doi: 10.17221/832/2014-PSE

Nitrogen leaching and residual effect of barley/field bean intercropping

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ABSTRACT

Cereal/legume intercropping may improve resource use efficiency in agroecosystems and increase yield per unit surface area and yield stability. Two field bean (*Vicia faba* L.) and four barley (*Hordeum vulgare* L.) cultivars were mono- and intercropped (additive design) in a 2-year lysimeter experiment on a sandy loam soil. The aim was to test the effect of the cropping system on dry matter and N yield of forage, the residual effect on the subsequent ryegrass crop (*Lolium multiflorum* Lam. *westerwoldicum*), and NO_3-N leaching in the rotation. Land equivalent ratios were 1.65 for dry matter and 1.67 for N yield, indicating a clear advantage of the intercrop over sole crops. Both species suffered from competition, especially in terms of N resources, but barley was less affected. Nitrate leaching was the lowest from intercrop. Preceding crop significantly affected dry matter, N content and NO_3-N leaching of ryegrass. Field bean sole crop gave the highest benefits to ryegrass in terms of forage dry matter and N content, but also the highest NO_3-N leaching, followed by the intercrop and the barley sole crop. Barley/field bean intercropping may be an effective strategy to reduce land requirements, N leaching losses and fertilizer inputs, thereby increasing the sustainability of farming systems.

Keywords: silage; crop rotation; mixture; N benefit; N loss

Intercropping grass and legume is promoted to increase yield per unit surface area and yield stability (Strydhorst et al. 2008). In temperate climates, cereal-legume intercropping has been more successful when used for forage than grain production (Anil et al. 1998). Forage obtained from cereal/legume intercrops (IC) always has a higher quality than that of cereal sole crops (SC), while dry matter yield advantage varies, due to large differences in growth conditions (Dordas and Lithourgidis 2011). Intercrop yield is generally between that of SC (Carr et al. 2004, Strydhorst et al. 2008), or higher than both of them (Karpenstein-Machan and Stuelpnagel 2000, Ghanbari-Bonjar and Lee 2003, Lithourgidis and Dordas 2010, Mariotti et al. 2012). According to Pursiainen and Tuori (2008), also silage produced from a cereal/pulse legume mixture has a higher nutritive value compared to that produced only from cereals, due to the higher concentration of crude protein, a higher degradability of nutrients and a better balance of protein and energy for rumen microbes.

Additional advantages of cereal/legume intercropping include (i) more efficient exploitation of the N resource, due to the complementarity of biological N_2 fixation and soil mineral N use by companion plants; (ii) reduction in leaching N losses; and (iii) a positive residual effect on the next crop (Hauggaard-Nielsen et al. 2003, Szumigalski and van Acker 2006, Pappa et al. 2012).

Limited research has been carried out on barley/field bean intercropping for forage production (Strydhorst et al. 2008, Lithourgidis and Dordas 2010), and to the best of our knowledge no one has studied its N leaching and residual effects so far. This is despite the fact that both crops have broad environmental adaptability, almost simultaneously reach the optimal growth stage for ensilage, and provide a high quality feed (Carr et al. 2004, Köpke and Nemecek 2010).

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Our trial assessed the agronomic advantages of barley/field bean intercropping for silage production, by investigating (i) dry matter and N yield of sole crops and intercrops; (ii) residual effect on the subsequent ryegrass crop, and (iii) NO_3-N leaching losses in the rotation. Since the choice of cultivar is a key factor influencing interspecific competition and the amount of N available to the system (Ross et al. 2004, Pappa et al. 2012), the combination of four barley (two 2-row and two 6-row) and two field bean cultivars was compared.

MATERIAL AND METHODS

The research was carried out in 2007–2008 and 2008–2009 at the Department of Agriculture, Food and Environment of the University of Pisa, Italy, which is located approximately 10 km from the sea (43°40'N, 10°19'E) and 1 m a.s.l. The climate of the area is hot summer Mediterranean, with mean annual daily air temperatures of 14.2°C and a mean annual rainfall of 971 mm. During both growing seasons, daily minimum and maximum temperatures and rainfall were obtained from a meteorological station located within 100 m of the trial site.

