Soil Water Content and Grain Yield Relationships in Some Algerian Wheat Varieties

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Abstract

In the semi-arid lands where the climate changes known a disaster impact bring about drought and high temperature, and the water is considered as the limiting factor of yield; the supplementary irrigation can be one of the resolutions. The aim of this study is to assess the capacity of five genotypes to dodge from drought and heats impacts. The experimentation was implemented during the seasons 2021/2022 and 2022/2023 at the experimental Algerian Technical Institute for field crops (ITGC) of Setif, Algeria, to determine phenological development length by evaluating varieties with great tolerance expressed by stress tolerance index (STI). Indeed, focusing on water use efficiency (WUE), and determination of the relationships among these parameters in relation to grain yield (GY) and its components of durum wheat. Five varieties, three of which are local were considered under two treatments; pluvial and supplementary irrigation by drip irrigation system. Significant differences were found among varieties in almost all studied parameters with an important effect of temperature on the length of phenological development with the higher value of 2600°C obtained by Mohamed Ben Bachir (MBB). For Boussellam variety a high performance is achieved in grain yield, WUE and STI with a values of 8.2 $t.ha^{-1}$,1.5 $kg.mm^{-1}$ and 0.19 respectively. The results proved the significance of using thermal time coupling with soil water content (SWC) to investigate models that determine different growth stages and control differently the WUE which has a very strong correlation with GY r=0.96. For STI and GY a negative correlation coefficient of r= -0.64 was recorded. The WUE and STI can be improved in selection programs with the advantage of using local varieties, and can also be controlled by irrigation amount and time which is really interesting at the sowing-emergence and heading anthesis period in order to increase GY.

Keywords: Wheat varieties; Thermal time; Water use efficiency; Soil water content; Grain yield; Algeria

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1.Introduction

Water is an essential component for human beings to consume in order to maintain an adequate food supply [1]. The rise in water demand was mostly tied to agricultural production [2], which controls around 80 percent of virtual water flows [3]. Those foods are required owing to population expansion, which is anticipated to exceed 10 billion by 2050 [4]. With limited arable land, threats to food security must be accomplished through the intensive agriculture [5]. One of those intensive agricultural techniques is the use of irrigation, to achieve twice the productivity of rainfed systems [3].

In Algeria, durum wheat (triticum durum) is the most cultivated food occupying 18.5 percent of agricultural lands in 2019 and producing about 3 billion tones given a yield estimated at 2 $t.ha^{-1}$ [6]. This recorded low of grain yield can be explained by many factors mainly the wheat cultivation area generally located under rainfed system through semi-arid regions characterized by a lack and irregularities in inter- and intra-annual precipitations. On the other hand, the significant impact of climate changes with the high insufficient of available water resource conducts to limited uses of irrigation system and looks for a new insight in order to keep the sources balanced [7,6]. Add to this, the increase in temperature due to climate changes that affects the length of growth cycle and plants development [8] and can be misleading irrigation management.

The understanding of crop phenological development can assist in several production management [9]. In the last few decades, several studies [10–12] have focused on the description of growth stages by cumulative growing-degree-days calculated by GDD (Growth Daily Degree), but, as far as we know, it has never been discussed for Algerian wheat varieties.

Thus, the challenge in this semi-arid region is to produce more wheat with less water, which may be accomplished by boosting crop water productivity called also water use efficiency (WUE). In other terms, make each drop of water more valuable [13,14]. In literature, the WUE is most often defined as the ratio between the produced biomass and transpiration [15–18]. However, in fields, the evapotranspiration partitioning to evaporation and transpiration is extremely difficult [14,19]. That's why it was suggested that the transpiration can be estimated on the base of data related to rainfall, irrigation and soil water content.

The genetic traits as well as the effect of water management practices on WUE were previously mentioned in the literature [14,20]. Also, many studies confirm that WUE can be affected by the timing of supply which means that supplementary irrigation in specific growth stages can improve grain yield and WUE [21–25].

To our knowledge, in addition to thermal time, the WUE has been poorly estimated for Algerian wheat varieties whose production takes into the account the grain number as the most important parameter determining the grain yield [26]. So, we suppose that the specific growth stages when plants really need water are different from those cited by [27] who determine the target growth stage after jointing and after anthesis.

To solve the above-mentioned issues namely low grain yield, lack of information about GDD of Algerian wheat varieties, the WUE and the timing of irrigation , we conducted a field experiment on durum wheat aiming to (i) determine the phenological growth stages using thermal time and daily time to evaluate the genetic effect and clarify the relationships between growth stage time and the environment conditions (ii) to estimate the WUE and its variations among varieties and environmental status with determination of parameters involved (iii) and to study the relationship between grain yield and its components and the WUE and growth conditions.

2. Material and methods

2.1. Study site and experimental procedures

Field experiments were implemented during the season 2021/2022 and 2022/2023 at the experimental Algerian Technical Institute for field crops (ITGC) in the semi-arid area of Setif, Algeria (36.1641538, 5.3701344). The soil was clay-loam in texture with pH of 7.51 and 0.23 ds m-1 electrical conductivity, filed capacity equal to 33.90% and wilting point of 14.56% with 1.32 bulk density give us available water capacity equal to 0.25 mm.

