ISSN : 1812-5379 (Print)
ISSN : 1812-5417 (Online)
http://ansijournals.com/ja

JOURNAL OF
AGRONOMY

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Journal of Agronomy 6 (2): 294-301, 2007
ISSN 1812-5379

Relationships Between Grain Yield Performance, Temporal Stability and Carbon Isotope Discrimination in Durum Wheat (*Triticum durum* Desf.) Under Mediterranean Conditions

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Abstract: The experiment was conducted during six cropping seasons (1997/98 to 2002/03), with the objective to study the relationships between grain yield performance, temporal stability and carbon isotope discrimination of durum wheat (*Triticum durum* Desf.) genotypes grown under semi-arid conditions of the eastern highlands of Algeria. The results indicated significant season and genotype × season interaction for grain yield and a non significant genotypic main effect. Mrb5 cultivar out yielded the evaluated entries during three out of six cropping seasons, Cyprus 1, Bicre and Daki were the top-yielding genotypes in two seasons and Waha, Belikh 2 and Heider/ Martes// Huevos de Oro, were high yielding during only one cropping season. Heider and Mrb16 showed a relatively high grain yield temporal stability, Derraa had the lowest value. The results of the present study indicated that grain yield measured during six cropping seasons was not significantly correlated with Δ^{13}C measured during one season. This suggested that carbon isotope discrimination could not be suggested as an indirect selection criterion to screen durum wheat genotypes for water use efficiency under the Mediterranean climate of the high plateaus of Algeria.

Key words: *Triticum durum*, yield performance, temporal stability, carbon isotope discrimination, mediterranean climate

INTRODUCTION

Under variable environments, such as those encountered in semi-arid areas, selection is directed toward the identification of cultivars that perform well in a wide range of seasons and locations (Annicchiarico, 1992; Bouzerzour and Dekhili, 1996; Bahlouli *et al*., 2005; Singh *et al*., 2006). The identification of such broadly adapted varieties becomes, however, difficult when the phenotypic response to changes in the environment varies among selected entries (Annichiarico *et al*., 2002). Plant characters, that influence performance, have often differing opportunities for expression in different environments and they become a source of genotype × environment interaction, reducing selection progress (Blum and Pnuel, 1990; Ebdon and Gauch, 2002). In order to allow a proper estimate of genotypic yield response to the environment, plant breeders developed the multi-site multi-location testing system from which the performance and stability of a given genotype is derived. When genotype × location is the main source of interaction, selection is directed toward specific adaptation to the target area (Annichiarico *et al*., 2006). When genotype × year is the major source of variation, due to changes in growth conditions from year to year, selection for large adaptation is favored (Atlin *et al*., 2000). Genotype by environment interaction is almost omnipresent under semi-arid conditions because yearly variation is typically the largest source of yield variation. Conducting variety trials at one location for several seasons is necessary, since the greater the number of years a genotype is tested the more reliable its evaluation will be (Yan and Hunt, 2001). Grain yield temporal stability is defined, in this context, as a decreasing crop failure frequency and a low range between extreme environments (Roseille and Hamblin, 1981; Ceccarelli *et al*., 1998).

When selecting varieties for variable environments, breeders are concerned with the avoidance of crop failure under harsh growth conditions. This is because large proportions of cereals are grown under low input conditions by subsistence farmers. Studies with small grain cereals have indicated the existence of a positive

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correlation between grain yield and carbon isotope discrimination ($\Delta^{13}C$) of mature grains (Condon *et al.*, 1987; Araus *et al.*, 2003). Craufurd *et al.* (1991) mentioned that correlations between grain yield and $\Delta^{13}C$ were significant under moderate stress and non significant under unstressed conditions. Grain yield and $\Delta^{13}C$ were closely associated with phenology because earlier genotypes escaped drought and showed high yields and high $\Delta^{13}C$ (Condon *et al.*, 2004). $\Delta^{13}C$ is considered to be a consistent characteristic of a given genotype, which means that we expect that ranking of the cultivars for $\Delta^{13}C$ will be similar over diverse environments. Sayre *et al.* (1995) reported a significant correlation coefficient between $\Delta^{13}C$ measured under drought stress and $\Delta^{13}C$ measured under irrigated conditions. This provided an indication of the inherent stability of $\Delta^{13}C$ and the absence of significant G × E interaction for this characteristic. The objective of this study was to describe the grain yield variation across seasons, to analyze and discuss the relationship between $\Delta^{13}C$, grain yield performances and grain yield temporal stability of a set of durum wheat lines and cultivars grown under semi-arid conditions of the eastern high plateaus of Algeria.

