Green manuring as sustainable management for southern Italy extensive cultivated areas

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SUMMARY – In the extensively-managed agricultural areas of Sicily, rainfall is often so limited that economically effective annual productions are not feasible. Bare fallow, the most extreme dry-farming technique, seems to be, under such conditions, the only suitable strategy. The introduction in these cropping systems of an annual legume to put early into the soil, as an alternative to bare fallow, may represent a technique able not only to prevent soil erosion, but also to improve the low soil organic matter reserves, with a direct benefit on the following yields and on the whole environment. The trial was aimed to verify the bioagronomical and qualitative behaviour of durum wheat managed under different cropping systems. Results, heavily influenced by very low rainfall (320 mm), stressed the extraordinary productive response of durum wheat cultivated after the green manure legume.

Key words: Green manure, durum wheat, cropping system, sustainable agriculture.

RÉSUMÉ – *"L'engrais vert pour la gestion durable dans les zones de cultures extensives du Sud de l'Italie". En Sicile dans les terrains destinés à la culture extensive, la pluviosité est tellement limitée que les productions annuelles économiquement rentables ne sont pas possibles. La jachère nue, la plus extrême des techniques d'aridoculture semble être, dans ces conditions-là, la seule praticable. L'introduction, dans ce système cultural, d'une légumineuse annuelle à incorporer d'avance dans le sol, en alternance avec la jachère nue, peut représenter une technique capable de prévenir l'érosion du sol, mais aussi d'augmenter le bas niveau de substances organiques du sol avec un avantage direct pour les productions successives et pour tout l'habitat. L'expérience devait vérifier le comportement bio-agronomique et qualitatif du blé dur soumis à différents systèmes de cultures.*

Mots-clés : *Engrais vert, blé dur, rotation culturale, agriculture durable.*

Introduction

In the middle-east Sicilian extensive agricultural areas, annual rainfall is so limited (<350 mm/year) that it does not permit annual remunerative agricultural practices.

In such conditions, bare fallow (about 100,000 ha in Sicily) an extreme rainfed agriculture technique, is often utilized (Istat, 2003).

Continuous bare fallow techniques, although they allow higher water availability for the cash crop as well as yield suitability and stability every two years, cause a fast soil organic matter content reduction which has negative repercussions on some chemical and physical soil characteristics (aggregate stability, soil water content, microbiological activity, etc) and the bare soil is subject to erosion processes due to rainfall determining a general depletion of soil fertility.

Introduction of legumes in the Sicilian cropping systems, to avoid traditional bare fallow and early leguminous green manuring to limit an excessive water consumption, could be an innovative management technique able not only to preserve soil from erosion risk but also to improve soil organic matter reservoirs determining a direct benefit on the following crops and on the environment.

Leguminous crops, can also improve, through their biological nitrogen fixation ability, great low cost atmospheric nitrogen quantities, probably used by the following crops in the cropping system.

Apart from the positive agronomic effects, these techniques seem to be suitable in relation to the new European agriculture policies (European Commission, 2003), aimed at an increase in the sustainability of the cropping systems, a reduction in external energetic inputs and protection of the environment (cross-compliance).

The aim of this paper is to compare the effects of five different cropping systems on durum wheat and verify the agronomic suitability of leguminous green manure in comparison to the traditional techniques.

Materials and methods

Trial site

The trial was carried out during 2001/2002 on the Experimental Farm Sparacia (AG, 37°37' N – 13°42' E) of the Department A.C.E.P. of Palermo University, site representative for durum wheat cultivations in the hilly Sicilian inland, characterized by a sub-arid climate with a yearly rainfall mean of about 500 mm concentrated in the fall-winter period, with minimum and maximum temperature means respectively of 9 and 21° C. The trial was carried out on a Eutric Vertisol representative of the pedotype of the area, according to WRB (FAO-ISRIC-ISSS, 1998).

Management and Layout of the Field Trials

The trial consisted of a randomized block design with three replications in which nine treatments were compared, as reported in table 1.

Table 1. Compared cropping systems

Cropping System	N rate	Acronym
1) durum wheat - bare fallow	0.80	W-F/0, W-F/80
2) durum wheat - grain vetch	0.80	$W\text{-}V_g/0$, $W\text{-}V_g/80$
3) durum wheat - hay vetch	0.80	$W\text{-}V_h/0$, $W\text{-}V_h/80$
4) durum wheat - green manure vetch	0.80	$W\text{-}V_{gm}/0$, $W\text{-}V_{gm}/80$
5) durum wheat - durum wheat	80	W-W/80

The first four cropping systems in interaction with two nitrogen levels were tested (N0, N80=80kg ha^{-1}); instead on durum wheat monocropping (control), only one nitrogen level (N80) was used. The durum wheat (cv Valbelice, a very rustic variety) sowing took place on January 04 2002 using 350 germinable seeds m^{-2} in rows 20 cm apart. Vetch, was sown on 15/11/00 using 200 seeds at m^{-2}.

