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Optimizing forage yield of durum wheat/field bean intercropping through N fertilization and row ratio

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Abstract

Intercropping (IC) cereals and legumes could be an option for obtaining forage suitable for ensiling and enabling reduced N fertilization. Two experiments were performed in central Italy with durum wheat (*Triticum durum* Desf.) and field bean (*Vicia faba* L. var. *minor*) grown for forage production in IC and as sole crops (SC) with different N rates (20 and 50 kg ha^{-1}) and row ratios (1:1 and 2:1 cereal/legume). The aims were to assess (i) whether IC is a feasible option to reduce N fertilization; (ii) the best combination of practices to obtain forage suitable for ensiling; and (iii) competition/facilitation effects exerted by field bean on durum wheat. Results showed IC allowed fertilizer-N reduction and led to improved forage yield with better quality, compared with SC. Land equivalent ratio indicated a high efficiency of the IC, by up to 26% with respect to SC. Field bean was the dominant species of IC, but N fertilization reduced its competitive ability and enhanced that of wheat. In the intercrop fertilized with 50 kg N ha^{-1}, the proportion of the wheat in the herbage (0·34–0·41 of the total dry matter) was sufficient for ensiling of the forage mass. Field bean exerted both competition and facilitation effects on the cereal. N uptake of durum wheat was greater under IC with beans than as wheat SC.

Keywords: intercropping, *Triticum durum*, *Vicia faba*, crude protein, nitrogen fertilization, row ratio, Italy

Introduction

Intercropping (IC), that is, the growing of two or more crop species simultaneously in the same field during a growing season (Ofori and Stern, 1987), can provide numerous benefits to cropping systems, through increasing total yield and land-use efficiency, improving yield stability, enhancing light, water and nutrient use, and controlling weeds, insects or diseases (Willey, 1985).

In temperate climates, mixtures of annual legumes and winter cereals are commonly used for herbage production (Anil and Miller, 1998). The inclusion of legumes in forage intercrops can provide a more sustainable source of N to cropping systems through biological N fixation (Crews and Peoples, 2004) and transfer of symbiotically fixed N from intercropped legume to intercropped non-legume crop (Xiao *et al.*, 2004). IC legumes with cereals may also minimize N losses commonly associated with legume sole crops (SC), through the immobilization of N into soil organic matter, because of higher cereal C/N ratio (Hauggaard-Nielsen *et al.*, 2003). Thus, the utilization of N-fixing legumes in IC allows reduction in N fertilizer use (Lunnan, 1989).

Intercropping a cereal and a legume may also be a useful system to obtain forage suitable for ensiling. Such mixtures can have better fermentation characteristics than legume-only whole crops and a higher nutritive value than cereal-only whole crops (Berkenkamp and Meeres, 1987; Chapko *et al.*, 1991; Anil and Miller, 1998; Salawu *et al.*, 2001).

Durum wheat (*Triticum durum* Desf.) is widely grown in Italy and occupies 1·5 Mha (ISTAT, 2008). The crop is utilized mainly for grain, and there are relatively few studies with the species utilized as forage (Tosti and Guiducci, 2010), although in high-yielding environments, durum wheat is usually favoured over other small grain cereals because of its superior biomass yield and nitrogen concentration (Albrizio *et al.*, 2010). Field bean (*Vicia faba* L. var *minor*) is utilized in the Mediterranean environment for grain, green manure and forage. It is well adapted to temperate growing conditions and might be a promising alternative to pea and common vetch for forage production, providing higher protein concentration and stem strength (Strydhorst *et al.*, 2008).

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The IC of durum wheat and field bean has potential for silage forage production, provided that the minimum proportion of wheat in the sward is about 0·25, the value that Pursiainen and Tuori (2008) considered necessary to obtain a good silage without the addition of conservation additives.

The competitive ability of field bean is higher than that of durum wheat in IC systems fertilized with low or nil-N rates (Campiglia *et al.*, 1991; Tosti and Guiducci, 2010). This can lead to a forage mixture in which the legume is the predominant component, so that the minimum wheat content of the sward may not be attained. Thus, there is a need to optimize both forage yield and wheat content.

Nitrogen fertilization can be an effective way to influence the interactions between crops and the proportion of the species in the IC, because it increases both the competitive ability of wheat and total forage yield (Ghaley *et al.*, 2005). Also, the field arrangement of IC components influences the relative performance and the competitive ability of each species, through modifications in the amount of light that reaches the lower layers of the canopy and in the availability of water and nutrients. Intercropped species can be arranged in complete mixing or in alternate rows, with different row ratios. Although IC mixtures and the relative proportions of the mixtures have been extensively studied, the row ratio of the components has received little investigation, and the literature is inconclusive about the most efficient arrangement. Chen *et al.* (2004), Lauk and Lauk (2008) and Aynehband *et al.* (2010) concluded that mixing of crop species within rows is the best arrangement for barley/pea, oat/pea and maize/amaranth intercrops, respectively. In contrast, Martin and Snaydon (1982a) and Dubey *et al.* (1995) found that alternate row systems produced highest yields for barley/bean and sorghum/soybean mixtures, respectively. Finally, Zaman and Malik (2000) observed higher yield of maize/ricebean intercrop, when sown in double-row strips.