Plants were grown in an open-air facility consisting of 42 lysimeters of 300-L volume (0.5 m^2 area and 0.6 m depth), spaced 20 cm apart, and embedded in expanded clay to avoid daily fluctuations in soil temperature. For leachate collection, lysimeters were attached to a 3 cm rigid PVC drain ending in a 30-L PVC tank. Approximately six months before seeding, lysimeters were filled with soil collected from a field previously cultivated with rapeseed (*Brassica napus* L.). Soil properties were: 56.8% sand (2 mm > Ø > 0.05 mm), 27.5% silt (0.05 m > Ø > 0.002 mm), 15.7% clay (Ø < 0.002 mm), 7.9 pH (H_2O), 2.1% organic matter (Walkley and Black method), 1.0 g/kg total N (Kjeldahl method), 22.0 mg/kg available P (Olsen method), 72.4 mg/kg available K ($BaCl_2$-TEA method), and 8.4% total $CaCO_3$ (Scheibler method).

In 2007–2008, experimental treatments consisted of two 2-row barley cultivars (Naturel and Ninfa), two 6-row barley cultivars (Gotic and Sonora), two field bean cultivars (Chiaro di Torrelama and Vesuvio), and eight intercrops obtained by the combination of each barley and field bean cultivar. In total there were 14 crop treatments arranged in a randomized block design with three replicates. The 2-row barley have more leaves per culm, more spikes per unit area and a higher mean kernel weight, but fewer grains per spike than 6-row cv. Field bean Chiaro di Torrelama is more cold resistant and taller than cv. Vesuvio.

Barley and field bean were sown on 9 November 2007. The seeding rate was 400 seeds/m^2 with a 16-cm row spacing for barley, and 50 seeds/m^2 with a 32-cm row spacing for field bean. Intercropping followed a 1:1 additive design, i.e. the density of each component was the same as the density of the sole crop (Figure 1). All SCs and ICs were fertilized pre-planting with urea, triple mineral phosphate and potassium sulphate, at rates of 15 kg/ha of N, 65 kg/ha of P, and 125 kg/ha of K.

Sole crops and intercrops were harvested for silage at the dough-ripening stage of barley (9 May 2008), when field bean was at the beginning of the pod development stage. In June 2008, crop residues were incorporated into the soil and, in order to estimate their residual effect, ryegrass was grown in all lysimeters. On 6 October 2008, ryegrass (cv. Jivet) was sown at a rate of 300 seeds/m^2 with a 16-cm row spacing. It was fertilized pre-planting with triple mineral phosphate and potassium sul-

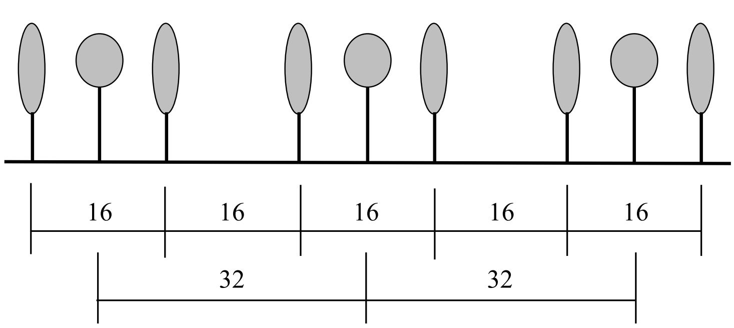

Figure 1. Crop distribution and row spacing (cm) in intercropping. B – barley; Fb – field bean

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phate, at a rate of 30 kg/ha of P and 60 kg/ha of K. No N fertilizer was applied. Ryegrass was harvested at the stage of spike emergence (14 May 2009).

