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Nitrogen efficiency component analysis in wheat under rainfed Mediterranean conditions: Effects of crop rotation and nitrogen fertilization

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SUMMARY – The research was carried out in 1999-01 in a typical Sicilian semi-arid area to evaluate the effect of crop rotation and N fertilization on the nitrogen use efficiency (NUE) in wheat. Crop rotations were: wheat-faba bean, wheat-chickpea, wheat-pea and continuous wheat; nitrogen fertilizer rates were: 0, 40, 80 and 120 kg N/ha. A split-plot design with three replications was used. Analysis of nitrogen efficiency components was performed according to the procedure of Huggins and Pan (1993) using grain yield, aboveground plant N, grain N and post-harvest inorganic soil N. Continuous wheat (WW) recorded the lowest grain yields while no differences were found in wheat grown after the three legume crops (LW); the yield benefits of LW vs WW declined as fertilizer rates increased. The differences in wheat grain yields were due mainly to N supply component at low N fertilization rates and to NUE at high N rates.

Key words: Wheat, crop rotation, N fertilization.

***RÉSUMÉ** – "L'analyse des composants d'efficacité de l'azote pour une culture de blé en conditions pluviales méditerranéennes : Effets de la rotation des cultures et de la fertilisation azotée". La recherche a été réalisée en 1999-01 dans un typique milieu semi-aride sicilien pour évaluer l'effet de la rotation des cultures et de la fertilisation azotée sur l'efficacité d'utilisation de l'azote (NUE) dans le blé. Les rotations des cultures étaient : blé-fève, blé-pois chiche, blé-pois et blé en monoculture ; les doses d'engrais d'azote étaient : 0, 40, 80 et 120 kg N/ha. On a adopté un dispositif expérimental split-plot avec 3 répétitions. L'analyse des composants d'efficacité de l'azote a été réalisée selon la procédure de Huggins et Pan (1993) employant le rendement en grain, l'N dans la phytomasse à la surface, l'N dans le grain et l'N inorganique dans le sol après la récolte. Le blé en monoculture (WW) a enregistré les plus bas rendements en grain tandis qu'aucune différence n'était trouvée dans le blé en succession aux trois cultures légumineuses (LW) ; les avantages de rendement de LW vs WW ont diminué par rapport à l'augmentation des doses d'engrais. Les différences des rendements en grain dans le blé étaient principalement liées au composant d'approvisionnement de N aux basses doses de fertilisation d'azote et au NUE aux doses élevées d'engrais.*

***Mots-clés :** Blé, rotation des cultures, fertilisation en N.*

Introduction

In rainfed Mediterranean environments, due to erratic annual and seasonal rainfall, cereal yields are unpredictable (and usually low). The development of cropping systems able to efficiently use water and nitrogen is essential in order to maximize yield, reduce costs and pollution. Nitrogen use efficiency (NUE) is a complex parameter given by soil and plant physiological factors that is affected by different crop management techniques (tillage, genotype, crop rotation, fertilization, etc.) as they can influence N availability and, as a consequence, plant N uptake and grain yield (Huggins and Pan, 1993; Lopez-Bellido and Lopez-Bellido, 2001). Therefore, it is possible to improve NUE by managing cropping system components. Our objective was to determine, in a typical semiarid Mediterranean area of Sicily, the effects of crop rotation and N fertilizer rates on yield, N grain and NUE in wheat.

Materials and methods

The research was carried out at Pietranera farm (37°32'74''N, 13°31'53''W; 182 m a.s.l.), on a Vertic xerochrept. The field experiment was established in 1999. Using a randomized block design with three replicates and plot dimensions of 32 x 6 m, the following crops were sown in December: durum wheat (cv Simeto, at 350 viable seeds/m^2), chickpea (cv Sultano, at 60 seeds/m^2), faba bean (cv Sikelia at 45 seeds/m^2) and pea (cv Perla at 80 seeds/m^2). P fertilizer at 92 kg/ha P_2O_5 was applied to all plots before sowing; wheat plots were also supplied with 80 kg N/ha (50% as urea at sowing and 50% as ammonium nitrate at tillering). Weeds were controlled with specific herbicides. At harvest, crop residues were surface-broadcasted on the plot and then incorporated by disk harrowing.