To provide information on the IC of durum wheat and field bean, two field experiments were set-up with the following aims: (i) to assess whether the IC of durum wheat/field bean is a feasible option to reduce N fertilization for forage production; (ii) to determine the best combination of practices to obtain high forage yield suitable for ensiling without the need to use additives; and (iii) to investigate how the competition and/or facilitation effects exerted by field bean on durum wheat were modified by nitrogen fertilization and row ratio.

In the first experiment, the effect on forage yield and quality of IC durum wheat and field bean with reduced N rate and different row ratios was compared to that of SC with optimal N rate. In the second experiment, we investigated the competition/facilitation effects exerted in the IC by field bean on durum wheat.

Materials and methods

Two field experiments were conducted during two consecutive growing seasons (2004–2005 and 2005–2006) with durum wheat (*Triticum durum* Desf., cv. Creso) and field bean (*Vicia faba* L. var. *minor* cv. Scuro di Torrelama) crops. Methods common to both experiments are presented first, followed by methods specific to each experiment. Field experiments were carried out at the experimental station of the Department of Agronomy and Agroecosystem Management, University of Pisa, Italy. The experimental site is approximately 10 km from the sea (43°40′ N, 10°19′ E) and 1 m above sea level. The climate is cold, humid Mediterranean with mean annual maximum and minimum daily air temperatures of 20·2 and 9·5°C, respectively, and precipitation of 971 mm per year (Moonen *et al.*, 2001).

Main soil physical and chemical properties were 53·1% sand, 27·8% silt, 19·1% clay; pH 8·4, organic matter 13·8 g kg^{-1} (Walkley and Black method); 10·2 g kg^{-1} total $CaCO_3$ (Scheibler method), 1·1 g kg^{-1} total nitrogen (Kjeldhal method), 5·7 g kg^{-1} available P (Olsen method), 88·8 g kg^{-1} available K (ammonium acetate test method).

The research was carried out in two adjacent fields, one for each year, with maize as the preceding crop. Soil was ploughed to 40 cm depth in October and sowing was at 3–5 cm sowing depth on 18 November 2004 and on 13 November 2005 by means of a Wintersteiger Oyjord plot drill. Phosphorus, as triple superphosphate, and potassium, as potassium sulphate, fertilizers were applied before ploughing at rates of 44 kg ha^{-1} of P and 83 kg ha^{-1} of K at all treatments. The application of N fertilizer, as urea, and seeding patterns are described separately for each experiment.

Forage was harvested at the hard-dough stage of grain maturity of wheat (stage 87 of the scale of Zadoks *et al.* (1974)). The forage grown in 1 m^2 area was cut by hand at 5 cm above soil level and was separated into wheat, bean and weeds. Crop plants were divided into stems, leaves and inflorescences (spikes and/or pods). Plant parts were oven dried for dry matter yield (DM) determination at 75°C to constant weight and were analysed for nitrogen (N) concentration (microKjeldahl). Crude protein concentration (CP) was calculated by multiplying N concentration by 6·25 (AOAC, 1990), and nitrogen yield (NY) was obtained by multiplying the N concentration by DM. In both years, durum wheat reached hard-dough stage in the first 10 d of May. At these dates, field bean was at the ripeness stage, according to the scale of StÜlpnagel (1984). No difference was recorded in the development of plants grown in IC or as sole crop.

Experiment 1

In both years, the experimental design was a randomized complete block design with three replications. Six treatments were applied, two SC and four IC (Table 1). SC, hereafter referred to as optimal sole crop, were grown following the recommended cultural technique for the site, i.e., 150 kg N ha^{-1} with 400 viable seeds m^{-2} and inter-row spacing 14 cm for wheat, and 20 kg N ha^{-1} with 50 viable seeds m^{-2} and inter-row spacing 28 cm for field bean. The four ICs were obtained from the combination of two N fertilization rates, 20 (N20) and 50 (N50) kg N ha^{-1}, and two alternate cereal/legume row ratios, 1:1 (R1:1) and 2:1 (R2:1). In the R1:1, every alternate row of wheat was replaced by bean, so that the seed density of wheat was 50% of the recommended drilling rate (RDR) and the seed density of bean was 100% of the RDR, with a final density of the intercrop equal to 150% of RDR. In the R2:1, every third row of wheat was replaced by bean, so that the seed density of wheat and bean was 66·7% of the RDR, and the final density of the intercrop was 133·4% of RDR.

The rates of N applied in IC were chosen on the basis that the lower value (N20) was considered optimal for field bean as starter N (Jensen *et al.*, 2010), and the higher (N50) was calculated considering a 50% maximum reduction in plant number imposed by row ratio and an hypothesized N transfer from field bean (Xiao *et al.*, 2004).

The two row ratios were chosen because they are easy to implement in the field with normal drills and because they match, theoretically, a feed containing not <33% of durum wheat, which is considered necessary to avoid the use of silage additives for forage conservation (Pursiainen and Tuori, 2008).

In the optimal field bean SC and in the ICs, the N was applied before seeding. In the optimal SC of wheat, 20% of the N was applied before seeding, 40% at the beginning of stem elongation (stage 30) and 40% 15 d after the beginning of stem elongation.

