Crop rotation, nitrogen fertilization and genotype effects on durum wheat productive characteristics

I. Poma, S. Saladino, F. Noto, A. Carrubba, M. Sarno and G. Venezia[1]
Dep. ACEP, Faculty of Agriculture, University of Palermo
Viale delle Scienze, 90128 Palermo, Italy

SUMMARY – A field trial was performed in 2000/01 and 2001/02 in the experimental farm "Sparacia" (Cammarata – AG – Sicily) in order to evaluate the qualitative and quantitative response of four varieties of durum wheat when grown after a legume crop (field pea) or in rotation with itself and when submitted to different N-fertilization levels: no fertilization (N0, control), 60 kg ha-1 (N 60, rate advised by the EC n. 2078/92 for the Sicilian territory) and 120 kg ha^{-1} (N 120, fertilization rate commonly used under the "traditional" cropping technique). In the first trial year, the fertilized trial expressed a better yield performance than the control, but in 2001/02, characterized by severe and prolonged dry periods, the effect of crop rotation and variety was shown to be more important.

Key words: Crop rotation, N-fertilization, genotype, durum wheat, yields, yield traits.

RÉSUMÉ – *"Effets de la rotation des cultures, de la fertilisation azotée et du génotype sur les caractères productifs du blé dur". Un essai a été exécuté en 2000/01 et 2001/02 dans l'exploitation agricole expérimentale "Sparacia" (Cammarata - AG - Sicile) afin d'évaluer la réponse qualitative et quantitative de quatre variétés de blé dur une fois développé après une culture de légumineuse (pois fourrager) ou en rotation avec elles-mêmes et une fois soumises à différents niveaux de fertilisation azotée : aucune fertilisation (N0, témoin), 60 kg ha^{-1} (N 60, taux conseillé par la CE nº 2078/92 pour le territoire sicilien) et 120 kg ha^{-1} (N 120, taux de fertilisation généralement utilisé sous la technique traditionnelle). Pour la première année d'essai, l'essai fertilisé a exprimé un meilleur rendement que le témoin, mais en 2001/02, caractérisée par des périodes sèches graves et prolongées, l'effet de la rotation et des variétés a montré une importance plus forte.*

Mots-clés : *Rotation, fertilisation azotée, génotype, blé dur, rendements, caractères de rendement.*

Introduction

In last 50 years, considerable breeding activity has been carried out on durum wheat *(Triticum turgidum* ssp. *Durum)*, concerning both the traits more closely correlated to yields and those linked to the quality aspects. Only in last 10 years, due to a stronger public concern about the quality of agricultural products, breeding aims to obtain varieties able to optimise productions both from the quantitative and the qualitative point of view, providing quality parameters, similar to those possessed by the "strong" durum wheat grains that Italian pasta manufacturers buy from abroad in order to blend with domestic flours. The "quality" traits of agro-food products are individuated by some traits which allow consumers' requests to be satisfied (D'Egidio *et al.*, 2001). A preliminary division of the quality process may individuate a field, a storage and a processing quality, and agronomists may play a role in all cropping choices (variety choice, fertilization and cropping system) which may influence field quality. Among these, N-fertilization and crop rotation play an important role in semi-arid environments.

Materials and methods

The trial was carried out in 2000/01 and 2001/02 in the experimental farm "Sparacia" (Cammarata – AG – Sicily, 37° 37' N – 13° 42' E), of the Department ACEP of Palermo University, the location

[1] This research was carried out equal parts by all authors.

being representative of durum wheat cultivation areas of the hilly Sicilian inlands, characterized by a sub-arid climate with an average yearly rainfall of approx. 500 mm, mostly concentrated in the autumn-winter period. The soil, representative of local pedotypes, is slightly sloping, deep, with a clayey-sandy texture and a sub-alkaline reaction. The seedbed was prepared with a summer ploughing 30 cm deep, followed by two autumn harrowings in order to control weed development. Fertilization was performed twice: during the preparation work, 92 kg ha^{-1} of P_2O_5 were distributed, together with one half of the total N dose, in ureic form, whereas the N left was spread as the crop reached the stage of 3-5 true leaves. The sowing of durum wheat was performed on rows 25 cm apart, respectively on December 9th 2000 and January 10th 2002, distributing 350 germinable seeds m^{-2}. All the collected data (Tab. 2 and 3) were submitted to ANOVA according to the experimental design used. Mean differences have been evaluated through Tukey's test (α = 0.05), only on the characters showing significant differences at the F test. In order to satisfy the condition of variance homogeneity, percentage data have been transformed using the square-root method as their values were ranging from zero to 30 % or from 70 to 100 %, whereas in characters with a higher variability range, they have been transformed in angular values using the arc-sine method.

