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Grain yield and its components study and their association with normalized difference vegetation index (NDVI) under terminal water deficit and well-irrigated conditions in wheat (*Triticum durum* Desf. and *Triticum aestivum* L.)

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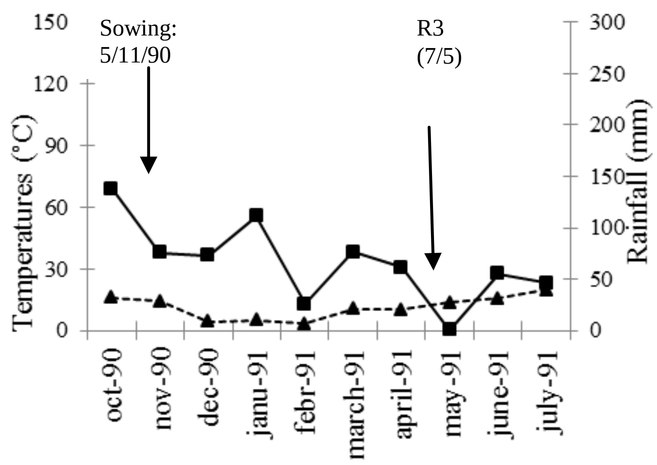
Six genotype of *Triticum aestivum* L. in 1991 and one genotype of *Triticum durum* Desf. and three of *T. aestivum* L. in 1992 were studied under different water regimes: full irrigation (R1), mild water stress (R3) and severe water stress (R2) at Magneraud (France). Traits evaluated were grain yield and its components, stress susceptibility index (SSI) and normalized difference vegetation index (NDVI). The analysis of variance revealed significant differences between regimes and among the cultivars for all traits except between regimes for thousand grains weight in 1991. The regime × variety interaction was significant for grain yield, thousand grains weight and NDVI in 1992 and for grain yield in 1991. For all traits, durum wheat (*T. durum* Desf.) has higher reduction in the two water stress than the common wheat (*T. aestivum* L.). Correlations studies revealed that grain yield, grains number/m², thousand grains weight and NDVI were associated with each other except for correlations between thousand grains weight on one hand and grain yield (1992) and grains number/m² (1991) on the other hand. 51.55, 27.88, 4.12% (1991) and 75, 43 and 20.2% (1992) of grain yield, grains/m² and thousand grains weight variability, respectively were explained by means NDVI variability. The grain yield and grains number/m² could be predicted using a single regression with NDVI.

Key words: Grain yield, grain yield components, NDVI, durum wheat and bread wheat.

INTRODUCTION

Yield safety can only be improved if future breeding attempts will be based on the valuable new knowledge acquired on the processes determining plant development and its responses to stress (Barnabás et al., 2008). Drought is a major factor limiting the productivity of wheat throughout the world in addition to other environmental stresses, particularly high temperature, salt and cold stresses. The average yield of wheat is quite low in the areas which present water stress. The extent of modification depends upon the cultivar, growth stage, duration and intensity of stress (Araus et al., 2002). For Siddique et al. (2000), the best option for crop production, yield improvement and yield stability under soil moisture deficient conditions is to develop drought tolerant crop varieties. Rajaram et al. (1996) suggested that simultaneous evaluation of germplasm should be carried out