MATERIALS AND METHODS

Trials description: Fifteen durum wheat (*Triticum durum* Desf.) genotypes were evaluated during 6 consecutives cropping seasons, from 1997/98 to 2002/03, at the Agricultural Experimental Station of the Field Crop Institute (ITGC) of Setif, located on the eastern high plateaus of Algeria (1081 m asl., 5°21' E, 36°9' N). The genotypes included Algerian varieties, originating from local land races, ICARDA (International Center of Agricultural Research in Dry Area) and European varieties. The experiment was laid down in a randomized complete block design with three replicates; including 45 plots, each one measuring 5 m long × 1.2 m wide. The trials were sown in mid November, in a back fallow-cereal cropping system. The soil of the experimental site is a deep brown calcareous earth classified, in the French classification system, as a steppic brown soil. The pH value is 8.2, the organic matter is 1.35% and the K fertility ranging from 140 to 180 mg kg^{-1} in the 60 cm soil profile. Soil composition is 13.9% sand, 41.3% silt and 44.7% clay. The mean water content, at field capacity and at permanent wilting point, were estimated to be 25 and 12%, respectively. Soil bulk density is 1.35 g cm^{-3} and the soil infiltration rate is 8.3 mm h^{-1} (Chennafi *et al.*, 2006). One hundred kg ha^{-1} of triple super phosphate 46% were applied in autumn, at sowing, according to soil mineral analysis and anticipated crop demand and incorporated with harrow disc. 100 kg ha^{-1} of urea 35% were broadcasted at the tillering stage, during the month of March. Weeds were controlled chemically with GranStar (*Methyl triberunon*), at 12 g ha^{-1} rate.

Measurements: The length of the vegetative period was calculated as the number of calendar days from January 1st to the day when more than half the plants in a plot reached the heading stage. The length of the vegetative period was also expressed in terms thermal time, calculated in growing degree-days, by summing the daily values of the mean temperature, with a base temperature of 0°C (Gallagher, 1979). At heading, 1m from the plot inner row was harvested to estimate the above ground dry matter. Fresh material was cut into small pieces of 5 cm long and oven dried for 24 h at 85°C. At maturity plant height was measured and a second harvest was made, from the inner row, to determine the accumulated dry matter and grain yield, these two variables were used to estimate the harvest index. The same vegetative samples were utilized to get the number of spikes and the 1000-kernel weight per plot. Grain yield was obtained from the mechanically harvested trial. The number of kernels per spike and the number of grains m^{-2} were deduced from the plot values of grain yield, thousand-kernel weight and number of spikes. Carbon isotope determination ($\Delta^{13}C$) was performed by the ratio mass spectrometry at the Plant Biotechnology Institute, South Paris University (France). $\Delta^{13}C$ values of mature grains were reported as deviations in parts per thousand expressed relative to air taken as 7.85‰ relative to belemnite from the Pee Dee Belemnite (PDB) formation in South Carolina following Farquhar and Richards (1984). $\Delta^{13}C$ was assessed during the 2001/02 cropping season for 8 entries among the 15 tested genotypes due to limited budgetary resources.

