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Carbon isotope discrimination, canopy temperature depression and nitrogen content as tools for grain yield assessment in Mediterranean conditions

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SUMMARY – Four experiments were conducted in 1997 and 1998 in two contrasting environments (irrigated and rainfed) in north-eastern Spain. Each experiment included 25 durum wheat genotypes grown in the Mediterranean region. Canopy temperature depression (CTD) from the air was determined at anthesis and milk-grain stage. Stable carbon isotope discrimination (Δ) and nitrogen (N) content were further determined in mature grains. Genotypical effects accounted for a small part of the variability found in all the traits. The year effect was very important to explain CTD differences at anthesis and N content of grains. Differences between the irrigated and the rainfed environment accounted for most of the variability found in yield and Δ , and were also important to explain differences in N. Broad sense heritabilities were higher for Δ and N than for grain yield, and were very low for CTD both at anthesis and at milk-grain stage. Carbon isotope discrimination was the trait most related to grain yield, the coefficient of correlation increasing from the worst (i.e. rainfed) to the best (i.e. irrigation) trials.

Key words: Carbon isotope discrimination, canopy temperature, nitrogen content.

RESUME – “Discrimination isotopique du carbone, dépression de la température du couvert et teneur en azote comme instruments pour l'évaluation du rendement en grain en conditions méditerranéennes”. Quatre expériences ont été menées à terme en 1997 et en 1998 dans deux milieux contrastés (terrains irrigués et non irrigués) du nord-est de l'Espagne. Chaque expérience comprenait 25 génotypes de blé dur provenant du bassin méditerranéen. Au stade de l'anthèse et au stade de grain laiteux, nous avons déterminé la différence de température entre le couvert végétal et l'air (CTD). Postérieurement, sur le grain mûr, nous avons analysé la discrimination isotopique du carbone (Δ) et la teneur en azote (N). D'après nos résultats, l'effet génotypique n'est responsable que d'une petite proportion de la variabilité détectée dans toutes les variables. L'effet de l'année est très important pour expliquer les différences de CTD au stade de l'anthèse et de la teneur en azote des grains. Les différences entre les terrains irrigués et non irrigués expliquent pour une large part la variabilité observée dans le rendement et dans Δ ; elles expliquent aussi la variation de la teneur en azote. Quant au facteur hérédité, pris au sens large, il est plus important pour Δ et N que pour le rendement grain, et très faible pour CTD, aussi bien au stade de l'anthèse qu'au stade de grain laiteux. La discrimination isotopique du carbone est la caractéristique la plus influente au regard du rendement grain. Le coefficient de corrélation entre ces variables est plus important dans les terrains irrigués que dans les terrains non irrigués.

Mots-clés : Discrimination isotopique du carbone, température du couvert, teneur en azote.

Introduction

Recent gains in durum wheat yield associated with crop breeding have been far lower in dry areas than in favourable environments (Evans, 1998). Until now, cereal breeding in Mediterranean environments has been based mostly on empirical selection for yield *per se* (Loss and Siddique, 1994). However, further genetic gains could be favoured through the understanding of the physiological processes and key traits that are currently limiting yield and quality. The knowledge of the association between grain yield and some morphophysiological traits is still limited in Mediterranean environments. Traits related to the photosynthetic performance of the crop, such as canopy temperature depression and carbon isotope discrimination (Δ), integrate to varying extents the photosynthetic/transpirative activity of the crop in a given environment. Thus, the instantaneous transpiration of the crop may be indirectly assessed by canopy temperature (Reynolds *et al.*, 1994), whereas carbon isotope discrimination measured in mature grains integrates the transpiration efficiency over the grain filling period (Farquhar and Richards, 1984; Condon *et al.*, 1990, 1993). Nitrogen content is not just a basic quality attribute of grains but can provide

an integrated view of the efficiency of nitrogen retranslocation during grain filling compared with photosynthetic activity (Araus and Tapia, 1987). The aim of this work was to assess the performance of these physiological traits for predicting genotypic differences in grain yield.

Materials and methods

Four field experiments were conducted in 1997 and 1998 under irrigated and rainfed conditions in Lleida (41° 38'N 0° 23'E). Twenty-five durum wheat genotypes were sown at a density of 550 germinable seeds/m² in an alpha-lattice design with 4 replicates in plots of 14.4 m². The agronomical practices were the usual ones in the area. Canopy and air temperatures were measured at anthesis and at milk-grain stage with an infrared thermometer taking five measurements per plot. Canopy temperature depression (CTD) was further calculated as the difference between canopy and air temperatures. Plots were harvested mechanically at ripening and grain yield (kg/ha) was determined for each plot and expressed at 10% moisture level. $\delta^{13}\text{C}$ and N values of mature grains were determined for each plot by mass spectrometry and gas chromatography respectively, at "Servicios Científico Técnicos de la Universidad de Barcelona". Carbon isotope discrimination (Δ) was further calculated from $\delta^{13}\text{C}$ values according to Farquhar *et al.* (1989). Broad-sense heritabilities were determined through the calculation of variance components. Stepwise regression analyses were carried out to ascertain the relationship between grain yield as the dependent variable and the morphophysiological traits as independent variables.