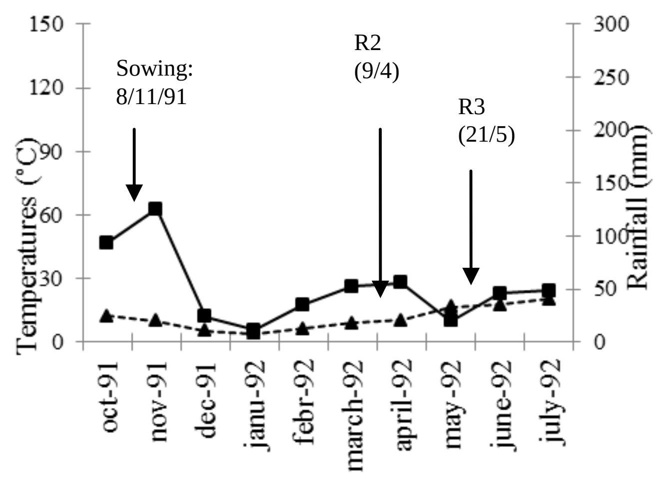


Figure 1. Rainfall and temperatures of the two years. ■ Rainfall (mm), ▲ Temperatures (°C). R2: severe water stress at meiosis, R3: Mild water stress at anthesis.

both under near optimum condition (to utilize high heritability and identify genotypes with high yield potential) and under stress conditions (to preserve alleles for drought tolerance). Several drought tolerance indices were suggested by different researchers. Among these indices, we can quote the stress susceptibility index (SSI) (Fischer and Maurer, 1978), the tolerance index (TOL) and mean productivity (MP) (Rosielle and Hamblin, 1981) and the stress tolerance index (STI) (Fernandez, 1992).

Recently, indirect assessments of agronomic and physiological traits can be also performed using spectral reflectance techniques (Araus et al., 2002). Spectral reflectance indices are non-destructive and instantaneous methods for assessing the physiological status of an entire crop or community in the field (Peñuelas et al., 1993).

Among the most widely used vegetation indices are the simple ration (SR) and the Normalized Difference Vegetation Index (NDVI) (Araus et al., 2001). The normalized difference vegetation index, based on the green vegetation absorbing solar radiation in the spectrum band by chlorophyll, and scattering in the near-infrared region, has been reported to be positively correlated with grain yield, and could serve as an indirect selection criterion to improve yield (Sharma et al., 2011).

The objective of this study was to investigate the effect of water stress on wheat (*Triticum durum* Desf. and *Triticum aestivum* L.) grain yield and its components and their relationship with NDVI, with the aim of its use in the screening of genotypes.

MATERIALS AND METHODS

Two field experiments were carried out during 1990/1991 and 1991/1992 growing seasons at ITCF experimental station of Magneraud (Charente Maritime, France) on clay-calcareous soil and hard limestone, under movable greenhouse. The experiments laid out in a randomized complete block design with two factors (water stress and varieties) during 1990/1991 and criss cross design during 1991/1992 with three replications in each test. Each plot consisted of 30 m². Six varieties of *T. aestivum* L. in 1991 and one variety of *T. durum* Desf. and three varieties of *T. aestivum* L. in 1992 were tested at Magneraud (France). The varieties studied were Artaban, Scipion, Beauchamp, Festival, Soissons and Thesee (bread wheat) during 1990/1991 and Ambral (durum wheat), Festival, Soissons and Thesee (bread wheat) during 1991/1992. The water regimes studied were full irrigation (R1) and mild water stress (R3) during 1990/1991, while in 1991/1992 a severe water stress (R2) was added. Mild water stress was applied from anthesis to maturity, while severe water stress was applied from meiosis to maturity. Whatever is the year; December, January and February (Figure 1) are the coldest months of the year with respective average temperatures of 4.2, 5.0 and 3.4°C (1991) and 4.3, 4.0 and 6.4°C (1992). July had the highest average temperatures with 19.9°C (1991) and 20.3°C (1992). The total of rains and irrigations receipts in 1991 are 828.5 mm (R1) and 618.5 mm (R3), whereas in 1992 the total is 633 mm (R1), 368 (R2) and 428 mm (R3). Greenhouse opening and closing were controlled automatically by pluviograph and moisten plate. Greenhouse comes to cover the crop when rain reaches 0.5 mm and opening when the rain stops. Greenhouses were installed on 7/5/1991 and 9/4/1992.

The agronomical practices were the usual ones of Magneraud.