Plants of all crops were cut 5 cm above ground level and intercrops were separated into cereal and legume. Ryegrass roots were separated from the soil by gently washing with water. Plant parts were oven-dried at 75°C to constant weight for determination of dry matter, and analysed for N concentration by the micro Kjeldahl method. Nitrogen yield was obtained by multiplying N concentration by dry matter (DM). Throughout the study, drainage water was collected from each lysimeter and analysed for volume and NO_3-N concentration (Orion ion analyzer, Witchford, UK).

The advantage in DM and N yield of barley/field bean IC compared to SCs was evaluated by the land equivalent ratio (LER), obtained as the sum of partial LERs (Trydeman-Knudsen et al. 2004). Partial LER of barley (LERb) and field bean (LERfb) were calculated as the ratio between the DM, or N, yield in ICs and SCs. The competitive ability of the two companion crops was estimated using the competitive balance index (C_b) as $C_b = \ln (LERb/LERfb)$ (Wilson 1988).

Field bean symbiotic N_2 fixation was estimated using the N-difference method (Trydeman-Knudsen et al. 2004) as $N_2 \text{ fixed}_{fb\ SC} = N_{fb\ SC} - N_{barley\ SC}$, and the amounts of N_2 fixed in intercropped field bean were calculated as:

$$N_2 \text{ fixed}_{fb\ IC} = (N_{fb\ IC} + N_{barley\ IC}) - N_{barley\ SC}.$$

Analysis of variance (ANOVA) was performed using CoStat 6.4 (CoHort Software, Pacific Grove, USA). Barley proportion in IC, LER and C_b data were analysed using a randomised block design with eight treatments. For all other characters, ANOVA was carried out using a randomised block design with 14 treatments. Significantly different means were separated at $P < 0.05$ by the least significant difference (*LSD*) test (Steel et al. 1997).

RESULTS AND DISCUSSION

The four barley and the two field bean cultivars did not differ statistically in terms of DM and N yield in SC and IC, as well as in terms of residual effect and N leaching. Accordingly, species mean effects only are reported.

The barley/field bean additive IC yielded 14 t/ha of forage DM, which was 100% and 40% higher than the yield of barley and field bean SCs, respectively (Figure 2). The LER for DM showed that resources were used 65% more efficiently in IC, while partial LERs (0.87 for barley and 0.78 for field bean) indicated that both species suffered from competition, with field bean being more affected. Although the quality of the forage mixture was not examined, the proportion of barley was 45%, falling within the range of 25–50% recommended for cereal/legume silage (Pursiainen and Tuori 2008).

Intercropping did not affect the N concentration of companion species and gave the N yield of 316 kg/ha