The resource complementarity was estimated by the land equivalent ratio (LER), an index commonly used to indicate the efficiency of IC in using environmental resources, compared to SC (Willey and Rao, 1980). Values of LER < l indicate a disadvantage for IC relative to sole cropping, because the resources are used more efficiently by SC than by IC; whilst when LER = 1, there is neither advantage nor disadvantage of IC, and when LER > 1, there is an IC advantage in terms of improved use of resources for plant growth. According to Mead and Willey (1980), the index was calculated as the sum of partial LER of cereal (LER_C) and partial LER of legume (LER_L) with the formulas:

$$LER = LER_C + LER_L$$

$$LER_C = (Ycl/Ycc)$$

$$LER_L = (Ylc/Yll)$$

where Ycl is the DM or NY of cereal growing in IC with legume, Ylc is the DM or NY of legume growing in IC

Table 1 Treatments used each year in the two experiments and number of plants m^{-2} resulting from the experimental design.

Experiment	Forage	N rate (kg ha^{-1})	Row ratio (cereal/legume)	Plants (No. m^{-2}) Cereal	Legume
1	Durum wheat optimal SC	150	–	400	–
	Field bean optimal SC	20	–	–	50
	Wheat/bean IC	20	1:1	200	50
		20	2:1	267	33
		50	1:1	200	50
		50	2:1	267	33
2	Durum wheat SC	20	1:1	200	–
		20	2:1	267	–
		50	1:1	200	–
		50	2:1	267	–
	Durum wheat IC	20	1:1	200	50
		20	2:1	267	33
		50	1:1	200	50
		50	2:1	267	33

IC, intercropping; SC, sole crops.

with cereal, and Ycc and Yll are the DM or NY of optimal sole cereal and optimal sole legume.

The competitive ability of a crop in IC was measured by the Competitive Balance Index (C_b), which was originally reported by Wilson (1988) and later modified by Williams and McCarthy (2001), to take into account the different proportions of the components of the mixture. The Competitive Balance Index measures the ability of one component in a mixture to obtain limiting resources, compared to its ability to utilize these resources when grown in pure stands (Snaydon, 1991). A C_b value of zero indicates equal competitive abilities between components, whereas any positive (or negative) value indicates that the species for which the calculation was performed has a greater (or lower) competitive ability compared to the other species. The index was calculated as:

$$C_b = \log_e\{[(\text{Ycl} \times \text{Zlc})/(\text{Ylc} \times \text{Zcl})/[\text{Ycc}/\text{Yll}]\}$$

where Zcl is the proportion of the intercropped area initially allocated to cereal, Zlc is the proportion of the intercropped area initially allocated to legume, and the other symbols have the same meaning as mentioned previously for LER.

Data were analysed statistically by analysis of variance (ANOVA), using the COSTAT statistical package (version 6.4; CoHort Software, Monterey, CA, USA). ANOVAs on DM, CP and NY of optimal SC and intercrops were performed to test the main effects of years, forage treatments and their interactions. ANOVAs on LER and C_b were performed using a 2 × 2 × 2 factorial design, to test differences among 2 years, 2 rates of N fertilization, 2 row ratios and their interactions. Significantly different means were separated at $P \leq 0{\cdot}05$ by the least significant difference test (Snedecor and Cochran, 1980).

Experiment 2

The experimental design was a randomized complete block design with three replications. Eight treatments were applied each year in a factorial combination: 2 cropping systems (wheat SC and wheat intercropped with field bean) × 2 nitrogen fertilization rates (N20 and N50) × 2 row ratios (R1:1 and R2:1) (Table 1). In all wheat SC treatments, we adopted the same inter-row spacing of wheat as in the IC treatments. The accommodation of another ANOVA factor allowed us to test the effect of competition and/or facilitation exerted by the field bean on wheat. Data on durum wheat DM, CP and NY were statistically treated by ANOVA, using a 2 × 2 × 2 × 2 factorial design, to test differences among 2 years, 2 cropping system, 2 rates on N fertilization, 2 row ratios and their interactions. Significantly different means were separated at $P \leq 0{\cdot}05$ by the least significant difference test (Snedecor and Cochran, 1980).

Results

Because the main effects of year and its interactions were not significant, data reported are the means of the 2 years. Although total rainfall during the growing season differed between years, 446 mm in 2004–2005 and 589 mm in 2005–2006 (Figure 1), in the period from February to May, when highest plant growth occurs, rainfall was similar (193 and 204 mm in the first and second years, respectively). This could explain the absence of a significant year effect on the growth and production of plants.

Fertilization and row ratio effects (Experiment 1)

ANOVA indicated a significant effect of the forage treatments on most of the analysed characters. The forage DM of durum wheat from IC was considerably

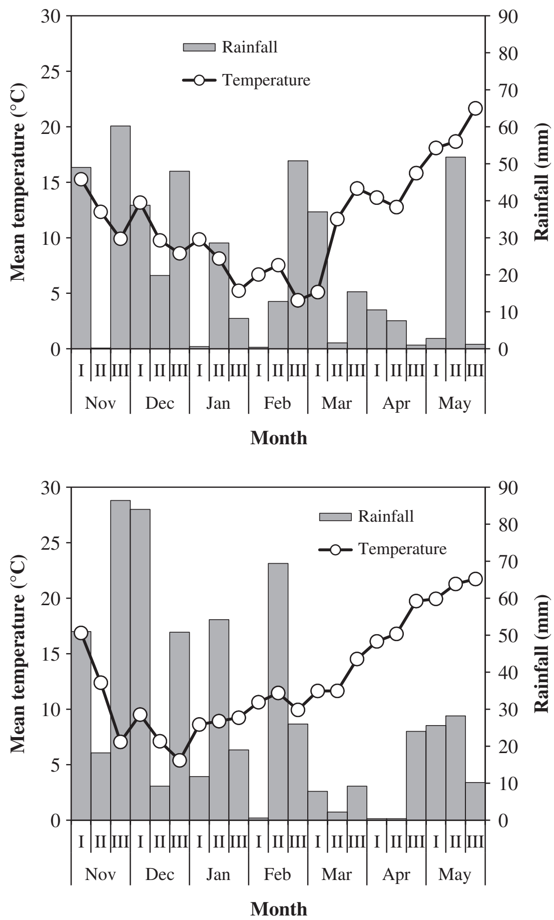

Figure 1 Rainfall and temperature during 2004–2005 (above) and 2005–2006 (below) durum wheat/field bean growing season.