In two experimental devices, one rainfed and one irrigated; the two devices are similar and factorial on randomized complete block design (RCBD) using 4 replicates.

On 5 January 2022 (first year) and 29 December 2023 (second year), five durum wheat (Oued ElBared, Boussellam and Mohamed Ben Bachir (MBB) for a locals varieties and Simito and Vitron like an introduce varieties)) were sown at planting density of 350 grains.m-2. During land preparation, Di-Ammonium Phosphate at rate of 100 kg ha-1 was applied. At GS25 and GS32 in both devises and years, the Urea contained 46% of N used as source of nitrogen with a rate of 120UN.ha-1.

The rainfall distribution indeed climatic data during both seasons collected from https://power.larc.nasa.gov/, in addition for the irrigated device a supplementary irrigation was applied (irrigation scheduling and quantity shown in table 1).

Table 1 Supplementary irrigation scheduling and rate on mm

Phenological stage*	First year	Second year
GS0-GS12	15	/
GS25-GS39	/	15
GS39-GS51	/	70
GS51-GS69	/	40
GS69-GS90	90	/

*The determination of phenological stage using a decimal code of zadoks [28]

2.2. Assessment of studied parameters

Yield and yield components

At harvest, spikes number. m^{-2} (NSM) was determined by taking 10 spikes from each plot to calculate grains number.$spikes^{-1}$(NGS). Furthermore, grain yield t. ha^{-1} (GY) and thousand grain weight TGW (g) after a passage by Simple Plot Combine Harvester. The grains number.m^{-2} (NGM) was estimated by multiplication of number of spikes by grains number.$spikes^{-2}$.

phenological development

During crop development, the time of each stage was determined, then we calculate the number of days after sowing DAS (DS1; Days after sowing to reach GS12. DS2; Days after sowing to reach GS25. DS3; Days after sowing to reach GS39. DS4; Days after sowing to reach GS51. DS5; Days after sowing to reach GS69. DSM; Days after sowing to reach GS90) and the thermal time target by the sum of growing degree days GDD (GD1; thermal time to GS12. GD2; thermal time to GS25. GD3; thermal time to GS39. GD4; thermal time to GS51. GD5; thermal time to GS69. GDf; thermal time to GS90) described in equation 1.

$$GDD = \frac{Tmax + Tmin}{2} - Tbase$$

(eq.1)

The GDD calculated by the daily average of temperature minus a base temperature equal to 0 C° for winter wheat [29].

Soil water content

To describe soil water content (SWC) at each stage, the sum of a daily time scale we used equation 2 based on soil moisture balance [30]. With addition of irrigation amount Irr and where R(t) represents daily precipitation, ETc the crop evapotranspiration and LQ represents the runoff and drainage result from water in excess of the available water capacity of root profile.

$$SWC = R + Irr - ETc - LQ$$

(eq.2)

The crop evapotranspiration (ETc) can be calculated by multiplication of evapotranspiration referential (ET0) and crop coefficient (Kc) [31] in equation 3 where ET0 was estimated by climatic data following the approach of Penman-Monteith [32] and described in [33] and the Kc from table FAO-56.

$$ETc = ET0 \times Kc \qquad \text{(eq.3)}$$

The study was developed into 3 trials; two of them (1 and 3) represented the soil water content of the irrigated device in first and second years, and the trial (2) the rainfed device of the first-year as represented in figure1.

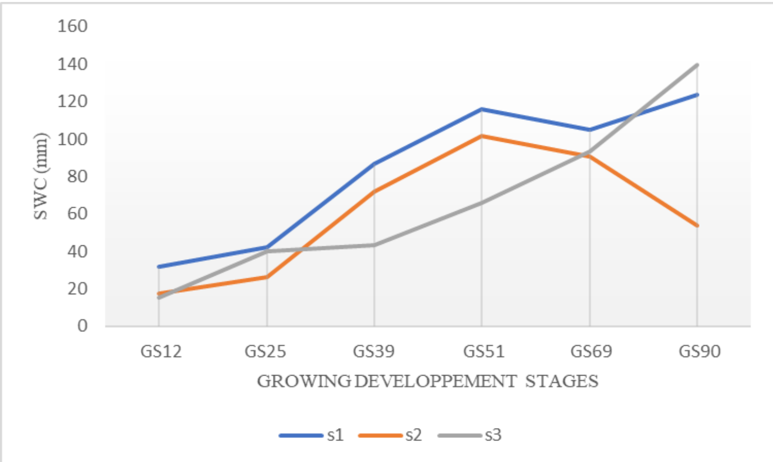


Figure 1 SWC in different trials. S1; trial 1, S2; trial 2, S3; trial 3, SWC; soil water content

Water use efficiency

To calculate water use efficiency (WUE), the GY (kg.ha^{-1}) of each plot was divided by growing season SWC (mm) and it's represented in equation 4.

$$WUE = \frac{GY(\text{kg. ha}^{-1})}{WCt(mm)}$$

(eq.4)

The irrigation water use efficiency (WUEi) was obtained by GY ($kg.ha^{-1}$) of irrigation plot (GYirr_plot) minus the versus plot in rainfed device (GYrain_plot) dividing by growing season irrigation amount (irr_amount) (mm) represented in equation 5.

$$WUEi = \frac{GYirr\_plot - GYrain\_plot}{irr\_amount}$$

(eq.5)

Stress tolerance index

The stress tolerance index (STI) showed in equation 6 was obtained by using the formula described by [34,35].

$$STI(\%) = \frac{GYs \times GY_p}{GYP^2}$$

(eq.6)

Where GYs is the grain yield under stress condition, GYp represented the grain yield potential of genotype and GYP is the grain yield under no stress environment.