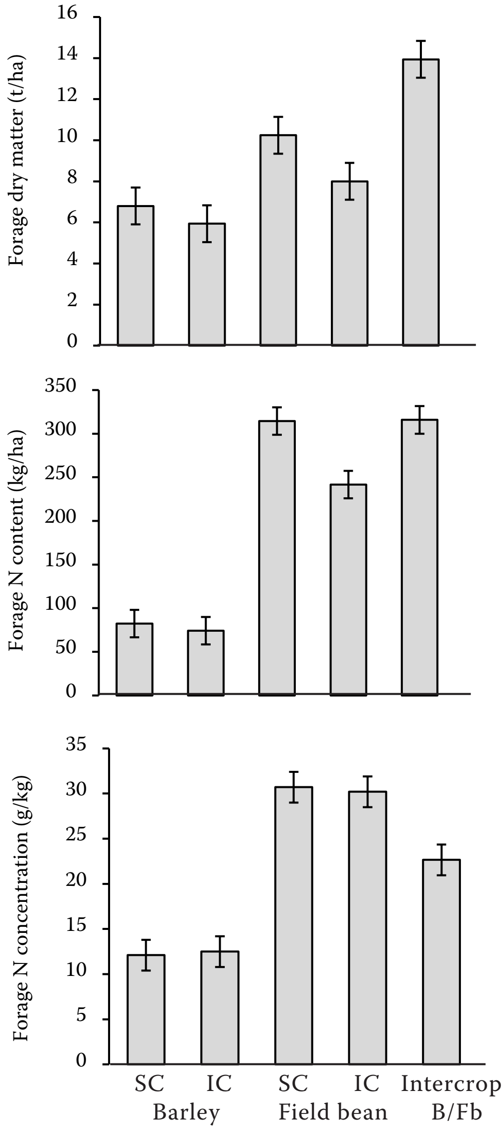

Figure 2. Forage dry matter, N concentration and content of barley and field bean sole crops and intercrops. In this and following figures, vertical bars denote *LSD*; when not visible, bars lie within the symbol. SC – sole crop; IC – intercropping; B – barley; Fb – field bean

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(Figure 2). Thus, the N yield of IC equalled that of field bean SC and was three times higher than barley SC. The LER showed that N was used 67% more efficiently in IC, while partial LERs (0.90 for barley and 0.77 for field bean) highlighted that field bean had suffered the most also in terms of N uptake. Since the N yield of barley was lower in IC than SC, and N concentration was not affected, it is suggested that there was no N-transfer from field bean to barley.

The results of the competitive balance index agreed with those of partial LERs, indicating that barley dominated over field bean in the IC. In addition, the higher C_b index for N (0.16) than for DM yield (0.11) suggests that barley was more competitive for N than for other resources (light, water). Field bean fixed the same amount of N in IC and SC (233 kg/ha) from which it is supposed that biological N_2 fixation was not affected by competition with barley (Dhima et al. 2007). In contrast, IC significantly reduced mineral N uptake of field bean, which accounted for only a 3% N content in IC compared to 26% in SC. The increased proportion of N derived from N_2 fixation in legumes intercropped with cereals suggests that root competition was greater than shoot competition (Martin and Snaydon 1982, Hauggaard-Nielsen et al. 2003, Trydeman-Knudsen et al. 2004). The higher competitiveness of grass roots is likely due to their faster growth in autumn-winter and to their finer and deeper root system, allowing a more efficient exploitation of the soil volume and a higher nutrient uptake (Hauggaard-Nielsen et al. 2009, Dordas and Lithourgidis 2011). In conditions that enable the growth of both companion species, the NO_3-N uptake of the grass causes a temporary decrease in its amount in soil, increasing the proportion of fixed N_2 of the legume (Opitz von Boberfeld et al. 2005, Szumigalski and van Acker 2006).

The amount of water drained throughout the entire growing season (Figure 3) was slightly lower in IC (271 mm) than SCs (approximately 295 mm) and represented 53–57% of rainfall (514 mm). Nitrate concentration in leachates was the highest in November–December, averaging 34 mg/L without appreciable differences among crop systems. Values decreased markedly in January and fell close to zero in February for barley and IC, and two months later for field bean (Figure 3). Total NO_3-N leaching was the lowest from IC (34 kg/ha), with a minor loss of 22 kg/ha compared to field bean SC, and 7 kg/ha compared to barley SC. Nitrate leaching in December accounted for 49% of total NO_3-N losses in field bean and 64% in barley and IC. After February, NO_3-N lost by leaching was negligible in all crop systems, due to reduced rainfall and increased crop evapotranspiration. It is believed that the lower water drainage and NO_3-N leaching from IC were primarily due to higher plant density. However, Hauggaard-Nielsen et al. (2001) reported that IC induced a faster lateral root development in both pea and barley and a deeper growing root system in the cereal, which could also contribute to reducing leaching.