During the first ten days of April, green manured vetch ($W\text{-}V_{gm}$) was incorporated in the soil at the flowering stage (about 15 t ha^{-1} fresh weight (d.m. 18%) and a nitrogen content of 1.6 % d.m. The crop was fertilized, in all its treatments, with 92 kg ha^{-1} of phosphoric anhydride.

Grain Yield, yield components and qualitative parameters

At harvest the plants were measured for the following characteristics: plant height (cm), spike numbers m^{-2} (n), dry seed production (t ha^{-1}); on the grain: shrivelled kernels (%), thousand kernel weight (g), Test weight (kg hl^{-1}), grain moisture (%).

The following analyses were carried out on whole flour: flour moisture (%), dry matter (%), total nitrogen (N% x 5.7 = Proteins d.m. %), dry gluten (d.m. %), gluten index (%), sedimentation index (ml) and ash (d.m. %).

Statistical Analysis

Analysis of variance was performed on all bioagronomic and qualitative data. The differences between the means were estimated with a Tukey test (α =0.01).

To compare single effects of the four different cropping systems, performance in comparison to the test cropping system (W-W/80), four groups "over nitrogen" were arranged (Gr.W-F, Gr. W-V_{gm}, Gr. W-V_g, Gr.W-V_h) to carry out contrasts (Steel and Torrie, 1980).

Percentages, to satisfy variance homogeneity conditions, were transformed through the square root method for percentage values and through arcsine transformation for protein. The coefficient of variation (cv), calculated as percent ratio between the standard deviation and the grand mean (Error $MS^{1/2}$/Grand mean x 100), was used to evaluate the experimental result reliability.

Growing Conditions during Trial Period

In 2001/2002 the rainfall was rather low (320 mm) and had an irregular distribution, and did not adequately satisfy the crop water requirements. In particular, two water shortage periods occur: the first in the September-October period (-24 and -60 mm respectively compared to the thirty-year means) did not allow the correct preparation of the sowing bed and above all did not allow an adequate soil water storage to be later used during the crop vegetative-productive cycle; the second during the 2^{nd} ten days of February– 2^{nd} ten days of March (overall -50 mm) caused a direct water stress on the young seedlings negatively conditioning their future development. A late rainfall, of about 40 mm, occurs during the second ten days of May. The temperatures were very similar to the thirty-year means.

Results and discussion

Low rainfall strongly determined agronomic performances of the different tested rotations. "Cropping system" factor was very significant for all measured parameters. (Tab. 2).

Table 2. Analysis of variance (mean square)

Parameters	Cropping system	cv%
Grain yield	3.06**	$3.34 \cdot 10^{-4}$
Plant height	730**	$1.96 \cdot 10^{-3}$
Spikes $\cdot$ m^{-2}	28616**	$2.05 \cdot 10^{-2}$
Earing	66.76**	$8.13 \cdot 10^{-5}$
Test weight	5.36**	$6.05 \cdot 10^{-5}$
Kernels weight	37.13**	$4.24 \cdot 10^{-4}$
Shrilled kernels	130.95**	$1.07 \cdot 10^{-2}$
Protein d.m.	0.14**	$1.76 \cdot 10^{-5}$
Gluten d.m.	0.14**	$2.51 \cdot 10^{-5}$
Gluten index	1.54**	$8.87 \cdot 10^{-4}$
S.D.S.	38.16**	$1.75 \cdot 10^{-3}$
Grain moisture	$3.4 \cdot 10^{-3}$**	$2.66 \cdot 10^{-6}$
Ash d.m.	$6.5 \cdot 10^{-3}$**	$4.86 \cdot 10^{-6}$

As far as the bioagronomic parameter is concerned yield of W-V_{gm} cropping system, always statistically different, was double in comparison to field mean (3.63 t ha-1 vs 1.96 t ha^{-1}) (Tab. 3); higher plant height (+26 cm); very high number of spikelets m^2 (419 vs 248).

Table 3. Contrast analysis among cropping systems for grain yield and spikes m^{-2}

	Grain yield				
	W-W	W-V$_{gm}$	W-V$_h$	W-V$_g$	W-F
Grain yield					
W-F	21.8**	100.2**	19.5**	16.9**	
W-V$_g$	1.13N.S.	208.3**	0.09N.S.		
W-V$_h$	1.72N.S.	199.6**			
W-V$_{gm}$	165.1**				
W-W					
Spikes m^{-2}					
W-F					
W-V$_g$					0.01N.S.
W-V$_h$				0.48N.S.	0.64N.S.
W-V$_{gm}$			188.8**	182.8**	181.9**
W-W		135.4**	0.18N.S.	0.36N.S.	0.39N.S.