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Abbreviations: SSI, Stress susceptibility index; **NDVI,** normalized difference vegetation index; **TOL,** tolerance index; **MP,** mean productivity; **STI,** stress tolerance index; **SR,** simple ration

Table 1. Mean squares, degrees of freedom and coefficients of variation (CV %) of variance analysis for the traits studied (1991).

Sources of variation	df	Grain yield	Grains/m²	Thousand grains weight	NDVI
Variety (G)	5	254.67***	69551080.00***	287.58***	0.0053***
Water regime (I)	1	399.17***	20783552.00***	0.16 ns	0.1285***
Block	3	37.65*	1882698.62 ns	3.38 ns	0.0003 ns
Interaction (G*I)	5	33.51*	1792902.38 ns	1.05 ns	0.0012 ns
Error	33	11.19	745747.38	2.14	0.0004
CV %		4.2	4.6	3.4	10.3

*, **, ***Significant at P<0.05, P<0.01 and P<0.001, respectively. NDVI: Normalized Difference Vegetation Index. ns: not significant.

Table 2. Mean squares, degrees of freedom and coefficients of variation (CV %) of variance analysis for the traits studied (1992).

Variation sources	df	Grain yield	Grains/m²	Thousand grains weight	NDVI
Variety (G)	3	136.86** (4.2)[1]	70464048.00*** (5.1)	239.12*** (1.7)	0.0078*** (3.02)
Water regime (I)	2	2121.05** (6.2)	47489696.00* (7.4)	120.30*** (2.8)	0.1125*** (2.13)
Block	2	118.45 ns	5500640.00 ns	1.95 ns	0.0010 ns
Interaction (G*I)	6	81.93** (4.3)	447576.00 ns (3.6)	19.28*** (3.0)	0.0024*** (2.13)
Error G	6	10.62	1114192.00	0.38	0.0002
Error I	4	22.90	2362616.00	1.12	0.0001
Error (G*I)	12	11.06	571780.00	1.22	0.0001

*, **, ***Significant at P<0.05, P<0.01 and P<0.001, respectively and (4.2)[1] = CV en %. NDVI: Normalized Difference Vegetation Index. ns: not significant.

The seeding rate was 250 grains/m². Nitrogenous fertilizer was estimated by projected balance method for 100 q ha^{-1}. Each trait was measured on 4 rows 2 m in length delimited at three-leaves stage. The traits measured in each experiment were grain yield, grain number/m², thousand grains weight, stress susceptibility index (SSI) or percentage of reduction and Normalized Difference Vegetation Index (NDVI). SSI and NDVI (Araus et al., 2002) were calculated as below:

$$SSI = \frac{(Yp - Ys)}{Yp} * 100$$

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

Ys: Yield of given genotype under stressed conditions; Yp: yield of a given genotype under non-stressed conditions. NIR: Near-infrared value, RED: red reflectance value.

A simulation radiometer SPOT type CIMEL (Guyot et al., 1983) was used to measure NIR and RED. This instrument gives reflectance corresponding to spectral channels of SPOT satellite (Dembele, 1989):

i. Channel 1: λ around 500 - 600 nm (green);
ii. Channel 2: λ around 610 - 680 nm (RED);
iii. Channel 3: λ around 790 - 890 nm (Near-infrared).

Only two channels, RED and Near-infrared, have been used to calculate NDVI for wheat and barley (Royo and Villegas, 2011). The measures are realized always at the same moment of the day, at the zenith, at clear time and without wind. The NDVI means were calculated from measurements of 12 days (1991) and 14 days (1992) from 4 June to 9 July and 3 June to 15 July, respectively, (corresponding to meiosis and maturity stages) for each plot of tests. The analysis of variance, Newman-Keuls test, correlation coefficients (r) for the pair-wise comparisons of traits and coefficients of determination (r²) were calculated.