2.3. Statistical analysis

Pooled data of all parameters for three trials were subjected to two-way ANOVA and extracts the means graphs using the package "Rcmdr" in R Software version 4.2.2 to define the difference of trait among factors. RStudio was used for both the Pearson's correlation coefficient and stepwise analysis in order to determine the relationship among traits and to choose the models components, also the

package "lavaan" and "semPlot" were used to get the path coefficient analysis in order to determine the direct and indirect effect hidden under a multiple linear regression [36,37].

3. Results

3.1. Variance analysis of phenological development on function of DAS and GDD

The trials (S) as well as the varieties (V) emerging from the experimentation are shown in Table 2. At both stages (GS12 and GS90), cumulative thermal time (GDD C°), the days after sowing (DAS) and the S xV interaction varied highly significantly with a p-value less than 1%. For the GS51 where the very high significative difference obtained among trials and varieties separately. In addition, for GS69 stages, the cumulative thermal time was highly significant with a p-value less than 0.01% among varieties.

Table 2Comparative effect of Trials and varieties on Cumulative Thermal Time (GDD C°) and days after sowing (DAS).

		Cumulative Thermal Time (GDD C°) and days after sowing (DAS)											
	Parameters	GS12		GS25		GS39		GS51		GS69		GS90	
		DAS	GDD	DAS	GDD	DAS	GDD	DAS	GDD	DAS	GDD	DAS	GD
P-Value	Trials(T)	>0.0001	>0.0001	n.s	n.s	n.s	n.s	>0.0001	>0.01	>0.0001	n.s	>0.0001	>0.0 1
	Varieties(V)	>0.05	>0.05	n.s	n.s	n.s	n.s	>0.0001	>0.0001	>0.0001	>0.0001	>0.0001	>0.0 1
	(TxV)	>0.01	>0.01	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	>0.0001	>0.0 1

DAS; days after sowing, GDD; growing degree days.

3.2. Cumulative thermal time (GDD C°) of different varieties

In figure 2 we observed that at GS12 (a) there is no difference among varieties at the same trial the difference only in the MBB variety where was distinguished from the other varieties since it accumulated 450°C in the 3rd trial, for all varieties a significative difference was observed among trials. For GS25 and GS39, the plots (b) and (c) were the irrigated and pluvial trial of the first year given the same value in contract with the third trial and showed clearly that the heat is the real factor to determine both stages. From the GS51 stage to GS90 stage, there is a distinctive difference between varieties ($p<0.0001$, table2).for GS51 the high difference among trials was observed between the trials S1 and S2 compared with S3 especially for Oued ElBared and Vitron, the same observation was recoded also for GS69 with the varieties Bousselam, Oued ElBared and Simito with the variety Oued ElBared register the lowest value of GDD in all trials, In the three trials at GS90 (figure 2 (f)), MBB variety registered the highest growing degree day and achieved an accumulation of 2600°C followed by Vitron variety (2550°C) which can be considered as a late-maturing varieties. On the other hand, we should point out that the two varieties Boussellam and Oued ElBared accumulated 350°C and 300°C respectively less than MBB variety.