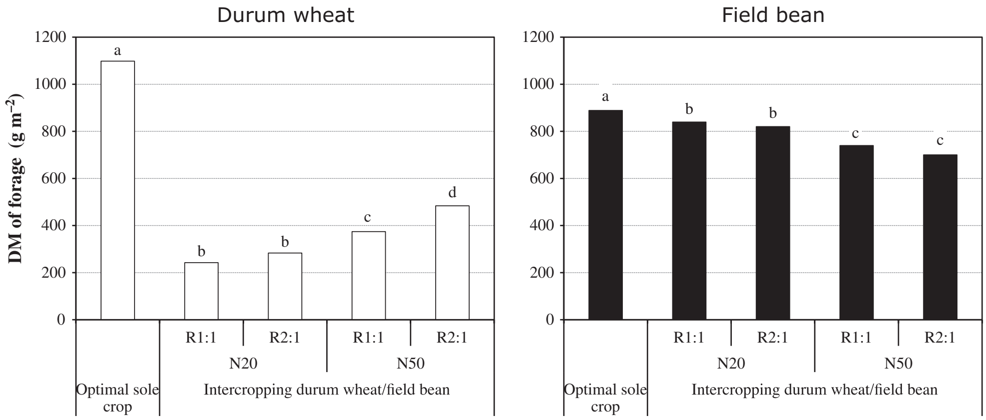

Figure 2 Experiment 1: Dry matter of forage by durum wheat and field bean optimal sole crop and intercropping. Bars with the same letter are not significantly different at $P \leq 0{\cdot}05$.

lower than that from the optimal sole crop (Figure 2). In IC, the reduction in growth of durum wheat, relative to the optimal SC, depends on the combined effect of the field bean, the N rate and the row ratio; the effect of the field bean will be investigated separately from the other effects in the second experiment.

In the IC durum wheat, the increase in N fertilization and row ratio increased the forage yield, with the highest difference (about 100%) between DM obtained with N20 R1:1 and N50 R2:1 (Figure 2). The effect of N fertilization was more pronounced than that of row ratio: from N20 to N50 DM values increased by 54% with R1:1 and by 71% with R2:1, whereas the effect of row ratio was negligible and statistically not significant when N rate was low and become significant (+29%) when the availability of nitrogen increased (Figure 2).

Forage yield of field bean was reduced by IC with wheat, and the effect was low. Variations were influenced by N rate, but were not appreciably affected by row ratio (Figure 2). At the N20 rate, the presence of the wheat reduced DM of field bean to values that were 93% of the optimal SC, and at N50, the values were 80% of the optimal SC.

Crude protein concentration of durum wheat was significantly affected by treatments. On average, CP of optimal sole crop was 68 and that of IC was 82 g kg^{-1}, with no appreciable variations because of N rate or row ratio (data not shown). In the case of field bean, CP was not appreciably modified, resulting in about 150 g kg^{-1} averaged over all treatments.

Nitrogen yield of durum wheat was markedly higher in SC than in IC. In all IC treatments, NY was enhanced by N rate, but was not appreciably modified by row ratio, so that NY at N50 was 75% higher than at N20 (Figure 3).

Compared with the sole crop, the NY of field bean was reduced by IC with wheat. The reductions, averaged over the two row ratios, were low at N20 (−12%)

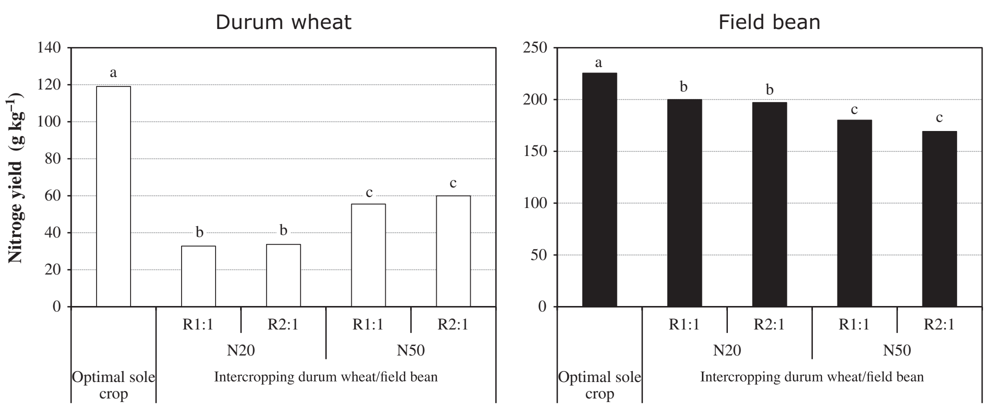

Figure 3 Experiment 1: Nitrogen yield of forage by durum wheat and field bean optimal sole crop and intercropping. Bars with the same letter are not significantly different for $P \leq 0{\cdot}05$.

and high at N50 (−23%). The increase in N rate from N20 to N50 also reduced the NY of field bean by 12% (Figure 3).