RESULTS

Analysis of variance (Tables 1 and 2) revealed significant differences for varieties in the two tests (1991 and 1992) for grain yield (p<0.001 and p<0.01, respectively, for 1991 and 1992), grains/m², thousand grains weight and NDVI (p<0.001 for the two years). Water regimes differences were significant for grain yield (p<0.001 and p<0.01, respectively, for 1991 and 1992), grains/m² (p<0.001 and p<0.05, respectively, for 1991 and 1992), thousand grains weight (p<0.001 for 1992) and NDVI

Table 3. Means of traits studied for each variety and each water regime and stress susceptibility index (SSI) (1991).

Varieties and means of water regime	Grain yield (q ha^{-1})			Thousand grains weight (g)	Grains number/m²	NDVI mean
	R1	R3 (stressed)	SSI. (%)			
Artaban	76.88^{cd}	**66.90^{d}**	**12.98**	**50.73^{a}**	**14166.25^{e}**	**0.580^{b}**
Scipion	86.48^{ab}	**83.58^{a}**	3.35	45.35^{b}	18802.63^{c}	0,625^{a}
Thesee	80.99^{bc}	76.00^{bc}	6.16	44.48^{b}	17655.75^{d}	0,601^{b}
Beauchamp	86.06^{ab}	79.58^{ab}	7.52	43.69^{b}	18969.13^{c}	0,632^{a}
Festival	72.32^{d}	72.48^{c}	-2.21	35.66^{c}	20303.88^{b}	0.596^{b}
Soissons	87.93^{a}	77.52^{bc}	11.83	35.31^{c}	23090.00^{a}	0.649^{a}
Mean R1	81.78			42.48	19489.29^{a}	0.666^{a}
Mean R3	-	76.01^{b}		42,59	18173.25^{b}	0.562^{b}
SSI (%)			7.06		6.75	15.62

For thousand grains weight, grains number/m² and NDVI, the interaction variety × water regime is not significant and the classification of varieties is the same in each water regime (Table 1). Different letters mean significant differences.

Table 4. Means of grain yield (q ha^{-1}) and thousand grains weight (g) and stress susceptibility index (SSI) for each variety and each water regime (1992).

Variety	Grain yield						Thousand grains weight			
	General mean of varieties	Means of varieties in each water regime			SSI%		General mean of varieties	Means of varieties in each water regime		
		R1	R2	R3	R2	R3		R1	R2	R3
Festival	75.98^{a}	85.18^{a}	62.89^{a}	79.87^{ab}	26.17	6.23	33.90c	35.70^{c}	31.13^{b}	34.87^{c}
Soissons	80.07^{a}	86.34^{a}	68.11^{a}	85.75^{a}	21.11	0.68	33.35^{c}	33.88^{d}	31.03^{b}	35.13^{c}
Ambral	71.96^{b}	90.63^{a}	49.80^{b}	75.44^{b}	45.05	16.76	37.27^{b}	42.23^{b}	29.50^{b}	40.07^{b}
Thesee	80.12^{a}	88.80^{a}	67.81^{a}	83.76^{a}	23.64	5.66	44.55^{a}	44.90^{a}	42.77^{a}	45.97^{a}
Means		87.74^{a}	62.15^{c}	81.21			39.18^{a}	39.18^{a}	33.61^{b}	39.01^{a}

Different letters mean significant differences

($p<0.001$ for the two years). Variety × water regime interaction was significant for only grain yield ($p<0.05$ and $p<0.01$, respectively, for 1991 and 1992), thousand grains weight and NDVI ($p<0.001$) during 1992 indicating the presence of variability in each agronomical trait as well as the diversity of the growing conditions in each environment. The highest coefficient of variation for two years is 10.5% (NDVI for 1991) (Tables 1 and 2). The mean of all the traits under all water regimes showed that the traits under stressed conditions were always lower than under non-stressed conditions in the two tests.

