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Effects of a winter or spring sowing date on soil nitrogen utilisation and yield of barley following a forage crop of red clover, lucerne or hybrid ryegrass

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ABSTRACT

An experiment tested the hypothesis that the yield and nitrogen content of a spring-cultivated barley (*Hordeum vulgare*) crop (cv. Riviera) would be higher than for a winter-cultivated barley crop (cv. Pearl) when following 3-year-old swards of either red clover (*Trifolium pratense*), lucerne (*Medicago sativa)* or hybrid ryegrass (*Lolium hybridicum*) maintained and harvested for silage. Four replicate, 15 m × 15 m plots of red clover, lucerne, hybrid ryegrass receiving 250 kg N ha^{-1} $annum^{-1}$ (250-N HRG) or hybrid ryegrass receiving 0 N ha^{-1} $annum^{-1}$ (Zero-N HRG) were sown on 2 September 2002. On 13 October 2004 and 17 March 2005, half of each plot was ploughed and sown with either winter or spring barley, respectively. Barley was harvested as whole-crop at the dough stage. Soil samples were collected from all plots in autumn 2004, spring 2005 and autumn 2005 for soil mineral N (SMN) analyses and ceramic cups were used to assess nitrate leaching from red clover plots. The grain DM yield of barley was higher when cultivating winter barley compared with spring barley when sown following Zero-N ryegrass ($P < 0.05$), whereas the grain DM yield was higher when cultivating spring barley compared with winter barley when sown following legumes ($P < 0.05$). In autumn 2005, following harvest of the barley crops, SMN and soil nitrate-N was higher in soils cultivated the previous autumn compared with soils cultivated in spring 2005 ($P < 0.001$). SMN was higher ($P < 0.05$) in red clover plots than Zero-N HRG plots, but there were no differences in SMN among the other treatments ($P > 0.05$). The total N leached from red clover plots was higher from winter-cultivated barley plots (57 kg N ha^{-1}) compared with spring cultivated barley plots (35 kg N ha^{-1}) ($P < 0.01$). Overall, the results showed that the best practice to optimise the recovery of SMN by a subsequent cereal crop following legumes in this study was to cultivate and sow barley in spring rather than in autumn whereas, when sowing cereals after ryegrass, the best use of SMN was obtained when cereals were sown in the autumn compared with the spring.

1. Introduction

With the rising cost of using inorganic fertilisers in both monetary and environmental terms, there is a renewed interest in the use of legumes to facilitate the development of more sustainable farming systems. Furthermore, with increasing fluctuations in world trade prices on soya and other protein feed sources for ruminants, many livestock farmers worldwide are under increasing pressure to maximise their use of home-grown forage-based diets for their livestock. Advances in silage technology have opened up the possibility for legume forages, such as red clover (*Trifolium pratense*) and lucerne (*Medicago sativa*), to be ensiled as high protein winter forage for livestock (Wilkins and Jones, 2000; Wilkinson, 2005). These ensiled forages, previously regarded as being unsuitable for ensiling due to their low water-soluble carbohydrate concentrations and high buffering capacity (Frame et al., 1998), have been found to improved growth rates in lambs due to improved N utilisation efficiency and higher levels of voluntary feed intake when compared to ryegrass silage (Marley et al., 2007). Furthermore, the subsequent manure from livestock fed on these high-protein silages to be used as a valuable source of nutrients when recycled within a livestock system (Marley et al., 2006).

The ability of legumes to fix atmospheric N and accumulate N in the soil for the benefit of following crops has been known for centuries and has been demonstrated in numerous studies around the world (Bruulsema and Christie, 1987; Bullied et al., 2002; Evans et al., 2003). The accumulation and release of N from legumes is

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dependent on factors such as legume harvest management and on N mineralisation of the legume residue (Janzen et al., 1990). Previous research has shown the need to optimise the uptake of the mineralised N in order to maximise the yield of a subsequent cereal crop and to reduce the losses of N by nitrate leaching following cultivation; for example, by avoiding cultivating for winter cereals and instead cultivating in spring for spring cereals (Stopes et al., 1996). Typically, pure legume crops are used as short-term 'break' crops in cereal rotations within arable farming systems (Strong et al., 1986; Evans et al., 2003) or as green manure crops produced solely for soil incorporation to build fertility within stockless organic systems (Talgre et al., 2012). There is greater soil N accumulation if legumes are mulched and the material left in the field (rather than been removed for silage production) and legume harvest management has been shown to have a major effect on the ability of legumes to accumulate soil mineral N (Shrestha et al., 1999).

These factors highlighted a need to determine the production and environmental impacts of incorporating legume forages into a ruminant livestock system when grown for silage production over a medium-term (2–3 years) period. The aim of this research was to determine the best approach by which to maximise the capture of soil mineral N following legume silage production, not only to benefit productivity but also to reduce potential losses due to N leaching to the wider environment. Here, we present the findings of an experiment comparing the effects of legumes or ryegrass, with the latter either treated or not treated with inorganic N, when grown as a silage crop for a medium-term on soil N changes and the forage and grain yield of a subsequent crop of either autumn sown or spring sown barley (*Hordeum vulgare* L.).