Data analysis: Data were subjected to an analysis of variance using the balanced analysis of variance subroutine of Irristat 5.0 release (2005). In the analysis of variance the cropping seasons and genotypes were considered as random and fixed, respectively. The effects were tested and the variance components estimated according to the procedure outlined by McIntosh (1983). In addition to the analysis of variance, an analysis of covariance has also been performed. Grain yield and $\Delta^{13}C$ were adjusted for phenology, when appropriate, utilizing the number of calendar days from January 1st to heading stage as a covariate: Adjusted GY or $\Delta^{13}C = Y_i\text{-}b\ (X_i\text{-}X)$, where Y_i is the observed GY or Δ of the ith genotype, X_i is the mean number of calendar days to heading of the ith genotype and X is the average number of days to heading of the entire tested group of genotypes. Temporal genotypic stability measure was based on both Finlay and Wilkinson (1963) regression coefficient and across season's variation. The across season's variance of the ith genotype was calculated as: $S^2_i = \sum (Y_{ij}-Y_i)^2/E-1)$. To weigh yield performance relatively to stability, a 5% probability of an undesirable event was used to compute for each cultivar the lower confidence limit. This is the grain yield obtained once in 20 cropping seasons. It represents the temporal stability (Ii) which is computed according to Eskridge (1990): $I_i = Y_i-Z\ (1-\alpha)\ [(b - 1)^2\ S^2y\ (1-1/E)]^{1/2}$, where $S^2y = \sum (Y.j - Y..)^2/(E-1)$ = across season's variation, E = number of seasons and Z (1-α) is the percentile from the standard normal distribution, with α set at 5% level.

RESULTS AND DISCUSSION

Grain yield variation across seasons: The analysis of variance of grain yield showed a significant season main effect and genotype×season (G×S) interaction. The genotypic main effect tested against the G×S mean square was not significant, having a nil component of variation as the G×S variance component was too large (Table 1). Season grain yield means varied from 180.3 to 333.5 g m^{-2}. This large variation among seasons reflected the large year-to-year variation in rainfall distribution and thermal regimes. The accumulated rainfall during the cropping cycle (October-June) ranged from 168.7 to 517.3 mm. Most rain falls in the cold winter period (October-March) and represents 56 to 88% of the total accumulated rainfall. No significant linear relationship was observed between season grain yield and the accumulated rainfall during winter (r = -0. 079^{ns}), spring (r = -0.2781^{ns}) or the whole season (r = -0.2693^{ns}). The correlation coefficients of individual genotype with winter, spring and total rainfall were non significant and varied from -0.3312 to 0.6452^{ns}; -0.3228 to 0.680^{ns} and -0.3133 to 0.7143^{ns}, respectively. In fact two cropping seasons, 2001/02 and 2002/03, showed almost similar grain yield (180.3 vs 212.9 g m^{-2}), while having quite different total rainfall (168.7 vs 517.5 mm) (Table 2, Fig. 1). This changes the relationship between grain yield and rainfall, which is usually linear (Blum and Pnuel, 1990) to quadratic (Fig. 2). According to Passioura (2004) the reasons for such change is that distribution of rain during the growing season can be unfavourable which plenty full water at some growth stages and water deficit associated with heat, or frost or diseases problems at other critical stages. The differential yielding ability of the genotypes was almost inhibited in 2002 and 2003 (Fig. 3), with a

Table 1: Analysis of variance of grain yield of 15 durum wheat genotypes grown for 6 seasons at one location, with partitioning of genotype×season interaction by joint regression analysis and analysis of variance of the carbon isotope discrimination of 8 genotypes among the 15 tested measured in one season

	Grain yield		Carbon isotope discrimination	
Sources of variation	df	Mean square	df	Mean square
Seasons (S)	5	179389.9**		
Blocks (Season)	12	1764.3	2	0.10
Genotype (G)	14	13699.8^{ns}	7	0.29*
G×S	70	15267.4**		
Regression	15	24659.0**		
Deviation from regression	55	12919.5**		
Pooled error	168	1358.1	14	0.10

ns, *, ** = Effect non significant and significant at 5 and 1% level, respectively

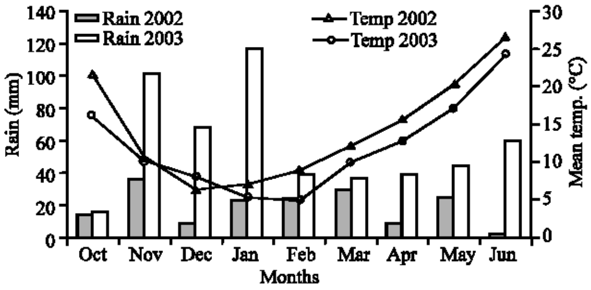

Fig. 1: Monthly rainfall and monthly mean temperature of the driest (2001/2002) and wettest (2002/2003) cropping seasons