Table 1. Parameters under study and respective tested levels. Experimental design: split-split-plot with 3 replicates

Main plot factor Crop rotation (CR)	Monocropping wheat - wheat (CR1) Rotation wheat - field Pea (CR2)
Sub-plot factor N-fertilization (N)	No N-fertilization (N0) - test 60 kg/ha N (N60)† 120 kg/ha N (N120)††
Sub-sub-plot factor Variety (V)	Appio (V1) Creso (V2) Valbelice (V3) Simeto (V4)

†N-level advised by the EC reg. n. 2078/92 for the Sicilian territory.
††N-level commonly used in the "traditional" cropping technique.

Results and discussion

1st trial year

During the first trial year total rainfall amounted to 653 mm, a much higher value than the pluriannual mean (496 mm); 357 mm were measured in the period ranging from the pre-sowing and the cover fertilization (1st ten-days of February), gaining 170 mm approx. more than the 30-year means. The yearly mean temperatures, except for November and December, have always remained lower than the pluriannual ones. The overall yield performance has been satisfactory. The ANOVA performed showed that all the examined yield and qualitative parameters have been affected by the single effects under study (CR, N and V), whereas only few interactions have shown statistically appreciable modifications (Table 2). Grain yield was positively affected by crop rotation with legume, with an increase of 1.06 t ha^{-1} from CR1 to CR2; N-fertilization caused an increase of 0.76 and 1.09 t ha^{-1} respectively from the control (N0) and the two fertilized trials N60 and N120. The average plant height has shown statistically significant differences as an effect of the interactions CR x V and N x V, revealing a high susceptibility of varieties to the crop rotation and the fertilization effects. Inside varieties, Valbelice (V3) has expressed the best performances under all treatments. The data about the beginning of anthesis showed statistically relevant differences both for the CR x V interaction and for the CR and V main effects. Among the most important qualitative and commercial characters (Table 3), the grain mass per hectolitre did not express statistically significant mean differences, for all single factors, except for V: inside varieties, the highest value (85.9 kg hl^{-1}) was recorded in cv Valbelice, whereas an opposite result has been shown by the cv Appio (82.91 kg hl^{-1}). In the interaction N x V, cv Valbelice has once again shown the best results (86.23 kg hl^{-1}) whereas in the interaction CR x N the highest values (85.30 and 85.29 kg hl^{-1}) were recorded for the two fertilization

levels (N 60 and N 120) and the monocropping. The interaction CR x N x V did not generate significant differences, showing the highest value (86.45 kg hl^{-1}) in the trial CR1 x N0 x V3. The 1000 seed mass represents an important parameter, being directly correlated to the semolina yield of grain, due to the favourable ratio between cortical area and endosperm. This parameter did not show significant mean differences concerning the CR factor, whereas it was significant in N and V. All interactions showed to be statistically significant, and the lowest values have been found in the earlier varieties. The gluten content was observed, as expected, to vary in agreement to the protein content. The effect of crop rotation on protein and gluten content was significant, and in the trial rotated with legumes they showed the highest values, with 12.91 and 10.84 % respectively. Also the fertilization positively influenced the protein and gluten content, with an enhancement of these values respectively of 1.04 and 1.03 % from N0 to N120.