2. Materials and methods

2.1. Experimental site and treatments

The plots were sited on an area of stony, well-drained loam of the Rheidol series (Rudeforth, 1970) (52°26′55″ N, 4°1′27″ W). The experiment was a split-plot design with four replicate blocks. A schematic representation of one 15 m × 15 m plot within the experiment, showing the timings of the main management actions, is presented in Fig. 1. Replicate 15 m × 15 m plots of red clover (cv. Merviot), lucerne (cv. Vertus) and two hybrid ryegrass (HRG) (*Lolium hybridicum*) (cv. AberExcel) treatments were sown on 2nd September 2002 in four blocks at a sowing rate of 14.5, 18.5, 36 and 36 kg ha^{-1}, respectively. One HRG treatment received 250 kg N ha^{-1} annum^{-1} as ammonium nitrate (34.5% N) and a HRG treatment receiving 0 kg N ha^{-1} annum^{-1} was included as a control. No N fertiliser was applied to the legume treatments or the other HRG treatment. To aid nodule development, the lucerne seed was mixed with a peat based *Rhizobium meliloti* inoculum immediately prior to sowing. All plots were treated with the insecticide Dursban 4 (chlorpyrifos 480 g l^{-1}; Dow Agrosciences, Hitchin, Herts.) applied at 1.5 l ha^{-1} on 4th September 2002 and with Lupus slug pellets (3% methiocarb; Bayer plc., Bury St Edmunds, Suffolk) applied at 5 kg ha^{-1} on 9th September 2002. Red clover and lucerne plots were treated with herbicide (Headland Judo, propyzamide 400 g l^{-1}; Headland Agrochemicals Ltd., Saffron Walden, Essex) at the rate of 1.75 l ha^{-1} on 13th December 2002.

In the first (2003) and second (2004) harvest years, plots were maintained by cutting with a Haldrup 1500 plot harvester (J. Haldrup a/s, Løgstør, Denmark) to a height of 10 cm on four occasions per annum. In 2003, silage cuts were taken from all plots on 30 May, 11 July, 27 August and 9 October; the HRG plots were also cut on 15 December. In 2004, silage cuts were taken from all plots on 21 May, 5 July, 16 August and 29 September; the HRG plots were also cut on 17 March 2005. The 250-N HRG plots received N as ammonium nitrate at 78, 64, 56 and 52 kg N ha^{-1} prior to each cut, respectively. Soil phosphate and potash levels were maintained at index 2 or 3 (Defra, 2010) throughout the experiment.

2.1.1. Barley

In autumn 2004, each plot was divided into two, equally sized sub-plots to be sown with either winter or spring barley. On 27 September, the winter barley sub-plots were treated with Glyphogan herbicide (glyphosate 360 g l^{-1}, Makhteshim-Agan (UK) Ltd., Thatcham, UK) at a rate of 4 l ha^{-1}. On 13 October 2004, these sub-plots were ploughed and power harrowed on the 1 November and sown with winter barley (cv. Pearl) at a sowing rate of 195 kg ha^{-1} on 2 November using a Fiona drill (Fiona Maskinfabrik A/S, Bogense, Denmark). Huron slug pellets (methiocarb 3% (w/w); Bayer plc., Bury St Edmunds, UK) were applied to winter barley plots at 5 kg ha^{-1} on 12 November 2004. The other half of each plot was ploughed on 17 March 2005 (weather conditions prevented the use of a herbicide) and power harrowed then sown with spring barley (cv. Riviera) on 21 March at a sowing rate of 180 kg ha^{-1}. Huron slug pellets (methiocarb 3% (w/w); Bayer plc., Bury St Edmunds, UK) were applied to all plots at 5 kg ha^{-1} on 26 April 2005. All plots were ploughed using a 2 furrow plough, set to a ploughing depth of 125 mm. All barley plots were sprayed with the herbicides Alpha Briotril Plus 19/19 (bromoxynil 190 g l^{-1}; ioxynil 190 g l^{-1}) (Makhteshim-Agan (UK) Ltd., Thatcham, Berks., UK) at 2 l ha^{-1} and Agroxone (485 g l^{-1} MCPA) Headland Agrochemicals Ltd., Saffron Walden, Essex, UK) at 3.5 l ha^{-1} on 26 April 2005. No fertilisers (N, P or K) were applied during the establishment or growing phase of the barley. Both barley crops were harvested as whole-crop at the dough stage (growth stage 87) (HGCA, 2006). The winter barley plots were harvested on 28 June 2005 and the spring barley plots on 25 July 2005.

2.2. Measurements

2.2.1. Legume and ryegrass forages

Plant populations of the legumes and tiller counts for the ryegrass plots were determined 8 weeks after sowing (2 December 2002) and then each spring (25 March 2003, 5 April 2004 and 7 March 2005) during the experiment. In spring 2005, plant populations were determined only from the sub-plots that were left for sowing to spring barley. Counts were recorded from 10 randomly placed 12 cm × 18.8 cm quadrats within each plot.

Fresh weight forage yields were determined by weighing the material cut from two areas per plots of 1.5 m × 5 m within each plot. Sub-samples of forage, as harvested, were taken to determine dry matter (DM) content and the botanical composition of the sward was divided into sown and unsown species to calculate the total yield of each component. A further sub-sample of the total forage harvested was taken and stored at −20 °C prior to subsequent freeze-drying and determination of total N (TN) content.

2.2.2. Barley

Winter barley plant populations and tiller counts were assessed on 10 December 2004 and 7 March 2005, respectively, and spring barley plant populations and tiller counts were assessed on 27 March and 6 May 2005, respectively. The DM whole-crop yield of both barley crops was determined by sampling a 3 m × 13 m area with a Haldrup plot harvester to a height of 6 cm. Sub-samples were taken and analysed for TN concentrations and botanical composition. Immediately prior to harvest, crop height and the number of stems 1 m^{-1} within eight rows of each split-plot were counted, harvested and thrashed to determine the grain:straw ratio and the total grain yield.