In 2000 each plot was split in four sub-plots (8 x 6 m) on which four nitrogen treatments were imposed (0, 40, 80 and 120 kg N/ha); in all the plots durum wheat (cv Simeto) was planted in 18 cm wide rows in December at 350 viable seeds/m^2. At all N application rates, half was applied before sowing and the remaining was applied as a top dressing at the beginning of wheat tillering. Soil samples (layer 0-60 cm) were taken on all sub-plots prior to wheat sowing and after harvesting and analyzed for 1 M KCl-extractable NH_4- and NO_3-N with a Bran & Luebbe II AutoAnalyzer. At maturity, in each sub-plot, samples of straw and grain were collected from an area of 2 m^2 to determine N content using Kijeldahl method. The crop was combine harvested in June (24 m^2 per sub-plot). According to Moll *et al*. (1982) and Pierce and Rice (1988), N efficiency ratios were estimated by the following parameters:

N supply: $N_s = N_{t0} + N_{h0} + N_f$; N available: $N_{av} = N_t + N_h$

where: N_{t0} = aboveground plant N in control plots (0 applied N); N_t = aboveground plant N; N_{h0} = postharvest soil nitrate in control plots; N_h = postharvest soil nitrate; N_f = applied N.

Differences observed among previous crop treatments on grain yield (G_w) and grain N (N_g) were evaluated by stepwise regression analyses of G_w and N_g vs crop rotation, and either N_f, N_s, N_{av}, or N_t to determine significant model parameters, in order to discriminate the influence of soil and plant factors, as outlined by Huggins and Pan (1993). Moreover, data and N efficiency ratios were subjected to analysis of variance. The two growing seasons were different according to the rainfall (373 and 599 mm respectively in Sept.-June 1999-00 and 2000-01). In 1999-00 rainfall was poor in Sept.-Oct. (42 mm) and well distributed throughout the winter and spring; in the 2000-01 winter rainfall accounted for more than 70% of the total annual and spring was particularly dry (65 mm).

Results and discussion

In 1999-00 grain yields were 2.18, 2.82, 2.97 and 2.36 t/ha respectively for chickpea, faba bean, pea and wheat. The residual biomass after harvest was significantly higher in chickpea and wheat (5.52 and 5.38 t/ha respectively) than in faba bean and pea (3.26 and 3.58 t/ha). On the whole, the total N returned to soil with aboveground plant residues was 46.2, 49.5, 36.3 and 27.0 kg N/ha for chickpea, faba bean, pea and wheat, respectively.

In 2000-01, wheat grain yield and N efficiency ratios were not significantly influenced by the three different preceding legume crops. Therefore, for simplicity, data of the three crop rotations were averaged and in this paper only data on continuous wheat (WW) and legumes-wheat (LW) are reported. The analysis of variance of soil and plant data used for N efficiency component analysis showed that all parameters were significantly affected by crop rotation (CR) and N fertilization (NR), but N_h for which the preceding crop effect was not significant (Table 1). The interaction CR x NR was significant only for G_w and N_g.

Preceding crop significantly influenced NUE (G_w/N_s), but was ineffective with the other N efficiency ratios (Table 2). On average, NUE values were higher in WW. The increase of N fertilizer rate produced reductions of NUE, available N efficiency (N_{av}/N_s), available N use efficiency (G_w/N_{av}), N utilization efficiency (G_w/N_t) and grain N utlization efficiency (N_g/N_s). Applied N did not affect available N uptake efficiency (N_t/N_{av}), available grain N accumulation efficiency (N_g/N_{av}) and N harvest index (N_g/N_t). The interaction CR x NR was significant only for N_g accumulation efficiency ratios (N_g/N_s, N_g/N_{av}, N_g/N_t). The effect of crop rotation on NUE (G_w/N_s) observed in this study appear divergent from results of Stockdale *et al*. (1997) and Lopez-Bellido and Lopez-Bellido (2001). However, it should be considered that NUE has usually a decreasing trend when N_s increases and that different cropping systems supplied with equal amounts of N fertilizer may show very different N_s values; these aspects can lead to an incorrect comparison of NUE values. In the present study, regression analysis of G_w vs crop rotation and either N_f, N_s, N_{av}, N_t revealed that crop rotation had a significant model parameter only for N_f and N_s; therefore regression models for G_w vs either N_f and N_s were developed separately for WW and LW (Fig. 1).