Considering the forage produced by both crops together, the forage yield from the entire harvested aerial part of optimal SC was about 10 t DM ha^{-1} (Figure 4). To make a correct comparison between SC and IC, the data of Figure 2 refer to the same surface area, and therefore, values of SC were averaged, whereas those of IC were pooled. Forage yield obtained by IC was higher than that obtained by the mixture of optimal SC, with low variations depending on N rate or row ratio. The highest DM was obtained with an N rate of N50 and a row ratio of R2:1.

The treatments greatly affected the proportion of wheat in the forage mixture (Figure 5). In IC treatments, the legume was always the predominant crop, although with different proportions: at N20, the forage comprised 25% cereal and 75% legume, regardless of row ratio, whereas at N50, the percentage of wheat increased to about 35% with R1:1 and just above 40% with R2:1.

All durum wheat/field bean intercrops had higher CP compared to the optimal SC, except the treatment with N50 and R2:1 (Figure 4), probably owing to a lower proportion of field bean in the mixture. CP concentration of the ICs was not appreciably affected either by N rate or by row ratio, and on average, it was 21 g kg^{-1} higher than for SC.

Nitrogen yield was about 60 kg N ha^{-1} higher in intercrops, compared to optimal SC, irrespective of N fertilization and row ratio (Figure 4). This difference was attributed to the higher DM and CP of the intercrops, compared to SC.

ANOVA performed on LER and C_b data indicated that second- and third-order interactions among treatments were never significant. The total LER calculated on a DM basis was appreciably modified by nitrogen rate and was not affected by row ratio, with values considerably higher than 1, from 1·17 to 1·20 (Table 2). According to these LER values, the IC treatments used environmental resources for plant growth more effectively compared with the respective optimal SC. The highest LER value was obtained with the highest N rate (Table 2).

Similarly, LER values calculated for NY were all considerably higher than 1, indicating a better utilization of soil N sources by the IC than by SC (Table 2). The efficiency of soil N utilization increased with N rate up to 26%. The increase in total LER with N rate, based on both DM and NY, was solely due to the strong increase in the partial LER of durum wheat, while the partial LER of field bean was reduced (Table 2).

The competitive ability of field bean was measured by the Competitive Balance Index (C_b). All values were positive, indicating that field bean was the dominant species (Table 2). However, N fertilization markedly decreased the competitive ability of field bean, reducing the disadvantage of the cereal against the legume.

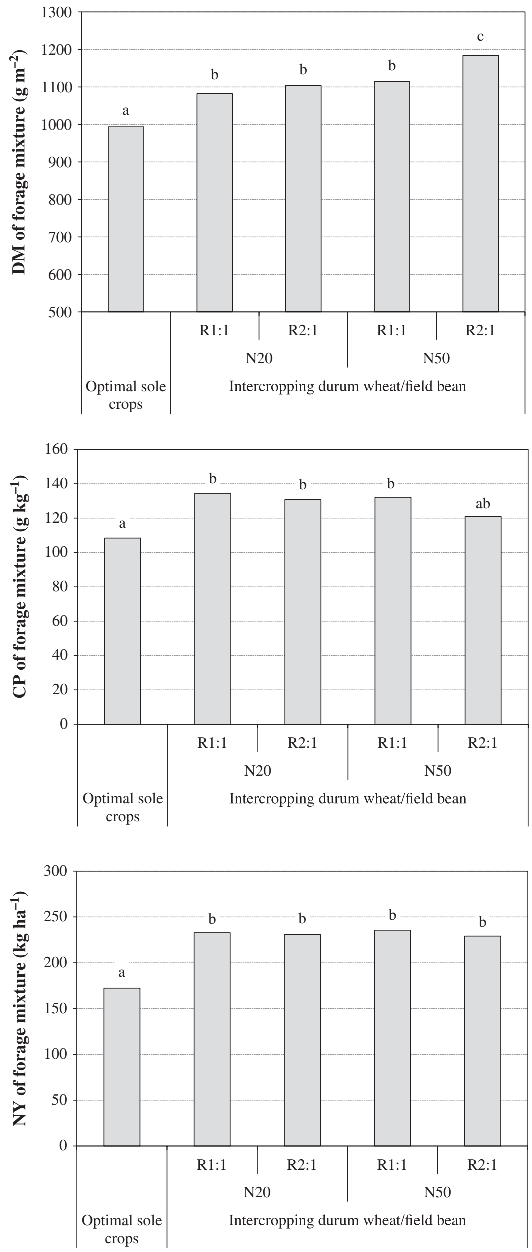

Figure 4 Experiment 1: Dry matter (DM), crude protein concentration and nitrogen yield (NY) of the two optimal sole crops (SC) and of intercropping (IC). DM yield and NY data were calculated on the basis of the same surface area: therefore, values of SC were averaged, whereas values of IC systems were pooled. Bars with the same letter are not different for $P \leq 0.05$.

