the Grain growth stage.
CWP : Crop Water Productivity