In 1991, the means of the grain yield (Table 3) varied from 87.93 q ha^{-1} (Soissons) to 72.32 q ha^{-1} (Festival) at R1 regime and 83.58 (Scipion) to 66.90 q ha^{-1} (Artaban) at R3 regime. Variety mean values over the two regimes varied from 50.73 g (Artaban) to 35.31 g (Soissons) for thousand grains weight; from 23090 (Soissons) to 14166.25 (Artaban) for grains/m² and from 0.649 to 0.580, for NDVI mean. The highest SSI based on the mean of the grain yield in 1991 (Table 3) are given by Artaban (12.98%) followed by Soissons (11.83%). Scipion gives the lowest SSI (3.35%), whereas Festival has negative index (-2.21%). The average reductions of the grains number/m² and of NDVI mean are respectively 6.75 and 15.62%. The decrease of the grains number/m² caused a better grain filling.

In 1992, the means of the grain yield (Table 4) varied from 90.63 q ha^{-1} (Ambral) to 85.18 q ha^{-1} (Festival) at R1 regime, 68.11 q ha^{-1} (Soissons) to 49.80 q ha^{-1} (Ambral) at R2 regime and 85.75 q ha^{-1} (Soissons) to 75.44 q ha^{-1} (Ambral) at R3 regime. At R1 regime, all the varieties gave grain yields statistically equal. Whereas at R2 and R3 regimes, the varieties behave differently, indeed, the variety Ambral has the lowest grain yields. For NDVI mean (Table 5), means values over the three regimes for the four varieties varied from 0.593 (Soissons) to 0.530 (Festival) for R1, from 0.408 (Soissons) to 0.321 (Ambral) for R2 and from 0.523 (Soissons) to 0.421 (Festival) for R3. Ambral has the highest stress susceptibility index (Table 4) for grain yield, thousand grains weight and grains number/m² at the two regimes, whereas Soissons presents the lowest stress susceptibility index for all the traits. For all traits, Artaban (bread wheat) and Ambral (durum wheat), in 1991 and 1992 respectively, have the

Table 5. Means of grains/m² and Normalized Difference Vegetation Index (NDVI) for each variety and each water regime and stress susceptibility index (SSI) (1992).

varieties	Thousand grains weight		Grains/m²			NDVI			
	SSI %		General mean of varieties	SSI %		General mean of varieties	Means of varieties in each water régime		
	R2	R3		R2	R3		R1	R2	R3
Festival	12.80	2.32	22328.71^{b}	15.39	3.99	**0.443^{c}**	**0.530^{c}**	0.377^{a}	**0.421^{c}**
Soissons	8.41	-3.69	**23955.31^{a}**	14.02	4.46	**0.508^{a}**	**0.593^{a}**	**0.408^{a}**	**0.523^{a}**
Ambral	30.14	5.11	19049.22^{c}	21.47	12.35	0.450^{c}	0.588^{a}	0.321^{b}	0.443^{c}
Thesee	4.74	-2.38	17948.41^{c}	19.94	7.75	0.475^{b}	0.560^{b}	0.391^{a}	0.473^{b}
Means R1			22660.56^{a}				0.568^{a}		
Means R2			18709.59^{b}					0.374^{c}	
Means R3			21091.09^{a}						0.465^{b}

Different letters mean significant differences.