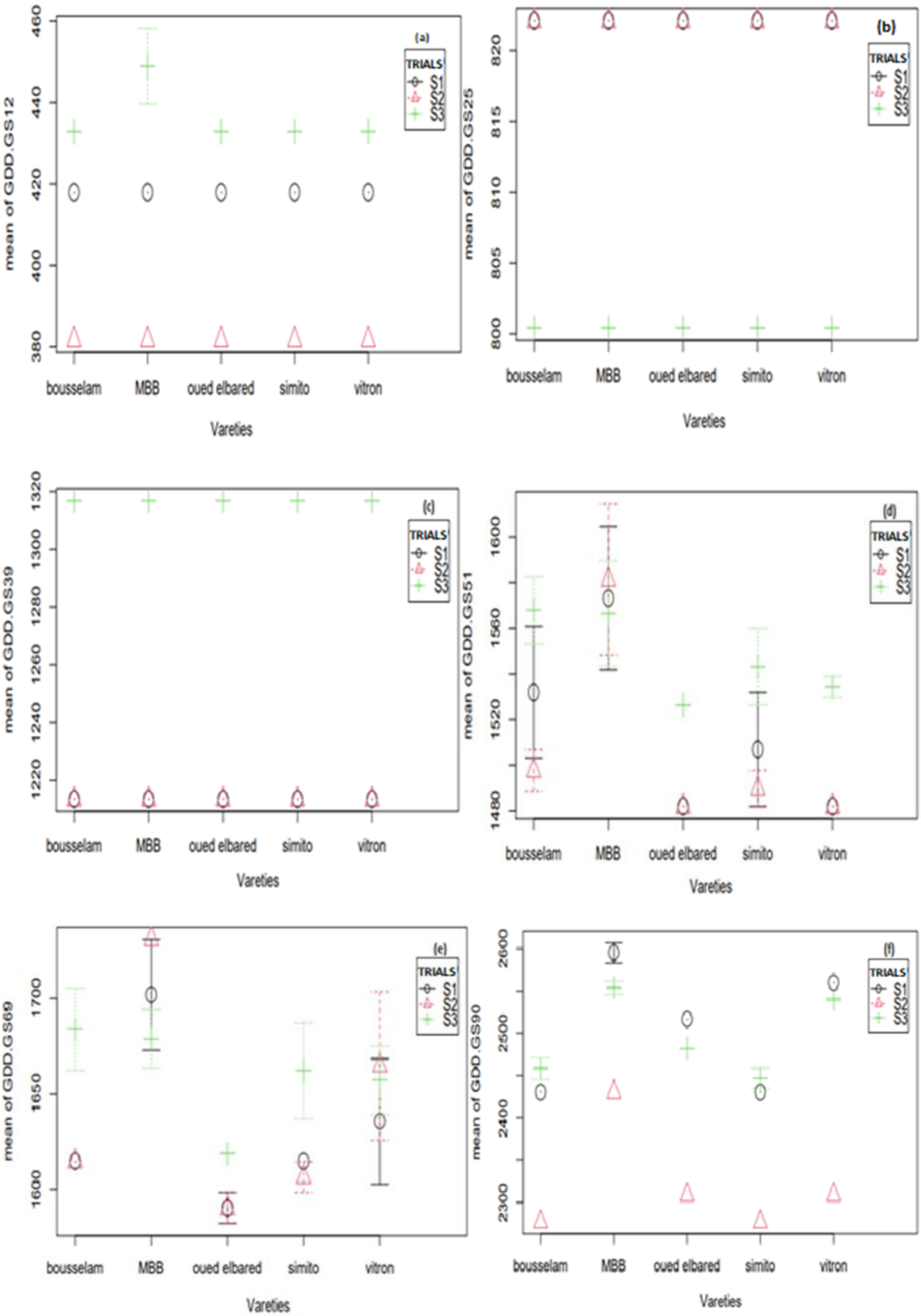


Figure 2cumulative thermal time (GDD C°) to reach development stage of different varieties

3.3. Models building of phenological stage by stepwise analysis

A stepwise regression analysis was carried out in order to remove non-effective traits in regression model on several phenological development time. results presented in table 3 showed a high performance of extractor models of two parameters (DS1 and DS4) revealing a coefficient of determination (R^2) value higher than 0.90, justified by the thermal time to reach each stage with SWC in the period before this stage, followed by the model of the DSM who forecast by heat and SWC in the grain filling stage with a R^2=0.79. For the model representing number of days to reach anthesis just the cumulative temperature involved but not sufficient to using the model obtained (R^2 = 0.21).

Table 3 models of each phenological stage and their coefficient of determination

Parameter	Model	R^2
DS1	y=0.1332*GD1-0.0593*SWC1-16.82	0.99
DS4	y=0.056*GD4+0.2*SWC4+21.06	0.91
DS5	y=0.04*GD5+64.02	0.21
DSM	y=0.034*GDf+0.066*SWC6+93.90	0.79

GD1; thermal time to GS12. GD4; thermal time to GS51. GD5; thermal time to GS69. GDf; thermal time to GS90. SWC1; Soil water content from GS0 to GS12. SWC4; Soil water content from GS39 to GS51. SWC6; Soil water content from GS69 to GS90. DS1; Days after sowing to reach GS12. DS2; Days after sowing to reach GS25. DS4; Days after sowing to reach GS51. DS5; Days after sowing to reach floraison. DSM; Days after sowing to reach maturity.

3.4. variance analysis for yield and their component, WUE, WUEi and STI

ANOVA results are presented in Table 4. For all the studied parameters a highly significant differences were evidenced except for the trials effects on WUEi Moreover, the interaction S x V was very highly significant with p-value less than 0.1%, for all parameters confirming the presence of a strong relationship between the yield components and irrigation rates at different stages.

Table 4 Comparative effect of trials and varieties on Yield components, WUE, WUEi and STI

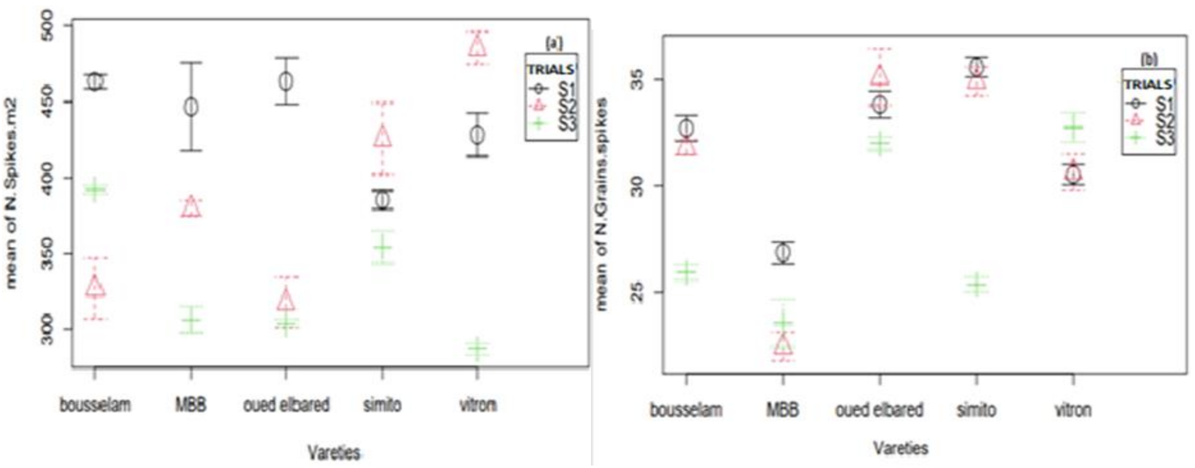
	Yield components, WUE, WUEi and STI							
parameters	NS. m^{-2}	NG.s^{-1}	NG. m^{-2}	TGW (g)	GY (t. ha^{-1})	WUE ($kg.mm^{-1}$)	WUEI ($kg.mm^{-1}$)	STI