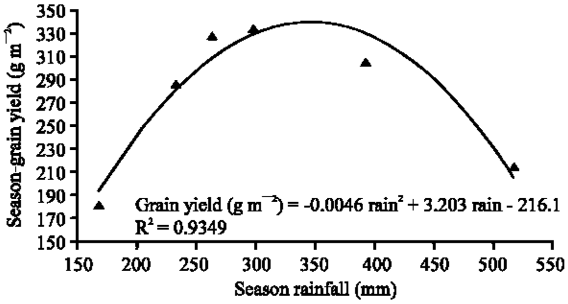

Fig. 2: Relationship between season mean yield and rainfall

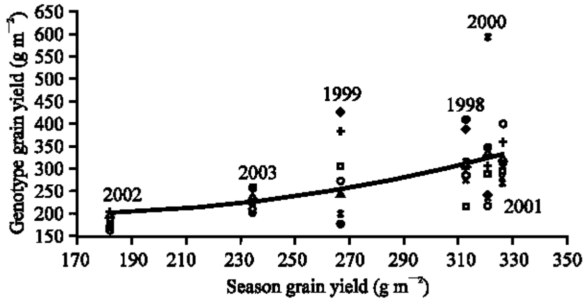

Fig. 3: Within season grain yield variation and relationship between genotype mean yield and season mean yield

Table 2: Total, winter, spring and ratio of winter/total accumulated rainfall per cropping season and mean grain yield (g m^{-2}) of the top yielding genotypes per season

Cropping seasons	1998	1999	2000	2001	2002	2003
Accumulated rainfall (mm)						
Total rainfall (mm)	393.3	233.1	299.1	264.3	168.7	517.5
Winter rainfall (mm)	220.7	198.2	188.0	231.8	134.2	375.9
Spring rainfall (mm)	172.6	34.9	111.1	32.5	34.5	141.6
Winter/Total rain ratio	0.56	0.85	0.63	0.88	0.80	0.73
Grain yield (g m^{-2})						
Mrb5	391.6*	426.6*	240.6	321.6	163.8	258.8*
Cyprus1	354.3	194.0	557.3*	307.0	260.0*	202.0
Waha	298.3	333.3	308.3	431.6*	149.7	180.9
Belikh2	216.6	305.0	288.0	306.6	189.2	256.2*
Mrb16/Ente//Mario	309.0	243.3	335.3	327.0	201.1	240.7*
Bicre	283.7	273.3	219.6	397.6*	161.5	234.4*
Deraa	316.7	200.0	593.0*	284.3	179.8	216.1
Daki	406.3*	178.3	344.6	318.3	169.5	257.2*
Heider/Martes//Huevos Oro	283.7	338.3	500.0	332.6	197.2	222.2*
Season mean yield	304.0	285.0	333.5	327.4	180.3	212.9

Total rain = Accumulated rainfall from October to June; winter rainfall = Accumulated rainfall from October to March; spring rainfall = Accumulated rainfall from April to June. LSD 5% = 36.11 g m^{-2}; * = Top-yielding genotypes per season

within season grain yield variance of 266 and 523, respectively, while ranging from 1351 to 14277 for the other cropping years. This suggested that the observed grain yield was not the expression of rainfall solely, but the results of the interaction between rainfall distribution pattern and temperature regimes. The mean monthly temperatures of the 2003 cropping year, from January to harvest, were 2.3°C lower compared to the mean monthly temperatures of 2002 (Fig. 1). The region of concern is known for it cold winter as well as late spring frost effects on crop production (Oosterom *et al*., 1993; Annichiarico *et al*., 2002; Mekhlouf *et al*., 2006). In fact both cropping years achieved almost equivalents number of spikes and number of kernels per spike (Data not shown). The results of 2002 could be explained easily by effect of the drought because 1000-kernel weight was very low; those of 2003 appear to be affected by the low prevailing temperatures (Fig. 1). The presence of G × S interaction detected by the combined analysis of variance was expressed in the change of genotypic performances in the different seasons experienced. Mrb5 out yielded the evaluated entries during three cropping seasons, Cyprus1, Bicre and Daki were the top-yielding genotypes in two seasons and Waha, Belikh2 and Heider/Martes// Huevos de Oro were high yielding during only one cropping season (Table 2). This indicated that high temporal stability was leaking in the tested entries.