Among all other theses W-F rotation, both for fertilized and non fertilized, was always more productive (2.01 t ha^{-1}). On the contrary W-W (monocropping), even if it was statistically different from W-V$_g$ and W-V$_h$, reached the lower field values (1.08 t ha^{-1}) (Fig. 1).

Influence of cropping system on the vegetative-productive cycle was very evident (Fig. 2). Green manured plots were characterized by a very late earing stage (+13 d in comparison to W-W), on the contrary all the other plots, due to an evident water stress, were subjected to an extreme early earing stage. Both W-V$_{gm}$ cropping systems, due to an extension of the vegetative-productive cycle, profit of late rainfall, ulteriorly exalting productive performances. Contrast between fertilization rate (0 and 80 kg ha^{-1}) was non statistically significant. In the field thermopluviometric conditions, nitrogen fertilization did not improve durum wheat performances; on the contrary on W-V$_g$ thesis the higher fertilization level reduced yield. (-0.16 t ha^{-1}). On green manured cropping systems, on the contrary, the highest fertilization level determined a yield increase even if not statistically different (0.4 t ha^{-1}). Durum wheat commercial parameters showed a less evident behaviour in relation to cropping systems. The field mean test weight was 84 kg hl^{-1} and plots N0, W-V$_{gm}$/80 and W-F/80 reached the highest values.

The "cropping system" factor significantly influenced kernel weight; kernel weight of W-V$_{gm}$/80 cropping system was, in fact, about 44.2 g, in comparison to about 41 g of both bare fallow plots and non fertilized green manure thesis. All other plots determined lower values, especially durum wheat monocropping (W-W) (34 g).

Higher commercial characteristic values determined by W-V$_{gm}$/80 cropping system is justified by low shrivelled kernel percentage (8.1 %) in comparison to a 22.6 % value (field average) characterizing a high water stress status.

As far as qualitative aspects are concerned, green manured thesis, characterized by a low shrivelled kernel percentage, showed an high protein content (15.1% d.m.) and gluten (13.8% d.m.) both comparable to results due to fertilized plots (N80) in which grain yield per hectare was slightly lower.

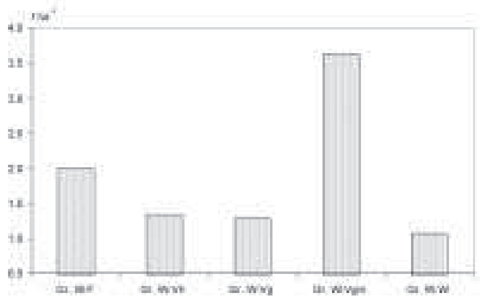

Fig. 1. Durum Wheat Grain Yield (groups average).

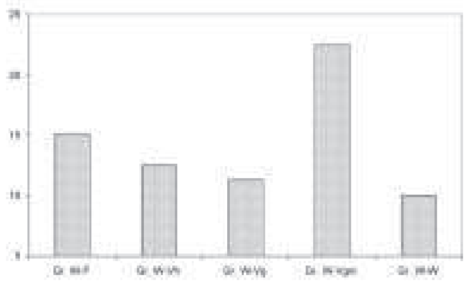

Fig. 2. Earing Stage (groups average).

Conclusions

Production of the green manured cropping system (W-V_{gm}), in the trial conditions characterized by very low rainfall, resulted extremely positive, determining grain yield higher than conventional cropping systems.

Productive difference of green manured cropping system (W-V_{gm}), in comparison to bare fallow cropping system put in evidence yield increase due to leguminous biomass incorporation in the soil and consequently to cropping system water use efficiency increase, more than previous crop water use and consumption.

The excellent grain yield was also characterized by a good commercial and qualitative grain level.

Leguminous green manure seems to be able to improve cropping system sustainability both in terms of a higher yield stability (soil organic matter buffer) in relation to climatic trend, and energetic input reduction.

Cropping system sustainability improvement, reducing the climatic and pedological variability effects determine an increase of yield stability over time allowing the possibility to obtain homogenous and consistent durum wheat stocks that are strongly sought by industry.

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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 1999-2001 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^{-1}. 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 1999-2001 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^{-1}. 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^{-1} P_2O_5 was applied to all plots before sowing; wheat plots were also supplied with 80 Kg N ha^{-1} (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^{-1}); 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^{-1} 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^{-1} respectively) than in faba bean and pea (3.26 and 3.58 t ha^{-1}). 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^{-1} 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 (Tab. 1). The interaction CR x NR was significant only for G_w and N_g.

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) 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
kg ha^{-1}												
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.

Preceding crop significantly influenced NUE (G_w/N_s), but was ineffective with the other N efficiency ratios (Tab. 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).