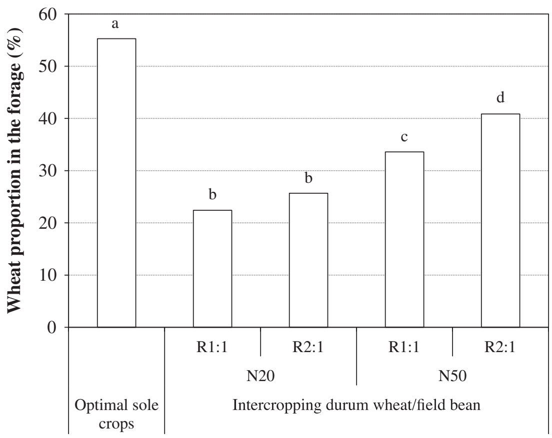

Figure 5 Experiment 1: Durum wheat proportion in the total forage (dry matter basis). Bars with the same letter are not different for $P \leq 0{\cdot}05$.

Competition ⁄ facilitation effects (Experiment 2)

ANOVA indicated a significant cropping system mean effect for the most analysed character and no interaction between cropping system and other treatments (Table 3). Averaged over N rate and row ratio, the DM yield of wheat was about 134 g m^{-2} lower with the legume as companion crop (Figure 6). Competition from field bean reduced the reproductive plant fractions of durum wheat more than the vegetative fraction (Figure 6), with a decrease of 38% for the former and of 22% for the latter. Consequently, the proportion of forage mass represented by the spikes decreased from 0·38 of SC to 0·32 of IC, because of a decrease in the number of spikes per unit area (Table 4).

Crude protein concentration of wheat was significantly increased by the presence of field bean in IC. Expressed as a mean of N fertilization and row ratio, CP was 48 g kg^{-1} in sole crop and 82 g kg^{-1} in the intercrops (Figure 7). The NY of wheat was also increased by about 9 kg ha^{-1} by the presence of field bean (Figure 7).

Discussion

The LER was defined as the relative land area under SC that is required to produce the yields achieved in IC (Willey and Rao, 1980). In this research, we obtained higher forage yields per hectare with IC than with optimal SC. To obtain the same DM and NY by the IC, the SC would have required 20% and 26% more land area, respectively.

In addition, all ICs had higher CP concentration and NY than SCs, so that these components of forage quality were also enhanced by IC. The higher CP of the ICs, compared to optimal SCs, may be attributed to: i) the high proportion (from 60 to 80%) of the field bean in the IC mixtures (Figure 5) and ii) the higher CP of the durum wheat cultivated in IC. These results are comparable to those obtained by other authors with wheat ⁄ bean and oat ⁄ pea IC systems, applying the same N rate to IC and SC (Ghanbari-Bonjar and Lee, 2003; Carr *et al.*, 2004). Conversely, in this study, the IC advantages, compared to optimal SC, were obtained when intercrops were fertilized with a 2·4 times lower N dose than SC. Thus, durum wheat ⁄ field bean represents a feasible option to reduce N fertilization for forage production.

In general, the results presented in Table 2 indicate that total LER values on a NY basis were higher than the corresponding LER on a DM basis; following Ghosh *et al.* (2009), this suggests that N is utilized by IC more than all other resources and that N is not the limiting factor in IC performance. This is confirmed by results on competitive ability (Table 2), indicating that competition for N is lower than competition for all resources.

An unexpected result of this study was the increase in resource complementarity with the increase in nitrogen rate, whereas previously reported studies have generally found reductions in LER with increasing N

Table 2 Experiment 1: land equivalent ratio (LER) and competitive balance index for field bean (C_b) calculated on dry matter (DM) and nitrogen yield (NY) basis, as affected by N rate.

N rate	DM basis				NY basis			
(kg ha^{-1})	LER_C*	LER_L†	LER‡	C_b	LER_C	LER_L	LER	C_b
20	0·24 a	0·93 a	1·17 a	1·02 a	0·28 a	0·88 a	1·16 a	0·80 a
50	0·39 b	0·81 b	1·20 b	0·39 b	0·48 b	0·77 b	1·26 b	0·12 b

In a column, values with the same letter are not different at $P \leq 0{\cdot}05$.
*Partial LER of cereal.
†Partial LER of legume.
‡Total LER.

Table 3 Experiment 2: results of the ANOVA on durum wheat crop.

	Source of variation: year (*A*) × cropping system (*B*) × N rate (*C*) × row ratio (*D*)†			
Character	***B***	***C***	***D***	***C* × *D***
DM of forage	*	*	*	*
DM of reproductive plant part	*	*	*	*
DM of vegetative plant part	*	*	*	*
Proportion of spikes	*	ns	ns	ns
Number of spikes	*	ns	*	ns
Dry weight per spike	ns	ns	ns	ns
CP of forage	*	ns	ns	ns
NY of forage	*	*	ns	ns

ns, not significant; CP, crude protein; DM, dry matter; NY, nitrogen yield.
*Significant at $P \leq 0{\cdot}05$.
†Only sources of variation with statistically significant effect are presented.

fertilization (Ofori and Stern, 1987; Andersen *et al.*, 2004; Ghaley *et al.*, 2005). In this research, however, we hypothesized a limiting factor other than the availability of nitrogen, and it is likely that N fertilization confers to the crop the ability to overcome it, thus enhancing resource complementarity.

The tested treatments produced stronger variations in durum wheat than in field bean: compared to optimal durum wheat SC, the durum wheat IC suffered a great DM yield reduction, with actual reductions ranging from 615 to 856 g m^{-2} among the different N rate and row ratio treatments (Figure 2). ANOVA indicated that the mean effect of cropping system and the interaction of N rate × row ratio were significant, whereas the interaction of cropping system × nitrogen rate × row ratio was not significant. Thus, the DM reduction in optimal wheat can be attributed to the presence of field bean and to the combined effect of N rate × row ratio. The reduction because of field bean is only a minor part of the total variation, because it can be estimated as 134 g m^{-2} through the difference between SC and IC (Figure 6). Consequently, the DM yield of wheat was affected more by N fertilization and number of plants per unit area than by the presence of the legume. Furthermore, wheat appeared more sensitive to variations in N fertilization than row ratio. These findings indicated that the latter factor was ineffective with N20 and became profitable with N50, probably because the increase in plant number was supported only by the increase in N availability in soil.