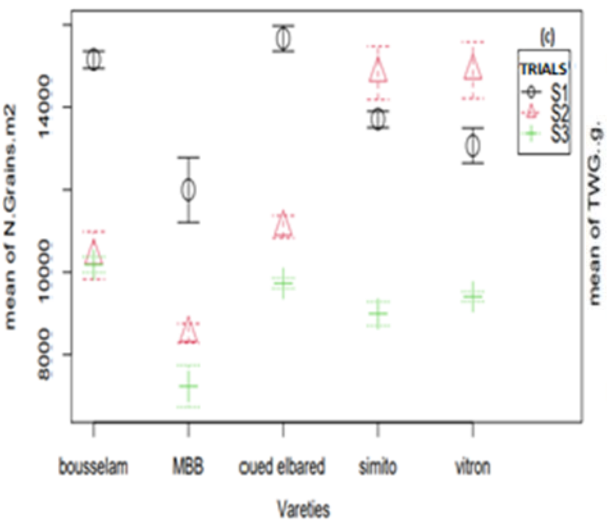
P-Value	Trials (S)	>0.0001	>0.0001	>0.0001	>0.0001	>0.0001	>0.0001	n.s	>0.0001
	Varieties (V)	>0.05	>0.0001	>0.0001	>0.0001	>0.0001	>0.0001	>0.0001	>0.0001
	Trials^Varieties	>0.0001	>0.0001	>0.0001	>0.0001	>0.0001	>0.0001	>0.0001	>0.0001

NS.m^{-2}; spikes number.m^{-2}. NG.s^{-1}; grains number.spike^{-1}. NG.m^{-2}; grains number.m^{-2}. TGW; thousand grains weight. GY; grain yield, WUE; water use efficiency, WUEI; irrigation water use efficiency, STI; stress tolerance index.

3.5. Yield and its components, WUE, WUEI and STI of different varieties

The results shown in figure 3 determine the trials and varieties V effects for all yield components, WUE, WUEI and STI.in figure 3(a) it appears a high difference among varieties and trials; with difference of trials ranking with the S3 has the less value, where Boussellem get a value corresponding to SWC from GS12 to GS25, for the others the SWC after GS25 has an effect in the NSM. For the NGS (b) a close value was registered between trials of the first year except for MBB and Vitron while can explain by the late flowering time. For the TGW the difference among varieties with the highest value of 57g was registered for Simito in the trial 1 and a relation of SWC after GS69 was outstanding. The figure 3 (e), unveiled a great variation in GY among different trials and varieties with suitable value for Boussellam and Oued ElBared. Boussellam achieved a higher value of 8.2 t.ha^{-1} than the other varieties at S1. Simito and Vitron both recorded high GY in the rainfed trial (S2) with 4.6 t.ha^{-1} and 4.3 t.ha^{-1} respectively, with a lowest value of 2.6 t.ha^{-1} obtained by MBB. The WUE (f) results are similar to those registred in GY (e). For the WUEI (g), Boussellam and Oued El Bared obtained the high values of WUEI with 4.6 kg.mm^{-1} and 3.9 kg.mm^{-1} respectively. For STI, Boussellam and MBB that had the lowest values of 0.19, 0.17 and 0.60, 0.63 in the first and second year respectively and considered the interesting varieties in both trials.




