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An assessment of nitrogen fixation in 'organically managed' spring-sown lupins and leaching under a following winter cereal

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Summary

Three spring-sown species of lupins (Bora, Prima and Wodjil) and peas were compared in terms of N fixation and subsequent leaching under a following winter cereal crop. Although peas out-yielded lupins (5.4 t compared with *ca* 3.5 t grain, respectively), the yellow lupin (Wodjil) fixed more N than peas (180 compared with 120 kg N ha^{-1}) and all three lupins contained more protein (> 30%) than the peas (22%). Wodjil was the most effective at suppressing weeds, carrying only 12% of the weed burden found in fallow plots, followed by peas (19%). Winter leaching amounted to > 50 kg nitrate-N ha^{-1} from under the winter cereal, regardless of whether the previous treatment was a legume crop or was left fallow. There were no significant differences in leaching between the three species of lupin. Leachate in the first 350 mm of drainage under the winter cereal exceeded the EU limit on nitrate in drinking water in all treatments. This work is part of a wider collaborative study supported by Defra which covers a range of UK sites.

Key words: Leaching, lupins, fallow, nitrate, phosphorus, potassium

Introduction

A major challenge to agriculture in the UK is to improve the management of plant macro-nutrients and to minimise losses to water courses to comply with the implementation of the EU Water Framework Directive, whilst maintaining economic sustainability. Organic farmers are under additional pressure as the derogation to allow the use of non-organic livestock feeds expired on 24 August 2005. Feeds must now be GM free and traceable. Lupins are not widely grown in the UK, but are able to fix nitrogen (N) from the atmosphere and produce grain which is high in protein with potential for use as a livestock feed in organic farming. Lupins are used as a forage legume or as a green manure in rotations with a winter cereals, but this raises concerns about the extent of nutrient losses, especially leaching. Experiments at IGER were undertaken to assess the suitability of three lupin species, managed 'organically' under UK conditions, in terms of yield and subsequent leaching under a following a winter cereal.

Materials and Methods

Two blue flowering species of lupin (*Lupinus angustifolius*, var. Bora and Prima) and one yellow (*L. luteus*, var. Wodjil) were compared with peas (*Pisum sativa*, var. Ventura) grown in field plots (3 m × 10 m) on a freely draining soil (sandy loam, FAO dystric or eutric cambisol). The soil was pH 5.5 and contained moderate levels of available phosphorus (P) and potassium (K). The experimental site (previously cropped to conventionally grown spring wheat and not in 'conversion') was ploughed on 1 April 2005 and then left for one month as soil conditions were too wet to prepare a seed bed. The plough furrows were then rolled, power-harrowed to produce a fine tilth and drag-harrowed to level the ground for sowing, but not rolled due to wet soil conditions. No fertilisers or herbicides were applied, as the crops were to be managed 'organically'. Seed rates (kg ha^{-1}) were: Prima, 216; Wodjil, 126; Bora, 122 and Ventura peas, 241. The lupin seeds were treated with a proprietary inoculum of rhizobia, specific to lupins (*Bradyrhizobium*). The recommended rate of inoculum was increased threefold (*viz.* 12 g peat-based inoculum to 1 kg seed) because the seed had to be weighed into small bags, 24 h before sowing. A small plot seed drill (Hege) was used with an overall drilling width of 1.35 m and a row spacing of 11.5 cm. An extra 'pinch' of the peat was also added to each bag of seed and shaken just before sowing to aid infection. Plots were sown on 12 May 2005 and then rolled to consolidate the seed bed. Each block also contained a fallow plot to assess the extent of weed infestation in the absence of a sown crop and also to provide an estimate of soil N supply which was deducted from the N yield in the treatment plots to estimate N fixation. Crops were harvested using three quadrats (0.5 m^2) placed randomly within each plot and cut to a standard height of 2.5 cm above ground level. Seed pods were removed by hand and air-dried for 72 h before shelling and all the plant trash was returned to the plots. The remaining area of each plot was cleared using a small plot harvester (Haldrup) and the residues ploughed in, power harrowed and sown on 7 October 2005 with 150 kg ha^{-1} winter barley (*Hordeum vulgare*, var. Pearl). Before emergence, 10 macrorhizon leaching tubes (Meijboom & van Noordwijk, 1996) were installed in each plot. The leachate sampling tubes were run to a central collection point between plots to minimise damage to the new cereal crop when samples were obtained. The macrorhizon tubes were put under vacuum by applying suction from a 60 mL syringe with the plunger held fully open by a peg for 24 h. The frequency of sampling leachates was dictated by the amount of precipitation and initiated whenever cumulative rainfall reached *ca* 50 mm. Sampling continued from October 2005 to the end of March 2005 when drainage ceased. All samples were frozen shortly after collection and subsequently analysed for nitrate-N and P (SRP, soluble-reactive P) by automated analyses and K by flame photometry.