Averaged across seasons, genotypic grain yield means showed less variation compared with season grain yield means and varied from 220.4 g m^{-2}, mean grain yield of Semito to 312.1 g m^{-2} mean yield of Cyprus1 and Heider/Martes//Huevos de Oro (Table 3). The regression analysis explained 34.5% of the observed G×S interaction. Among the tested entries 439/ Adamillo// Duillio/3/Semito showed a slope significantly greater than unity. Semito and Massara had a slope not significantly different from zero and the remaining entries were characterized by a slope equal to unity (Table 3). Mrb16/Ente//Mario, Belikh2, Heider, 439/ADS, Waha and Beliouni presented a low across season's variance, while Cyprus1 and Deraa had a relatively high across season's variance. Heider and Mrb16/Ente//Mario showed a relatively high temporal stability while Deraa had the lowest value (Table 3). The carbon isotope discrimination measured during the 2001/2002 cropping year showed a significant genotypic effect. The mean values varied from 15.60 to 16.40‰ which indicated the presence of intrinsic genotypic differences in $\Delta^{13}C$ (Table 1 and 3). The values reported here were in agreement with those reported in the literature, so far for the C_3 species ranging from 13.0 to 22.0‰ (Sayre *et al*., 1995; Ebdon *et al*., 1998; Condon *et al*., 2004). According to Sayre *et al*. (1995), the genotypic differences in $\Delta^{13}C$ are reflecting those in the C_i/C_a and are mainly caused by variation in assimilation weighted stomatal conductance rather than by variation in photosynthetic capacity. Delgado *et al*. (1994) mentioned that, in the absence of stress, high $\Delta^{13}C$ values reflect rapid crop canopy assimilation rates due to increased stomatal conductance and consequently higher yields. High $\Delta^{13}C$ values are also indicative of high canopy transpiration rates which will reduce leaf temperature, contributing to heat avoidance (Araus *et al*., 2003; Condon *et al*., 2004). Under the conditions of terminal drought associated with increased solar radiation and air temperature, like those experienced by the genotypes tested in the present study, early genotypes tended to have a large $\Delta^{13}C$, because they assimilate most of their carbon under low vapor pressure conditions, in contrast with late heading cultivars.

Table 3: Regression coefficient (slope), across season's variance (S^2), temporal stability (I_i, g m^{-2}), mean grain yield (GY, g m^{-2}) and grain carbon isotope discrimination values ($\Delta^{13}C$ ‰) of the durum genotypes evaluated during the six cropping seasons

Order	Genotype	Slope	$S^2 \times 10^3$	I_i	GY	$\Delta^{13}C$
1	439/Adamillo//Duillio/3/Semito	1.60^{b*}	1.6	207.8	273.5	--
2	Massara	0.31^{a}	3.4	142.7	237.9	--
3	Mrb5	0.86^{b}	6.7	165.5	300.5	15.76
4	Cyprus1	1.30^{b}	12.4	129.7	312.4	--
5	Waha	1.46^{b}	2.4	204.0	283.7	--
6	Belikh2	0.51^{b}	1.4	197.9	260.3	15.82
7	Mrb16/Ente//Mario	0.81^{b}	0.5	239.4	240.1	15.60
8	Bicre	0.83^{b}	3.1	170.6	261.7	16.40
9	Derraa	1.63^{b}	15.6	92.9	298.4	16.02
10	Daki	1.02^{b}	4.3	170.8	279.1	15.66
11	Heider/Martes//Huevos de Oro	1.41^{b}	4.0	208.5	312.4	--
12	Heider	0.97^{b}	1.6	245.5	293.4	15.98
13	Mohammed Ben Bachir	0.86^{b}	6.4	161.5	241.1	--
14	Semito	0.47^{a}	4.1	135.6	220.2	16.40
15	Beliouno3258	0.98^{b}	2.6	172.5	257.0	--

a, b and b* = regression coefficients non significantly different from zero, significantly different from zero, significantly different from 1, respectively, LSD 5% yield main effect = 200.1 g m^{-2} and = 0.55‰ for $\Delta^{13}C$