(c)
TRIALS
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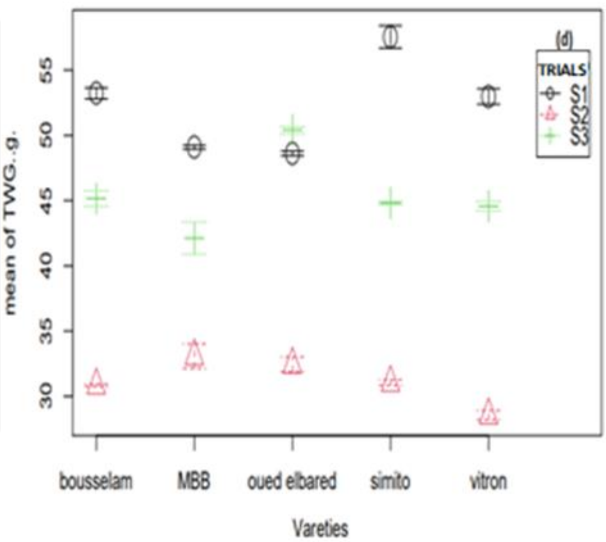
(d)
TRIALS
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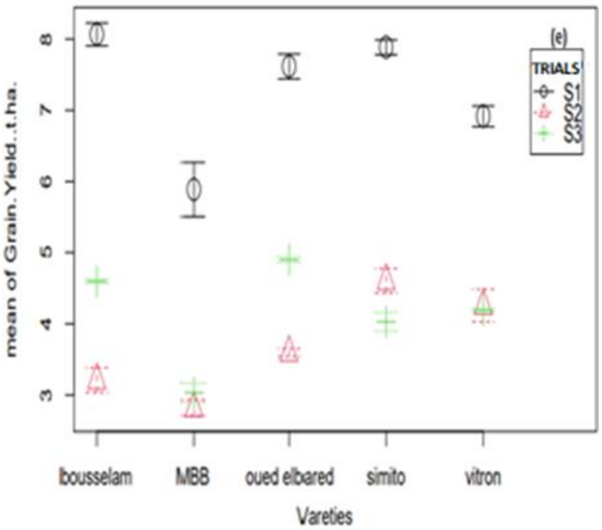
(e)
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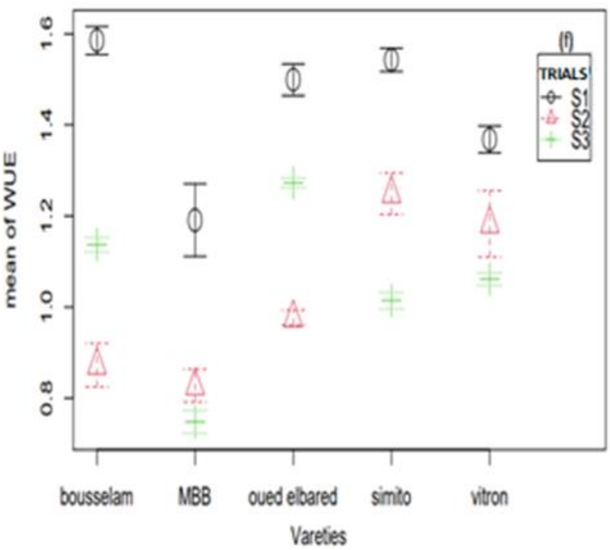
(f)
TRIALS
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mean of WUE
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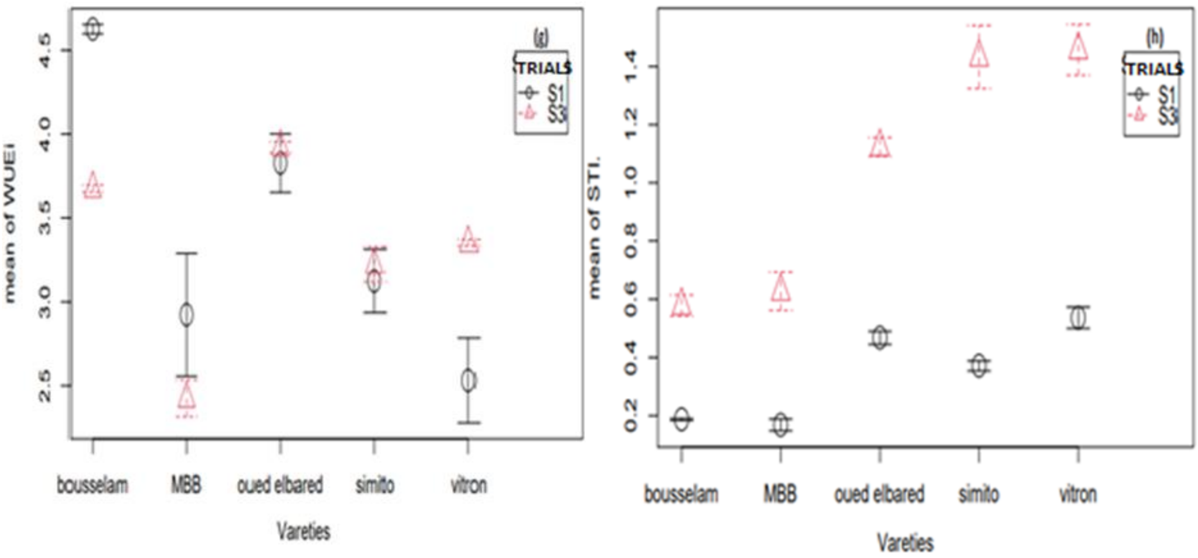


Figure 3 grain yield, their components, WUE, WUEI and STI variation among trials and of different varieties

3.6. Building models of grain yield, its components and WUE

Building models by successively adding and removing traits expressed by a Stepwise regression was used to extrapolate appropriate models hold a set of independent variables that significantly influence the dependent variable. In addition, using the same analysis to describe the grain yield model in relation with all others parameters mentioned previously and the results represented in the table 5.

The stepwise revealed the significant effect of thermal time and soil water content to describe yield, yield component and WUE with a determination coefficient of R^2=0.92, R^2=0.54, R^2=0.69, R^2=0.69, R^2=0.93 and R^2=0.79 for GY, NSM, NGS, NGM, TGW and WUE respectively. In addition, the thermal and daily time to reach a phenological stage with soil water content in the vegetative period justified 77% of STI.