Table 2. Mean values and significance of F-ratios in the yield characters

Main factors	2000/01						2001/02					
	GY	HI	FSS	KRS	HGT	A	GY	HI	FSS	KRS	HGT	A
CR CR1	4.40	0.34	16.2	35.3	93.7	141	1.55	0.28	12.5	22.6	64.2	121
CR2	5.46	0.33	17.2	41.0	97.2	143	1.89	0.31	14.2	26.8	63.7	121
Signif.	*	*	N.S.	N.S.	*	**	**	N.S.	N.S.	*	N.S.	N.S.
N N0	4.31b	0.35a	15.5b	36.4b	90.3c	142	1.74	0.32a	13.2	22.3c	65.8a	121
N60	5.07a	0.34b	17.0a	39.2a	96.6b	142	1.73	0.28b	13.6	27.3a	63.6b	120
N120	5.40a	0.32c	17.6a	38.8a	99.5a	142	1.69	0.27b	13.3	24.5b	62.4b	120
Signif.	**	**	**	**	**	N.S.	N.S.	**	N.S.	*	**	N.S.
V V1	4.75	0.33ab	17.3a	35.0c	88.4b	143b	1.84a	0.30a	13.8a	21.1	59.2c	121b
V2	4.49	0.32 b	17.1ab	38.5b	81.4c	148a	1.31b	0.23b	12.7c	24.1	54.3d	123a
V3	5.01	0.33ab	16.5bc	36.9bc	120.5a	138d	1.87a	0.32a	13.3b	26.1	78.7a	119c
V4	5.46	0.36ab	15.9c	42.2a	91.5b	139c	1.86a	0.30a	13.6ab	27.5	63.6b	119c
Signif.	**	*	**	**	**	**	**	**	*	N.S.	**	**
Interactions												
CR x N	N.S.	N.S.	N.S.	**	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	*	N.S.
CR x V	N.S.	**	*	N.S.	**	**	**	**	N.S.	N.S.	**	**
N x V	*	**	*	**	**	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
CR x N x V	**	N.S.	N.S.	*	N.S.	N.S.	N.S.	N.S.	N.S.	*	N.S.	N.S.

GY: grain yield (t ha^{-1}); HI: Harvest Index; FSS: number of fertile spikelets $spike^{-1}$; KRS: number of kernels $spike^{-1}$. HGT: plant height (cm); A: anthesis (days from sowing time).
*, ** values significantly different at P≤ 0.05 and P ≤ 0.01, respectively.

The high rainfall amount has favoured the quantitative aspects rather than qualitative ones. SDS, that gives unequivocal information about the quality of total protein content and gluten, confirmed the good aptitude of cv Simeto and Creso to yield good quality grain. Among the interactions, the highest value has been recorded in the rotation with legume (CR2) combined to the N 120 level.

2nd trial year

The climatic trend of the 2nd cultivation year was not very favourable to the crop: the total rainfall amount was very low (355 mm) and irregularly distributed, unable to satisfy the water requirements of the crop. Two periods have in particular shown a lack of rainfall: the first in September-October (24 and -60 mm respectively less than the 30-years average values) did not allow a proper preparation of seedbed and a good storage in the soil of the water reservoirs to be utilized during the vegetative and productive cycle of the crop; the second period, from the 2nd half of February to the 2nd half of March (50 mm less than the 30-years average values) has caused a direct water stress on the young plants, with a negative repercussion on their development. In this trial year, the effect of crop rotation caused significant variations in grain yield in relation with the variety, as shown by the high level of significance of the CR x V interaction. All varieties performed better under the CR2 treatment, allowing an increase of total yield from 12 % (cv Simeto) to 32 % (cv Valbelice) from the monocropping to the rotated trial. Unlike in the year before, inside the fertilizer rates, the highest grain

yields (even if not statistically significant) have been observed at the lower fertilizer rates (N 60 and N 0), with values of 1.73 and 1.74 t ha^{-1} respectively. The variety showing the highest aridoresistance level, with the highest mean yield, was cv Valbelice (1.87 t ha^{-1}). Average plant height reached rather low values and was not affected by crop rotation or fertilization, whereas the genotype effect was significant. Many of the examined commercial and qualitative parameters were significant, both as an effect of the simple factors and for their interactions. The 1000 grain mass was significantly influenced by all the interactions of 1st and 2nd order, and as concerned the main effects, it was significantly higher under the N0 fertilization level (46.5 g), and in the cv Simeto (47.6 g), which shows in this way a good attitude to transformation into semolina.