Results

Plant establishment, measured three weeks after sowing, gave mean populations (plants m^{-2}) of: 46 (Prima), 32 (Wodjil), 28 (Bora) and 36 (Peas) which were well below the target populations of 100, 70, 70 and 80, respectively and probably reflected insufficient preparation of the seed bed. Peas matured first and were harvested on 31 August, followed by Prima on 5 September. The other lupins (Wodjil and Bora) ripened together and were harvested between 19 and 23^{r}September. The three lupin species all remained upright with no signs of lodging through to harvest.

Grain yields (Table 1) were obtained from quadrats and represent gross grain production, without the loss of seed normally associated with mechanical harvesting. Peas gave the highest yield, maturing after 111 days from sowing and of the lupins, Prima performed best, producing most grain and ripening after 119 growing days with Bora and Wodjil taking 130 days to ripen from sowing. Wodjil had the highest grain protein content and the least weeds; it also had the highest plant biomass (Table 2), fixing significantly greater amounts ($P < 0.05$) of N than the other species and contained more P and K in the plant trash.

Table 1. *Grain yield (kg ha^{-1}) at 15% moisture content, grain nutrient content (kg ha^{-1}), % crude protein in grain and weed burden (as % of the weeds in fallow plots), 2005*

Crop:	Peas	Bora	Prima	Wodjil
Grain yield	5387c	3215a	3864b	3548ab
Grain N	161a	140a	161a	197b
Grain P	18.6b	11.1a	18.7b	12.2a
Grain K	51.2b	32.1a	47.0b	35.6a
% protein	22	32	31	41
% weeds	19	27	30	12

For comparisons between species, values that have different letters are sig. diff. $P < 0.05$

Table 2. *Dry matter yield and content of major nutrients in plant trash (without grain) and estimated N fixation (kg ha^{-1}) in above-ground biomass, 2005*

Crop:	Peas	Bora	Prima	Wodjil
DM yield	3375a	3970b	3512ab	5439c
N	50.5c	39.6b	31.0a	68.9d
P	2.43b	1.45a	1.50a	3.43c
K	21.7a	54.1c	29.9b	47.8c
N Fixation	126b	94.4a	107ab	181c

For comparisons between species, values that have different letters are sig. diff. $P < 0.05$

Under the newly sown winter barley crop, leachate (Fig.1) from all the plots (including previously fallow) consistently breached the EU drinking water limit for nitrate during the first 350 mm of drainage. Although plots previously with Wodjil had the highest concentrations, there were no significant differences between treatments and there were similar patterns of decline in concentrations, all returning to below 5mg nitrate-N l^{-1} by the end of drainage.