Table 4: Coefficient of simple correlation of the measured variables per season with grain yield (GY) and with carbon isotope discrimination ($\Delta^{13}C$)

Measured characters	NG_{m-2}	NG_S	NS_{m-2}	TKW	BIO_H	HI	PHT	DHE_{DAYS}	DHE_{GDD}	GY
1998										
GY	0.94**	0.76*	0.77*	-0.27	0.07	0.73*	-0.28	0.22	0.16	1.00
$\Delta^{13}C$	-0.34	-0.30	-0.06	-0.22	-0.43	-0.04	-0.15	-0.29	-0.20	-0.44
1999										
GY	0.98**	0.62	0.62	-0.05	0.24	0.74*	-0.45	0.62	0.58	1.00
$\Delta^{13}C$	-0.27	0.15	-0.62	0.14	-0.12	-0.14	0.59	-0.04	-0.02	-0.29
2000										
GY	0.98**	0.79*	0.58	-0.19	-0.67	0.96**	-0.26	0.31	0.31	1.00
$\Delta^{13}C$	-0.18	-0.16	-0.19	0.04	0.73^{*}	-0.44	0.40	-0.16	-0.18	-0.22
2001										
GY	0.76*	0.78*	0.27	-0.25	-0.59	0.86**	0.66	-0.35	-0.33	1.00
$\Delta^{13}C$	-0.89**	-0.46	-0.66	0.79*	0.52	-0.64	-0.74*	0.16	0.13	-0.64
2002										
GY	0.74*	0.73*	0.27	0.17	0.09	0.74*	-0.22	0.01	0.02	1.00
$\Delta^{13}C$	-0.72*	-0.29	-0.16	0.71*	0.66	-0.64	-0.76*	-0.45	-0.43	-0.19
2003										
GY	0.77*	-0.09	0.83**	0.14	0.45	0.76*	0.63	0.23	0.22	1.00
$\Delta^{13}C$	0.06	0.41	-0.33	-0.59	-0.27	-0.79^{*}	-0.56	-0.25	-0.25	-0.63

NG_{m-2} = Number of grains m^2; NG_S = Number of grains spike; NS_{m-2} = Number of spikes m^2; TKW = 1000-kernel weight; BIO_H = Accumulated biomass at heading; HI = Harvest index; PHT = Plant height; DHE_{DAYS} = Number of calendars days to heading; DHE_{GDD} = Growing degree-days to heading

Relationships between grain yield, $\Delta^{13}C$ and the measured variables per season: Among the 15 genotypes, grain yield was significantly correlated with the genotypic regression coefficient (r = 0.71*) but not with the temporal stability (r = 0.170^{ns}) and with the across season's variation (r = 0.451^{ns}). The temporal stability was negatively correlated with the across season's variation (r = -0.807*), but not with the regression coefficients (r = 0.012^{ns}). This indicated that (1) high grain yield is expressed by genotype having a slope significantly larger than unity, (2) grain yield performances are independent of temporal stability and season's variation and (3) less responsive genotypes to the favorable growth conditions are relatively more stable over seasons than the sensitive ones. Among the 8 genotypes, used for $\Delta^{13}C$ measurements, grain yield was positively correlated with the number of grains m^{-2} and with the harvest index, during the 6 cropping seasons (Table 4). Grain yield was either correlated with the spike fertility or with the number of spikes m^{-2}. This indicated that yield determinant was the number of grains m^{-2}. The yield components contributing to this trait are the spike fertility or/and the number of spikes m^{-2} and all together contributed to the harvest index increase. Grain yield showed no significant relationships with the biomass accumulated at heading, with plant height and with phenology, measured in terms of calendars days or growing-degree days (Table 4). $\Delta^{13}C$ values showed inconsistent relationships with the measured variables, being no significant with grain yield, spikes number, spike fertility, temporal stability and number of days to heading. The relationships were significant and negative with the number of grains m^{-2} and with plant height and positive with 1000-kernel weight during two seasons and with harvest index and the biomass accumulated at heading in one season (Table 4).