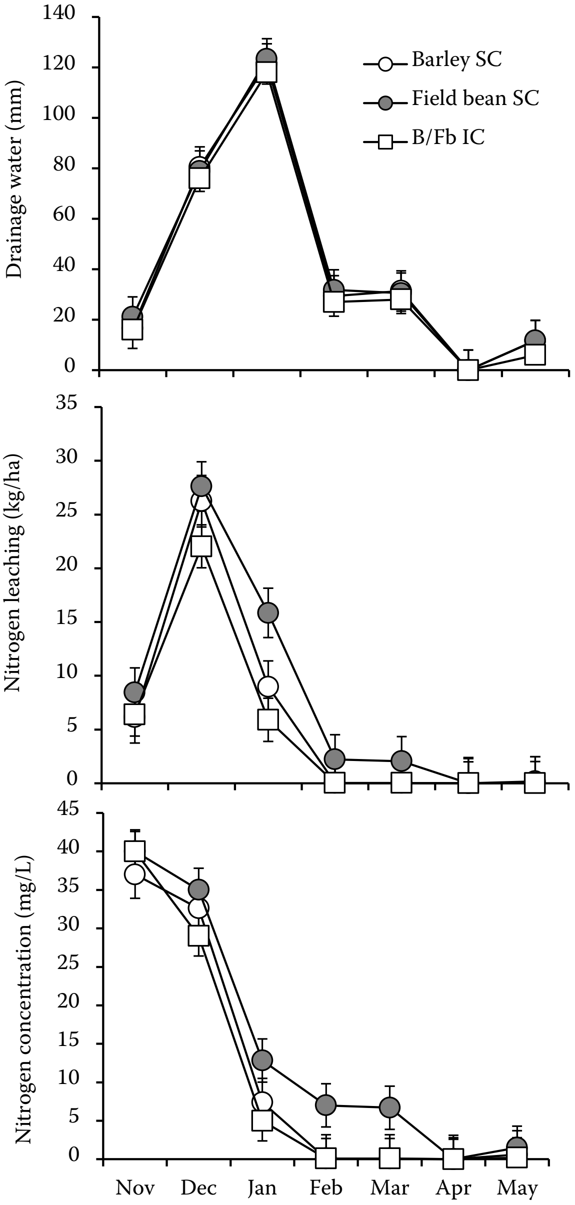

Figure 3. Water drainage, NO_3-N concentration in leachate, and NO_3-N leached by barley and field bean sole crops and intercrops. SC – sole crop; IC – intercropping; B – barley; Fb – field bean

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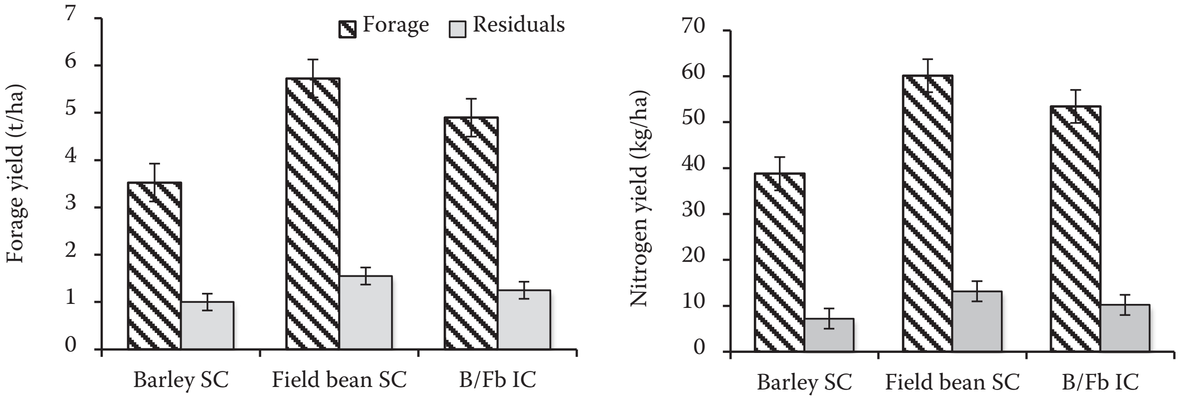

Figure 4. Dry matter and N content of ryegrass forage and residuals (roots + stubbles). SC – sole crop; IC – intercropping; B – barley; Fb – field bean

The DM yield of ryegrass forage was significantly affected by preceding crop (Figure 4). The greatest yield was observed after field bean SC, which was 62% higher than after barley SC, but only 17% higher than after IC. Nitrogen concentration was not affected by preceding crops (results not shown); thus the N content of ryegrass forage after field bean was 55% higher than after barley and 12% than after IC (Figure 4). Similar rankings were observed for residuals (roots + stubbles), whose ratios to forage were approximately 3.7 for DM and 5.1 for N content, without appreciable differences due to the preceding crop.