Table 1. Grain yield (G_w), grain N (N_g), N supply (N_s), available soil N (N_{av}), aboveground plant N (N_t), and post-harvest soil N (N_h) (kg/ha) for wheat crop as influenced by N rate (NR), and crop rotation (CR). WW: continuous wheat, LW: legume-wheat

N rate	G_w		N_g		N_s		N_{av}		N_t		N_h	
	WW	LW	WW	LW	WW	LW	WW	LW	WW	LW	WW	LW
0	4253	5207	81	118	124	159	124	159	117	151	7	8
40	4884	5502	101	126	164	199	155	183	146	175	9	8
80	5573	5645	125	135	204	239	178	202	168	193	10	9
120	5406	5657	127	146	244	279	190	217	181	207	9	10
Analysis of variance												
CR	*		*		**		*		*		NS	
NR	***		***		***		***		***		**	
CR X NR	*		**		NS		NS		NS		NS	

*,**,***Significant at 0.05, 0.01, 0.001 probability levels, respectively; NS: not significant.

Table 2. Nitrogen use efficiency ratios for grain yield and grain N of wheat as influenced by N rate (NR) and crop rotation (CR). WW: continuous wheat, LW: legume-wheat

N rate	G_w/N_s		N_{av}/N_s		G_w/N_{av}		N_t/N_{av}		G_w/N_t		N_g/N_s		N_g/N_{av}		N_g/N_t	
	WW	LW	WW	LW	WW	LW	WW	LW	WW	LW	WW	LW	WW	LW	WW	LW
0	34.2	32.7	1.00	1.00	34.2	32.7	0.94	0.95	36.4	34.5	0.65	0.74	0.65	0.74	0.69	0.78
40	29.7	27.6	0.94	0.92	31.5	30.1	0.93	0.96	33.5	31.5	0.61	0.63	0.65	0.69	0.63	0.72
80	27.3	23.6	0.87	0.85	31.3	27.9	0.94	0.95	33.3	29.3	0.61	0.56	0.70	0.67	0.74	0.70
120	22.1	20.3	0.78	0.78	28.5	26.2	0.95	0.95	30.0	27.5	0.52	0.52	0.67	0.67	0.71	0.71
Analysis of variance																
CR	*		NS		NS		NS		NS		NS		NS		NS	
NR	***		***		***		NS		***		***		NS		NS	
CRXNR	NS		NS		NS		NS		NS		***		*		*	

*,**,***Significant at 0.05, 0.01, 0.001 probability levels, respectively; NS: not significant.

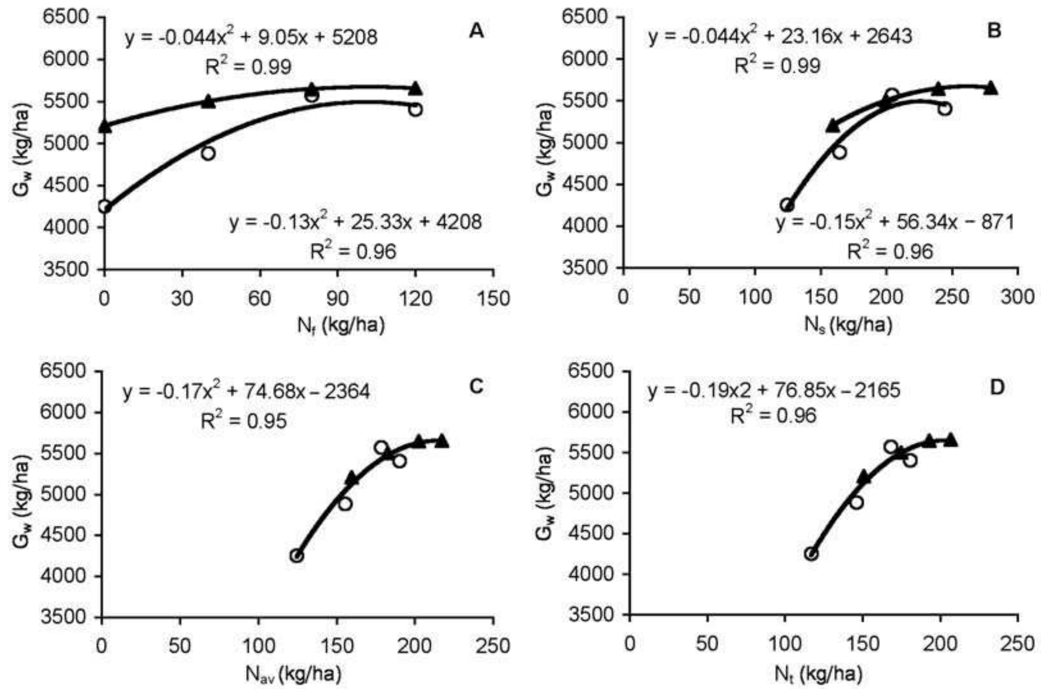

Fig. 1. Relationships between grain yield and applied N (A), N supply (B), available N (C) and aboveground plant N (D) for WW (❍) and LW (▲).