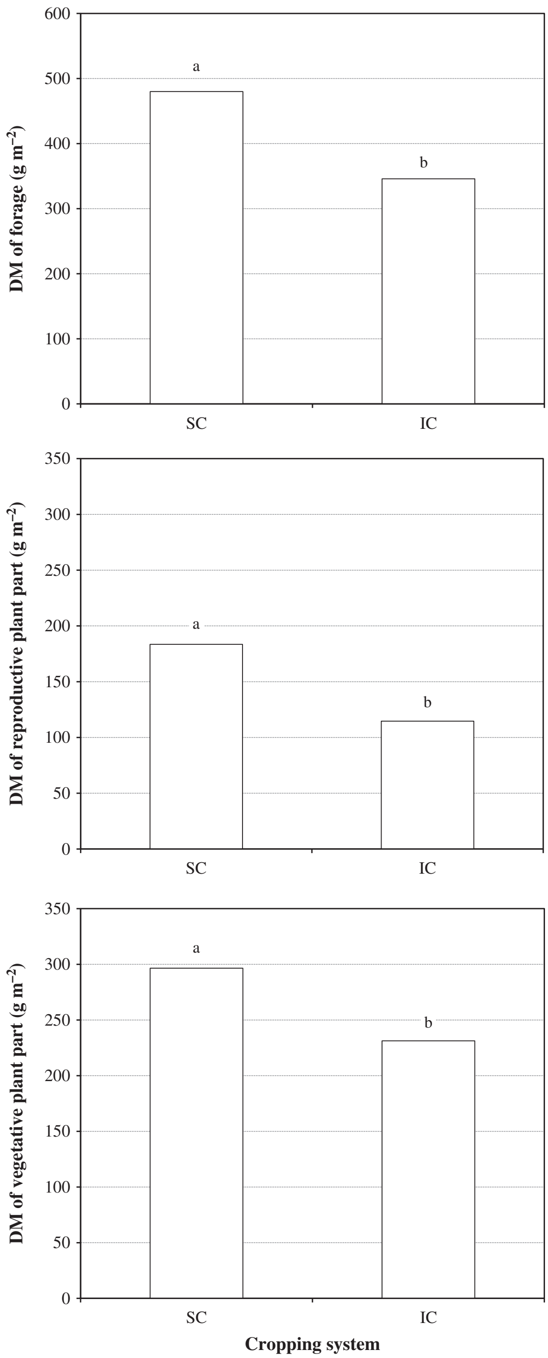

Figure 6 Experiment 2: Forage, reproductive and vegetative dry matter yield of durum wheat as affected by cropping system. Bars with the same letter are not significantly different for $P \leq 0{\cdot}05$.

All tested treatments caused important modifications in the proportion of wheat in the mixture, which represents a key factor for the utilization of the forage.

Table 4 Experiment 2: proportion of forage mass represented by the spikes, number of spikes per unit surface and spike dry weight in durum wheat forage, as affected by the cropping system.

Cropping system	Proportion of spikes (g g^{-1})	Number of spikes (No. m^{-2})	Dry weight per spike (g)
Sole crop	0·38 a	261·5 a	0·74 a
Intercrop	0·32 b	162·9 b	0·69 a

In a column, values with the same letter are not different at $P \leq 0{\cdot}05$.

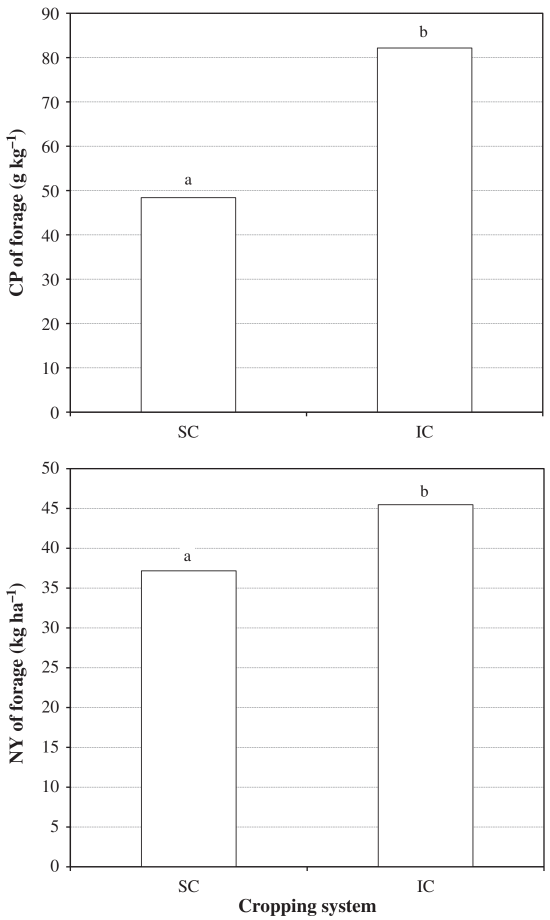

Figure 7 Experiment 2: Crude protein concentration and nitrogen yield of durum wheat forage as affected by cropping system. Bars with the same letter are not significantly different for $P \leq 0{\cdot}05$.