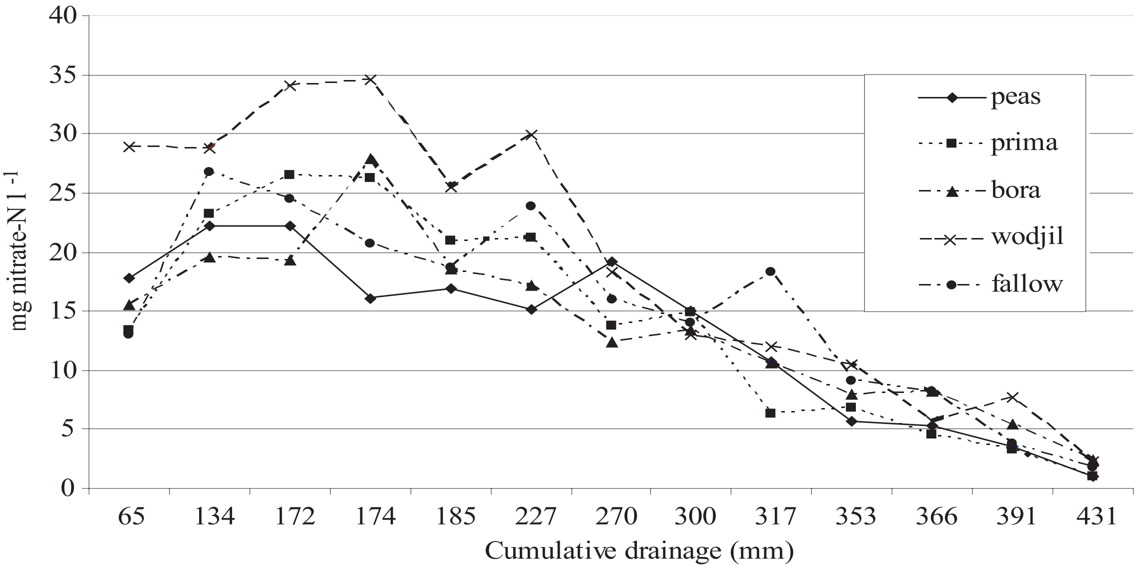

Fig 1. Concentrations of nitrate-N in leachate collected in over-winter (2005/6) drainage from under winter barley previously cropped with legumes or left fallow.

Total losses of N through leaching were >50 kg N ha^{-1} (Table 3) and were similar for all previous treatments, with the greatest loss recorded after Wodjil, although this was only at a low level of significance ($P < 0.1$). Only small quantities of SRP were leached under the barley crop from all the previous treatments and the ratio of N:K leached (mean of 5.9:1) was fairly consistent between all treatments.

Table 3. *Nutrients leached (kg ha^{-1}) under winter barley in 2005/6*

Nutrients	Peas	Bora	Prima	Wodjil	Fallow
N	55.9	54.6	61.6	93.8	69.0
P	0.10a	0.12a	0.10a	0.16b	0.11a
K	9.1	10.3	6.3	15.1	9.2
N:K	6.1	5.3	5.9	6.2	7.5

For comparisons between species, values that have different letters are sig. diff. $P < 0.05$

Discussion

Although plant populations were below-target, the plots remained relatively weed-free. Better growing conditions overall in 2005 (despite the wet conditions at sowing) also gave improved yields over the previous year, when the same crops were grown in an adjacent field (Hatch *et al*., 2006); Prima being the first to ripen in both growing seasons. The later ripening species (Wodjil and Bora) invested fewer nutrients in grain production and consequently yielded a greater proportion of above-ground biomass. Wodjil was the most effective at suppressing weeds, followed by peas. This may be partly due to its branching growth habit, higher biomass production, or possibly some allelopathy towards certain weed species. Over-winter leaching, following fallow with weeds, was comparable to leaching where lupins had been grown previously, although others (McLenaghen *et al*., 1996) found more leaching from fallow ground when compared with a growing lupin crop. The winter barley was to be harvested in 2006 to assess the nutrient supplying capacity of the legume rotational phase. The differences between nutrient content of an 'organically grown' barley crop on plots previously occupied by legumes, will be compared with the plots which were previously left fallow.

Conclusions

The new spring sown species of lupin could provide a valuable source of home-grown, non-GM feed for farm animals as an alternative break crop for arable systems and are of interest for inclusion in livestock rations because of their higher protein content compared with peas. This work has shown that they also offer the prospect of certain environmental benefits such as low nutrient requirements and can provide an additional source of N from fixation for the organic farmer. On free-draining soils, however, there may be losses from unharvested crop residues and/or weeds and from accumulated soil N following the break crop, that are vulnerable to leaching when soil drainage begins, if not fully utilised by the following winter cereal.

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