The differences of yield observed in LW compared to WW (ΔG_w) calculated using the regression equations G_w vs N_s, were partitioned into different N efficiency components (Table 3) according to Huggings and Pan (1993). In control plots (0 applied N), the 73% of the yield increase of LW on WW was explained by the increase of nitrogen availability determined by the legumes as preceding crops ($\Delta G_{w(Ns)}$), whereas the remaining portion was due to the improved NUE ($\Delta G_{w(Gw/Ns)}$).

Table 3. Nitrogen efficiency components of yield (ΔG_w) and grain N (ΔN_g) differences among crop rotations (kg/ha) (LW subtracted from WW)

N rate	ΔG_w †	$\Delta G_{w(Ns)}$	$\Delta G_{w(Gw/Ns)}$	$\Delta G_{w(Gw/Nav)}$	$\Delta G_{w(Nav/Ns)}$	$\Delta G_{w(Nt/Nav)}$	$\Delta G_{w(Gw/Nt)}$
0	1000.1	732.6	267.6	0.0	267.6	0.0	0.0
40	477.4	384.0	93.4	0.0	93.4	0.0	0.0
80	212.0	35.4	176.6	0.0	176.6	0.0	0.0
120	203.9	-313.1	517.1	0.0	517.1	0.0	0.0
N rate	ΔN_g	$\Delta N_{g(Ns)}$	$\Delta N_{g(Ng/Ns)}$	$\Delta N_{g(Ng/Nav)}$	$\Delta N_{g(Nav/Ns)}$	$\Delta N_{g(Nt/Nav)}$	$\Delta N_{g(Ng/Nt)}$
0	39.3	21.7	17.6	0.0	17.6	0.0	0.0
40	22.6	14.1	8.5	0.0	8.5	0.0	0.0
80	16.3	6.6	9.7	0.0	9.7	0.0	0.0
120	20.1	-1.0	21.1	0.0	21.1	0.0	0.0

†Calculated using regression equations given in Fig. 1B.

The differences of grain yield between the two crop rotations declined as fertilizer rate increased; similarly the $\Delta G_{w(Ns)}$ decreased to <0 kg/ha at 120 kg applied N/ha. In contrast, $\Delta G_{w(Gw/Ns)}$ component increased to 517 kg/ha at highest N rate, whereas, as previously indicated, NUE (G_w/N_s) declined uniformly for both WW and LW. This can be explained by the different yield response at high N_s values of WW and LW. Furthermore, because crop rotation did not affect the G_w relationship with N_{av} and N_t, all the $\Delta G_{w(Gw/Ns)}$ component was derived from $\Delta G_{w(Nav/Ns)}$. In other words, at the same N_s value, LW had more N_{av} than WW and the differences gradually rose as N_s increased. The values of ΔN_g declined as fertilizer rate increased but with variations less marked than those observed for grain yield. At 0 N applied, ΔN_g was due for more than 50% by differences in N_s. For the other components of N efficiency trends similar to G_w were observed.

Conclusions

Legumes as preceding crop gave, compared to continuous wheat, significant benefits both on grain yield and N grain yield; the differences between the two crop rotations gradually declined when N fertilizer was applied from 0 to 80 kg N/ha; a further fertilizer increase up to 120 kg N/ha caused a yield reduction in continuous wheat. The N efficiency ratios were highest for continuous wheat and declined for both crop rotations as N fertilizer rate increased. However, the N efficiency component analysis, according to the Huggings and Pan (1993) method, showed that the differences of grain yield and to a lesser extent also for grain N, in control plots (0 N applied) were mostly due to differences in N_s between LW and WW (+35 kg N/ha), whereas at the highest N fertilizer rate it seemed due to an improvement of the soil component of N efficiency ($\Delta G_{w(Nav/Ns)}$).

Acknowledgments

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