Some authors have indicated that silage produced from a mixture of whole-crop cereals and whole-crop grain legumes has satisfactory fermentation characteristics and a higher nutritive value compared with silage produced from a cereal-only whole crop, because of a higher concentration of CP (Walton, 1975; Berkenkamp and Meeres, 1987; Lunnan, 1989; Chapko *et al.*, 1991; Anil and Miller, 1998) and a higher degradability of nutrients in the rumen (Mustafa *et al.*, 2000; Salawu *et al.*, 2001). Pursiainen and Tuori (2008) suggested that to obtain good quality silage from a mixture of wheat and field bean without the use of conservation additives, the minimum proportion of wheat in the sward should be 0·25. It emerged from this study that to obtain this proportion of wheat in the mixture, the fertilizer-N rate should be at least 50 kg N ha^{-1}, and at this N rate, the proportion of wheat was 0·34 and 0·41 at row ratios of R1:1 and R2:1, respectively.

The dominant species of IC was always the field bean, as indicated by the high proportion of legume in the total DM and by competitive-ability data (Figure 5 and Table 2). Nitrogen fertilization increased the competitive ability of durum wheat, thereby reducing the disadvantage of the cereal against the legume; this was also obtained in IC systems with oat/vetch and wheat/pea (Assefa and Ledin, 2001; Ghaley *et al.*, 2005).

Campiglia *et al.* (1991) and Tosti and Guiducci (2010) attributed the higher competitive ability of field bean relative to durum wheat to its higher plant height. Indeed, it is commonly accepted that taller plants have most of their leaves in the upper canopy layer and thus are able to intercept more light and restrict the growth of smaller plants by shading (Zerner *et al.*, 2008). In our research, field bean was taller than wheat by about 0·2 m at the time of harvest, irrespective of the N fertilization rate and row ratio (data not shown).

The competition from field bean also modified the plant morphology of wheat, reducing the reproductive plant fraction more so than the vegetative fraction. Similar results were obtained in IC systems with wheat, field bean and pea by Campiglia *et al.* (1991) and Tofinga *et al.* (1993). When overall competition was separated into above- and below-ground components, the negative effect on wheat spikes was attributed only to the former, probably because of the low radiation level that reached wheat plants (McMaster *et al.*, 1987; Tofinga *et al.*, 1993). Thus, it is likely that in this research, the reduction in the number of spikes of wheat was mainly a consequence of shading.

As yield components are determined at different stages of wheat development, the affected component can give some indication of when competition of field bean occurred. The percentage of plants that emerged did not change appreciably with the presence of the field bean (data not shown), but the number of fertile tillers per plant was reduced; therefore, we can infer that the competition of the legume was not exerted at emergence but started around the stage of tillering.

The competition with field bean did not alter the capacity of durum wheat to take-up nitrogen from the soil, as indicated by the increase in CP and NY in the presence of the legume. The higher CP concentration in IC durum wheat, compared to SC durum wheat, is consistent with previous studies with cereals and grain legumes and can be attributed to the higher competitive ability of wheat for inorganic N sources (Table 2) and to the higher N availability because of the presence of the legume (Martin and Snaydon, 1982b; Jensen, 1996; Ghaley *et al.*, 2005).

There was a greater uptake of N from soil in wheat intercropped with field bean than in sole-cropped wheat, with the difference slightly <10 kg N ha^{-1}. This result confirms that, in this research, interspecific facilitation, as defined by Hauggaard-Nielsen and Jensen (2005), was effective. The greater N acquisition by a non-legume crop intercropped with a legume has been frequently reported in the literature (Francis, 1986; Vandermeer, 1989; Stern, 1993). The transfer of N from legumes to companion graminaceous plants has been well documented with the ^{15}N isotope technique (Jensen, 1996; Xiao *et al.*, 2004). Although we cannot quantify precisely the N transfer from legumes to cereals, NY of cereals was increased by the presence of field bean, so we can assume, therefore, that the transfer occurred.

In summary, field bean had both competition and facilitation effects on durum wheat: the former occurred for light and reduced wheat growth by approximately 12%, while the latter occurred for nitrogen and increased wheat N uptake by about 7%. This suggests that for durum wheat in IC with field bean, the effect of competition for light was greater than the facilitation for nitrogen. Plant breeding objectives in winter wheat have led to a well-documented reduction in height, to reduce the risk of lodging and also to increase harvest index (Austin *et al.*, 1989). Conversely, these characters have not been important in field bean production, and cultivar heights have remained tall and unchanged. Breeding development of high-yielding field bean varieties for IC may, therefore, depend upon the selection of shorter bean cultivars that match the height of the companion wheat.

In this research, field bean appeared negatively influenced by the combined effect of N rate and the presence of the durum wheat, although with small effects. However, considering that durum wheat shows greater competitive ability for inorganic N sources and that low N rate probably did not affect field bean growth, it is likely that the observed yield reduction in field bean was not because of nitrogen fertilization *per se*, but to the increased competitive ability of wheat.

In conclusion, durum wheat/field bean is an attractive IC system for the production of forage with higher yield and better quality than sole cropping. The greater benefits in terms of DM and N yields, with fewer constraints for forage conservation practices, were obtained with 50 kg ha^{-1} N and a row ratio of 2:1 cereal/legume in alternate rows.

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