Table 3. Mean values and significance of F-ratios in the commercial and qualitative characters

	2000/01						2001/02					
Simple factors	1000g	Hlm	Nwv	Pro	Glu	SDS	1000g	Hlm	Nwv	Pro	Glu	SDS
CR CR1	52.63	85.23	24.19	10.77	7.93	33.27	44.36	82.15	5.59	14.82	13.46	30.59
CR2	50.39	84.33	3.05	12.91	10.84	38.66	44.31	82.26	1.91	14.79	13.05	34.30
Signif.	N.S.	N.S.	**	*	*	*	N.S.	N.S.	*	N.S.	N.S.	**
N N0	53.49a	85.03	20.33a	11.35b	8.85	34.49b	46.48a	84.67a	11.09a		11.02c	8.74c
28.44b												
N60	51.34b	84.73	15.11b	11.71b	9.26	35.52b	43.55b	81.34b	0.11b	15.98b	14.85b	34.20a
N120	49.71c	84.58	5.42c	12.39a	9.88	37.89a	42.98b	80.60c	0.05b	17.43a	16.24a	34.70a
Signif.	**	N.S.	**	*	N.S.	*	**	**	**	**	**	**
V V1	50.99b	82.91c	10.05 b	12.00	9.50	36.55	43.82c	80.32c	5.99a	14.34b	12.93b	29.14c
V2	49.53b	85.37b	10.98 b	11.84	8.93	40.65	46.23b	82.55b	2.62b	15.22a	14.00a	36.48b
V3	46.56c	85.99a	15.58 a	11.90	10.37	26.87	39.67d	83.72a	3.39b	14.88ab	13.74ab	23.34d
V4	58.97a	84.85b	17.88 a	11.50	8.55	39.79	47.63a	82.22b	3.01b	14.80ab	12.45b	40.82a
Signif.	**	**	**	N.S.	N.S.	**	**	**	**	**	**	**
Interactions												
CR x N	**	*	**	N.S.	N.S.	**	*	**	**	**	**	**
CR x V	**	N.S.	**	N.S.	**	N.S.	**	**	**	N.S.	N.S.	**
N x V	**	*	**	N.S.	N.S.	N.S.	**	N.S.	**	**	N.S.	**
CR x N x V	*	N.S.	**	N.S.	N.S.	N.S.	**	N.S.	**	N.S.	N.S.	N.S.

1000g: 1000 seeds mass (g); Hlm: grain mass per hectolitre(kg hl^{-1}; Nwv: non-wholly vitreous seeds (%);Pro: seed protein content (% on d.m.); Glu: dry gluten content (% on d.m.); SDS: Sodium dodecyl-sulphate (ml).
*, ** values significantly different at P≤ 0.05 and P ≤ 0.01, respectively.

The percentage of non-wholly vitreous seeds in the main factors showed the statistically lowest average values under the fertilization level N 120, in rotation with the legume and in cv Simeto; in these trials, grain had good commercial characteristics. The shrinking of kernels varied significantly as an effect of fertilization and variety; this parameter seemed to affect negatively the 1000-seed mass and the grain mass per hectolitre, probably as a combined effect of fertilization and high temperatures during the ripening phase. The protein content showed significant mean differences between the main factors F and V, between the interactions CR x N and N x V but always with values not lower than 11.5 % (minimum value as stated in reg. UNI 10709 concerning the qualitative classification of grain), except for in the non fertilized trial. The gluten content was, as expected, directly correlated with the protein content. The N-level and the crop rotation have sharply influenced the total content of protein and gluten, whose values ranged from 10.55 to 18.52, and between 7.07 and 17.40 respectively for protein and gluten and with the lowest contents in the trial CR2 x N0 x V4 and the highest ones in CR2 x N120 x V2.

Final considerations and conclusions

The high variability of total amount and distribution of rainfall seems to have deeply characterized the quantitative and qualitative crop performance and the N-uptake in plants. In the first year, the yields were on the whole satisfactory for all the productive characters, whereas the qualitative traits may be put in class C for protein content and in class A for grain mass per hectolitre, according to the

actual rules for the evaluation of the qualitative requirements. The second year, unlike in the year before, allowed low yields but high grain qualitative value. In a year with a favourable rainfall trend, the combined effect of rotation with a legume crop/low N-fertilization is enough to satisfy the nutritive crop requirements, thus reducing the energetic inputs on cereal systems as advised by the EC Reg. N. 2078/92. Under the driest condition, a correct varietal choice plays a more important role. Cv Simeto confirmed its appreciable characteristics in both years, whereas Valbelice has stood out for its good yield ability and stability. Wheat gave the highest grain yields after a legume; in both years of fertilization with N120 and N60, with respect to the non fertilized trial, allowed an enhancement of protein and gluten content.

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