Results and discussion

The analyses of variance revealed that the year and site effects were significant for most of the variables analyzed ($p < 0.01$). However, differences between genotypes were less evident for some traits, especially CTD. Indeed, genotypical effects accounted for a small proportion of the total variability found in the variables considered (Table 1). The percentage of the total variability explained by the year effect was low for CTD measured at milk-grain stage and for grain yield, but high for N content and CTD at anthesis (Table 1). However, differences between irrigated and rainfed sites explained most of the variation in grain yield, Δ and N.

Table 1. Percentage of the sum of squares of the analyses of variance explained by the main factors in the analyses. The variables analyzed were grain yield, canopy temperature depression at anthesis (CTD_A) and at milk grain filling (CTD_M), nitrogen content (N) and carbon isotope discrimination (Δ) of mature grains

Factor	Grain yield	CTD _A	CTD _M	N	Δ
Year	1.0	39	0.4	28	5.2
Site	60	3.6	3.7	34	73
Year x site	0.1	17.5	0.6	6.3	5.5
Genotype	4.4	1.2	3.8	5.1	2.3
Year x genotype	3.4	1.0	3.0	2.0	0.7
Site x genotype	1.7	1.0	2.0	2.0	0.7
Year x Site x genotype	3.5	1.3	1.3	1.3	0.7

Broad sense heritabilities were higher for carbon isotope discrimination and N content (0.69 and 0.61 respectively) than for grain yield (0.44), whereas those for canopy temperature depression measured either at anthesis (0.28) or at milk-grain stage (0.06) were the lowest.

Regression analyses for each combination between year and site showed that carbon isotope discrimination was the only trait that significantly ($p < 0.05$) entered all of them. The percentage of variability in grain yield explained by this trait was higher than 43% for three of the four combinations, and 64% when all the years and sites were considered together. In this last case CTD at anthesis also entered the equation but it only added 3% to the explanation of grain yield variation. The correlation coefficient between carbon isotope discrimination and grain yield within each of the trials assayed was always

positive. However, the coefficient tended to increase with site mean grain yield (Fig. 1), suggesting that the predictive value of Δ is higher under optimal (i.e. irrigated) than stressed (i.e. rainfed) areas. The relationship between N content and carbon isotopic discrimination in the grain was negative and highly significant when the two irrigated trials were combined, but no relationship was observed when the two rainfed environments were combined (Fig. 2). Thousand kernel weight was only significantly correlated with either N content and carbon isotope discrimination in the most productive environment ($r = -0.53$, $p < 0.01$ and $r = 0.67$, $p < 0.001$, respectively) probably due to the favourable conditions leading to genotypical differences being best expressed.

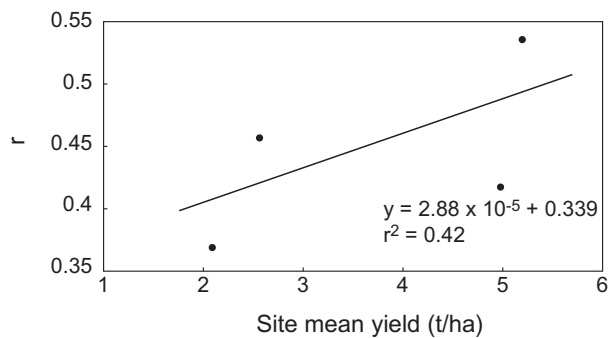


Fig. 1. Relationship between the site mean yield and the correlation coefficient across the 25 genotypes between carbon isotope discrimination and grain yield within each site.

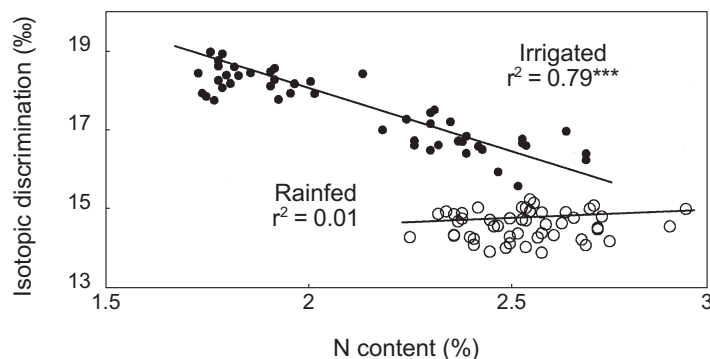


Fig. 2. Relationship of N content and carbon isotope discrimination in grains of 25 durum wheat genotypes grown under irrigated and rainfed conditions.

Our results suggest that the carbon isotope discrimination and the nitrogen content of grains may be useful tools for complementing selection for grain yield under Mediterranean conditions. However, the use of carbon isotopic discrimination as a grain yield estimator seems to be more suitable for areas with few limitations in the water available for the crop.

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