No leaching occurred from the harvest of barley and field bean SC and IC to the sowing of ryegrass. During ryegrass growth, drainage volume was not affected by preceding crops while the amount of NO_3-N leached was 31 kg/ha after field bean SC, 27 kg/ha after IC, and 21 kg/ha after barley SC (Figure 5). From 89–98% of total N was leached in November, with a flow-weighted N concentration of approximately 24 mg/L following field bean and IC, and 19 mg/L following barley. After November values were lower than 1 mg/L.

Residual effect and N leaching of the following crop are both related to the N content and decomposition rate of preceding crop residues. Compared to cereal residues, those of grain legumes are higher in the N content and lower in C/N ratio, which results in fast and high N mineralization and accumulation of NO_3-N in soil, available either for subsequent crop uptake or leaching (Karpenstein-Machan and Stuelpnagel 2000). This explains both the higher residual effect and NO_3-N leaching after field bean than after barley SCs. Intermediate values obtained after IC may be due to a slower net N mineralization during residue decomposition, because N released from field bean residues may be immobilised by those of the companion barley that have a greater C/N ratio (Hauggaard-Nielsen et al. 2003). The more balanced chemical composition of IC residues may result in less net

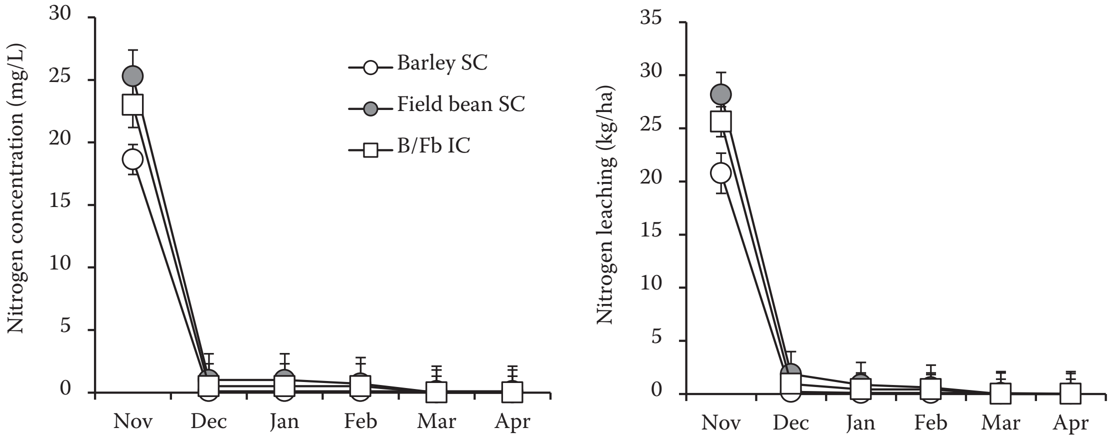

Figure 5. Nitrate concentration in leachate and NO_3-N leached by ryegrass. SC – sole crop; IC – intercropping; B – barley; Fb – field bean

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N mineralization in autumn-winter leading to a lower N leaching compared to field bean SC, and a higher residual effect compared to barley SC.

In conclusion, compared to SCs, additive barley/field bean IC increased forage yield, maintained a good quality for ensilage, and reduced NO_3-N leaching. Residual effects of IC were intermediate between those of field bean and barley SCs in terms of yield and N benefits, and N leaching to subsequent ryegrass. The choice of cultivar, either for barley or field bean, did not affect significantly crop performance in SC and IC. Barley/field bean IC can reduce land requirements, N leaching losses and fertilizer inputs, thus complying with several goals of sustainable cropping.

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Received on October 24, 2014
Accepted on January 20, 2015

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