Table 5 models of grain yield, their component and WUE associated with determination coefficient

parameter	Model	R^2
NSM	y=171.4*GD2+29.8*GD5-19.09*SWC1+28.37*SWC4-6.922*SWC5-497.9*DS5	0.54
NGS	y=-0.944*GD1-0.027*GD4+1.43*GD5-0.154*GD6+15.77*SWC1-11.27*SWC2-0.208*SWC5-24.36*DS5+3.05*DSM	0.69

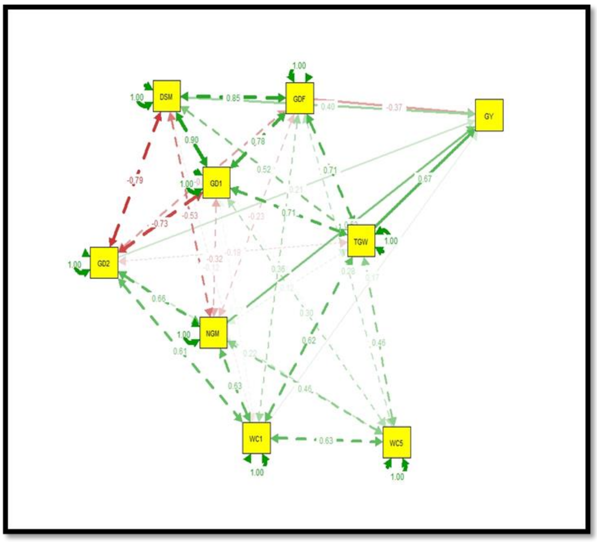
NGM	y=-195.05*GD1-266.38*GD5-53.99*GDf+1806.65*SWC1+291.52*SWC4-216.91*SWC6-4435.94*DS5-653.92*DSM+210850.18	0.69
TGW	y=-0.57*GD1+0.89*GD4-0.017*GDf+11.72*SWC1-6.92*SWC2-0.804*SWC4-14.75*DSM+890.53	0.93
GY	y=-0.218*GD1+0.378*GD5-0.033*GDf+3.17*SWC1-1.6*SWC2+0.24*SWC4-0.075*SWC5-0.11*SWC6+0.467*DSM+298.12	0.92
WUE	y=-0.05*GD1+0.09GD5-0.007*GDf+0.73*SWC1-0.41*SWC2+0.065*SWC4-0.02*SWC6-1.54*DAS5+0.11*DSM+72.03	0.79
STI	Y=0.02*GD1-0.06*GD5-1.05*SWC2-0.16*SWC4+0.03*SWC5-0.04*DS4+1.04*DS5+19.85	0.77
GY.F	y=-0.02*GD1-0.086*GD2-0.006*GDf+0.262*SWC1+0.025*SWC5+0.092*DSM-0.069*NGS-0.005*NSM-0.093*TWG-0.0002*NGM+7.98*WUE+73.12	0.99

GD1; thermal time to GS12. GD2; thermal time to GS25. GD4; thermal time to GS51. GD5; thermal time to GS69. GDf; thermal time to GS90. SWC1; Soil water content from GS0 to GS12. SWC2; Soil water content from GS12 to GS25. SWC4; Soil water content from GS39 to GS51. SWC5; Soil water content from GS51toGS69. SWC6; Soil water content from GS69 to GS90. DS4; Days after sowing to reach heading. DS5; Days after sowing to reach floraison. DSM; Days after sowing to reach maturity. NSM; spikes number.m^{-2}. NGS; grains number.$spike^{-1}$. NGM; grains number.m^{-2}. TGW; thousand grains weight. GY; grain yield. GY.F; grain yield final.

3.7. Path analysis

The path coefficient technique was used to decompose the correlation coefficients between grain yield and yield related traits into direct and indirect effects via alternative traits or pathways. For this analysis, NGM used like a representative parameter of NSM and NGS and delate WUE to clean up the data and avoid multicollinearity in the structural model equation (sem)

The path coefficient analysis was used in order to identify the direct and indirect effect of each component on grain yield. As shown in figure 4, TGW and NGM were a direct effect on GY with 0.67 and 0.54 respectively. the others parameters affect the GY indirectly via those components in positive or negative way; for the SWC before emergence and between heading and anthesis stages has a positive indirect effect via both components TGW and NGM with 0.42, 0.23 and 0.31, 0.16, the thermal time and daily time to maturity has an indirect effect positive only via TGW with a value of 0.48 and 0.35 respectively.



GD1; thermal time to GS12. GD2; thermal time to GS25. GDf; thermal time to GS90. WC1; Soil water content from GS0 to GS12. WC5; Soil water content from GS51toGS69. DSM; Days after sowing to reach maturity. NGM; grains number.m-2. TGW; thousand grains weight. GY; grain yield

Figure 4 Path coefficient of the direct effects of (GD1), (GD2), (NGM), (TGW),(SWC1),(SWC5),(GDF), (DSM) and grain yield (GY)

4. Discussion

This study aims to determine the phenological growth stages using thermal time and daily time and evaluate the genetic effect and clarify the relationships between growth stage time and the environment conditions with an estimate the WUE and its variations among varieties and environmental status with determination of parameters significantly involved and to study the relationship between grain yield and its components and the WUE and growth conditions.