The results of the present study diverged from those reported by Sayre *et al.* (1995) who found a positive correlation between $\Delta^{13}C$ and grain yield under drought stress conditions, however the corresponding correlation was weaker in the absence of drought stress. Araus *et al.* (2003) found also a positive correlation between $\Delta^{13}C$ and grain yield across trials and reported that water input from heading to maturity was the determinant variable explaining the observed variation in $\Delta^{13}C$, grain yield and the relationship between grain yield and $\Delta^{13}C$. Craufurd *et al.* (1991) reported a negative relationship between grain yield and $\Delta^{13}C$ in barley. According to Araus *et al.* (2002), a negative relationship between $\Delta^{13}C$ and grain or above ground biomass can be expected in Mediterranean trials with very low water input during the crop cycle and mainly during the gain filling period. Under such growth conditions, similar to those experienced by the tested genotypes of the present study, high grain yield appears to be related to high transpiration efficiency and to low $\Delta^{13}C$. Condon *et al.* (2004) mentioned that there is a high level of inconsistency observed in the relationship between $\Delta^{13}C$ and grain yield, varying from negative, neutral to positive. The relationship between $\Delta^{13}C$ and grain yield is sensitive to water input throughout the cropping cycle and mainly during the grain filling phase and expresses the differential genotypic ability to use water. A positive relationship have been encountered in environments where regular rainfall events throughout the growing seasons have maintained a high soil water status. In these environments the faster growth of high $\Delta^{13}C$ genotypes has usually been translated directly into higher above ground biomass and grain yield (Condon *et al.*, 2002). Under growth conditions favoring early growth, high $\Delta^{13}C$ genotypes exhaust the available soil water too quickly before the onset of heading, they yielded less due to no water to sustain grain filling. Under similar growth conditions, low $\Delta^{13}C$ genotypes are more conservative in their water use, sustaining growth rate during the grain filling phase and allowing the translocation of the assimilates laid down in the stem before or shortly after heading which culminate in a relatively high grain yield (Voltas *et al.*, 1999; Rebetzke *et al.*, 2002). A positive relationship between $\Delta^{13}C$ and grain yield indicates the differential ability of the tested genotypes to use more water while a negative correlation indicates the differential ability to make the best use of the limited available water. Selection for high $\Delta^{13}C$ will improve the yield potential under favorable growth conditions while selection for low $\Delta^{13}C$ will improve the adaptation to drought stress. Under the growth conditions of the present study, $\Delta^{13}C$, measured in one season, showed a neutral relationship with grain yield and inconsistent relationships with the yield components, leading to inconclusive results about its use in selection to improve grain yield of durum wheat grown in water limited environment of the Algerian high plateaus. This could be explained as mentioned by Araus *et al.* (2002) fact that high grain yield is achieved because of a high water use efficiency in some genotypes, while in other genotypes, it is because they are able to use more water, or because they are less sensitive to low temperature and thus the combinations of all these responses lead to non significant relationship between the carbon isotope discrimination and grain yield.

CONCLUSIONS

Drought combined with high temperature is the main constraint to cereal production in the Mediterranean area. Breeding tolerant varieties is still the relatively easy way to increase grain yield under such environments where multi-sites and multi-seasons trials are conducted to investigate the magnitude of genotype × environment usually encountered. This investigation makes apparent the magnitude of genotype × season interaction that must be confronted in a durum breeding evaluation program. As a highly heritable trait, relatively easy to manipulate in breeding, $\Delta^{13}C$ appears as a potential candidate for use in breeding to improve water use efficiency via greater assimilation relatively to transpiration. The results of the present study indicated that grain yield measured during six cropping seasons was not significantly correlated with $\Delta^{13}C$ measured during one season, $\Delta^{13}C$ could not be recommended to be used routinely in the screening of durum wheat genotypes characterized by high water use efficiency in the water limited environment of the Algerian high plateaus.

ACKNOWLEDGMENTS

The first author thanks Pr. J.L. Prioul for the stay in his Laboratory at Paris South University and for constructive comments on the manuscript; thanks are also extended to Madam C. Lelarge for the carbon discrimination analysis.

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