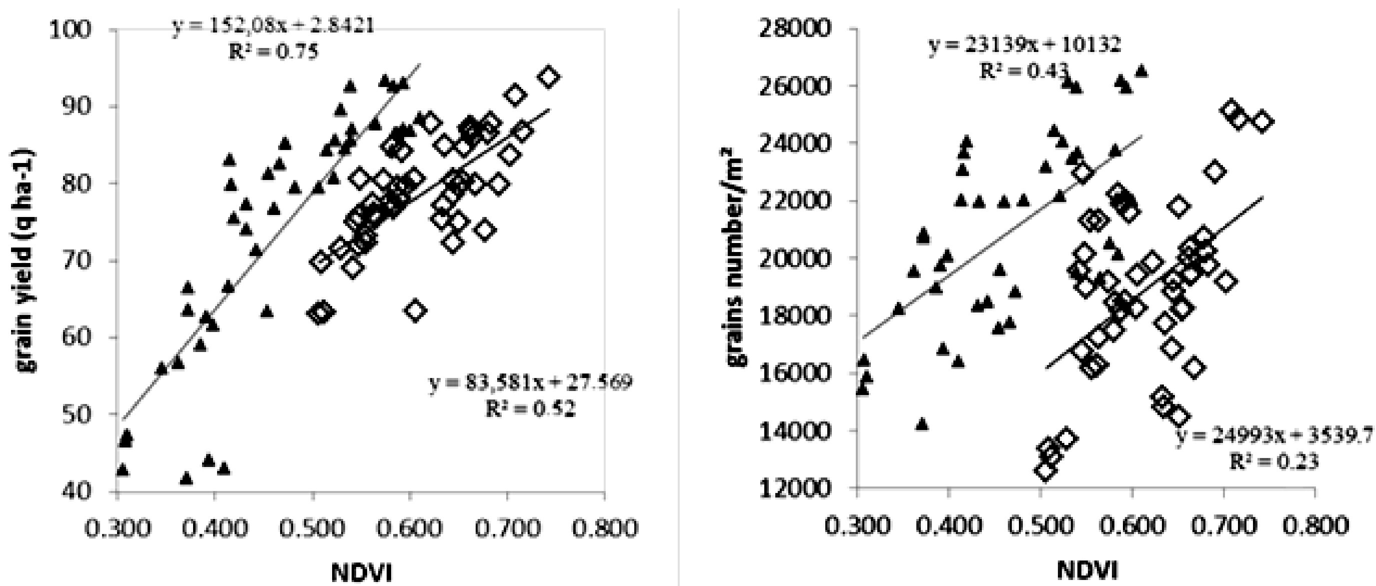

Figure 2. Relationship between grain yield, Grains number/m² and NDVI □: 1991, ▲: 1992.

highest reduction in the water stress compared with the others wheat varieties. Among the other bread wheat varieties, Thesee followed by Soissons have the lowest reduction in 1992 for grain yield but Artaban followed by Soissons have the highest reduction in 1991 (Tables 3 and 4) and Festival the highest in 1992.

The correlations between traits showed that grain yield was mainly correlated with grains number/m² (r = 0.531*** and 0.754***, *, ** and *** significant at $p<0.05$, 0.01 and 0.001, respectively, for 1991 and 1992) and NDVI (r = 0.718*** and 0.866***, respectively, for 1991 and 1992). The correlations between NDVI and grains number/m² were also high (r = 0.528*** and 0.656*** for 1991 and 1992, respectively). The correlation between NDVI and thousand grains weight is significant in 1992 (r = 0.449**) and non-significant in 1991 (r = -0.203). 51.55, 27.88, 4.12% (1991) and 75, 43 and 20.2% (1992) of grain yield, grains/m² and thousand grains weight variability, respectively, were explained by means NDVI variability (Figure 2).

DISCUSSION

Statistically significant genotypic variation for grain yield and its components have been reported previously in bread wheat (Abd El Moneim et al., 2010; Shamsi and Kobraee, 2011) and durum wheat (Elhani et al., 2007) under full irrigation and water stress conditions. In this study, we used six wheat genotypes (six genotype of *T.*

aestivum L. in 1991 and one of *T. durum* Desf. and three of *T. aestivum* L. in 1992. These genotypes expressed high variation for all the traits studied (grain yield, grains number/m², thousand grains weight and NDVI) and for the two tests in all regimes except for grain yield at R1 in 1992. The significance of genotype term suggested that genetic differences exist among the varieties studied, but also a genotype × water regime interaction was found in our study. According to Gallais (1990), the presence of genotype × environment interaction means that expression of the genes is not the same under diverse environmental conditions. On the basis of percentage reduction (SSI) calculated for yield and yield components certain varieties are more stable than others. It is the case of Festival, however this variety gives grain yield lower than the others in both regimes in 1991. In 1992, it behaves as the other bread wheat varieties. The mean of all the traits under all water regimes showed that the traits under stressed conditions were always lower than under non-stressed conditions in the two tests. At R1 regime, all the varieties gave grain yields equal statistically in 1992. Whereas at R2 and R3 regimes, the varieties behave differently, indeed, the variety Ambral gave the lowest grain yields. According to Bányai et al. (2012), in the case of the water deficit there was an increase in the number of sterile basal and apical spikelets, but the grain loss affected all the spikelets in the ear.