In table 2 we investigated the differences in phenological development stages in calendar days (DAS) and cumulative thermal time (GDD) between a set of local and improved varieties developed in three trials considering SWC and temperature in order to assess the behavior of genotype in different environments, Globally, our results were consistent with earlier research that show the effect of heat and water shortage on different wheat genotypes. [38–41].

Our research substantiates that the heat unit is more efficient than the calendar days required for specific development stage and this approach was follow in various crop models [42,43]; in APSIM-Wheat module [44] where, particularly, the sowing – emergence period and the interpretation were discussed. Based on our results and similarly to these findings the heat, the SWC were the parameters effect the length of sowing-emergence period. Furthermore, many researches when estimating phenology development phases, they target generally sowing to anthesis and sowing to maturity stages [45–47]) mentioned that the GDD method with a photoperiod adjustment can effectively determinate the calendar day of sowing anthesis period and which align harmoniously with the conclusions drawn by our study which recorded that the heat determines only 21% of the prediction DAS of anthesis. This is somewhat at odds with the findings of [45] and [48] who notably suggested that the GDD explained more than 84 % of the variation in DAS of anthesis. According to [48], for the maturity stage, the GDD determines 64% of the maturity day and according to our results when we add the SWC, the prediction of the length in days from sowing to maturity is more acceptable with r2=0.79.

Our results showed a variation in response of varieties to diverse trials at the yield and component levels, which was observed in various research. [49,48,50]. Indeed, each component we analyzed was linked differently to GDD, SWC in key stage and DAS to a target stage, therefore affected the grain yield.

On the other hand, we conclude that using the STI with a lower value is more appropriate [51] and it was confirmed by the estimated correlation coefficient between grain yield and STI equal to r= -0.64. with lowest value outstanding for the local varieties Boussellam and MBB characterized by drought tolerance [52], compared to the introduced variety Vitron which considered as a highly sensitive genotype [53]. This parameter is used to be a suitable selection criterion for breeding genotypes [34] and used in several studies to reach in out a variety whose could withstand high temperature [35,54,55].

Concerning WUE, [20] suggest that the WUE was highly heritable and consider a polygenic character, that can interpret the difference between genotypes and the response in determinant environment conditions. With opposite of STI, the WUE have a positive correlation with grain yield r=0.96. Also, the stepwise analysis revealed that the WUE was associated to phonologic parameters and to SWC in different development periods and not with the total quantity of water. However, we confirm the possibility to improve WUE with an efficient irrigation management instead of breeding strategies [16].

The grain yield estimation was the most important parameter in this study, for that a path coefficient analysis was carried out to show the real effect of others parameters on it, the NGM and the TGW were the most relevant with a direct positive affect of 0.53 and 0.67 respectively as confirmed by a several authors [26,56]. Moreover, the time needed by plants to reach the maturity had a positive effect on GY. This can be explained by the fact that the plant has time to a sufficient resources uptake, also the earlier maturity genotype can be not useful for confrontation the future warning of climate change [21,57,58]. However, attention should be drawn to the fact that the long period to reach maturity in thermal time is not required with a negative direct effect (-0.37) especially in the semi-arid area, where the climate changes known a dangerous stretch and can lead to a reduction in yield by the high temperature during grain filling [59].

Other parameters have an indirect effect via NGM and TGW as the SWC in the first period from germination to emergence with a positive effect via NGM that can be explained by avoiding the inhibition of germination and increase number of plants [60,61] leading to death if the emerging stage within a particular time period is not reached [44]. Interestingly, our study evidenced a negative effect of thermal time to emergence on NGM. The same authors have determined the leaf area expansion and increasing from the emergence stage to GS25 allowing the interpretation of the positive reaction between thermal time and NGM. In addition, the SWC between heading and anthesis had a positive effect on NGM representing the peak of water consumption, that conformed with [62,27]. The negative effect of DAS maturity and thermal time to maturity might be clarified by the heat effect on grains number [63]. Also, the positive effect of those parameters on TGW illustrated previously by giving the plants the sufficient time to uptake all nutrients. In regards to the effect of water between GS51 and GS69 on TGW, there is a positive effect due to reducing the impact of high temperature discussed by [64,63,65] who considered that the high temperature at this period can reduce grain weight.

5. Conclusion

In this study we provide a varietal characterization of phenological development by the thermal time and conclude that the thermal time coupling with SWC are able to be determinant of different growth stage instead of daily time, with a lack at anthesis timing prediction who needs more genotypic parameters such photoperiod and vernalization sensitivity. The phenological phases and SWC in each stage are managed differently in the WUE, whereas the total available water of the growing season is ignored. The WUE known a very high significant correlation between it and GY; but for STI and GY a moderate negative correlation coefficient was noticed and favorite in the local varieties compared to others, these genetic factors, which can be improved in selection programs with the advantage of using local varieties, can also be controlled by irrigation amount and time. In order to increase GY, in the management aspect, the SWC in the sowing-emergence and heading anthesis period are the most important parameters beside yield components. At the varietal aspect the choose of earlier varieties have an advantage to increase GY compared with the tardive varieties, in addition the sowing date prefer to be earlier to avoid the dodge of varieties from high heat by shortening of phenological development and exploiting the positive effect of the rise in phenological development length with daily time.

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