Artaban (1991) and Ambral (1992) have the highest SSI for grain yield, but percentage reduction for thousand grains weight and grains number /m² is the highest at the two regimes for Ambral. Among the bread wheat varieties, Soissons has the lowest stress susceptibility index for the majority of traits in 1992, but it has the highest in 1991 and Festival the highest in 1992. In 1991, it is Scipion who has the lowest SSI, whereas Soissons has a SSI almost equal to that of Artaban for grain yield. Therefore, the tolerance to water stress depends on varieties within the same species and the environment in which they are cultivated. For all traits, the bread wheat Artaban (in 1991) has the highest reduction in the water stress compared with Thesee, Festival, Soissons, Scipion, and Beauchamp. The durum wheat Ambral (in 1992) has the highest reduction in the water stress compared to Thesee, Festival Soissons (Table 4). Our results in 1992 are similar to those of Marty and Slafer (2007). According to these authors, averaged yield was similar for both wheat, but bread wheat out yielded durum wheat in severely stressed environments while durum wheat possessed a higher yield potential. It is likely that the tolerance to the water stress of the common wheat compared with the durum wheat is due to the D genome in the bread wheat. The D genome originated from *Aegilops tauschii* (Coss.) Schmalh. (*Aegilops squarrosa* auct. non L.). The genus *Aegilops* L. represents an important natural source of useful genes for wheat breeding with particular emphasis on biotic and abiotic stress resistance (Belkadi et al., 2003). Bread and durum wheat genotypes were characterized by different physiological reactions to the applied drought stress and by clearly different molecular responses (Aprile et al., 2009). According to these authors, the genome organization accounted for differences in the expression level of hundreds of genes located on D genome or controlled by regulators located on the D genome.

The correlations between traits showed that grain yield was mainly correlated with grains number/m² and NDVI. The correlations between NDVI and grains number/m² were also high. Grain yield, grains/m² and thousand grains weight variability were explained by means NDVI variability (Figure 1). Our results confirm those reported by Gutièrrez-Rodriguez et al. (2004) who showed that NDVI has stronger association with yield under drought conditions. Grain yield can be predicted using single regression with NDVI (Lobos et al., 2014). In the irrigated treatments, plants remained green longer than water stressed treatments. Our results are in agreement with those of Bányai et al. (2012). Indeed, the normalized difference vegetation index (NDVI) based on the green vegetation absorbing solar radiation in the spectrum band by chlorophyll. The water stress causes a decrease of the photosynthetic surface and thus a decrease of NDVI.

Conclusion

Results obtained in these experiments indicate that drought stress significantly decreased the grain yield, grains number/m², thousand grains weight and Normalized Difference Vegetation Index (NDVI). For all traits durum wheat (*T. durum* Desf.) has the highest reduction in the two water stress than the bread wheat (*T. aestivum* L.). The treatments x variety interactions were significant for grain yield, thousand grains weight and NDVI in 1992 and for grain yield in 1991. Correlations studies revealed that grain yield, grains number/m², thousand grains weight and NDVI were associated with each other except for correlations between thousand grains weight on one hand and grain yield (1992) and grains number/m² (1991) on the other hand. 51.55, 27.88, 4.12% (1991) and 75, 43 and 20.2% (1992) of grain yield, grains/m² and thousand grains weight variability, respectively, were explained by means NDVI variability. The grain yield and grains number/m² could be predicted using a single regression, with NDVI.

Conflict of interests

The authors did not declare any conflict of interest.

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