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Agricultural Ecology Research: Its role in delivering sustainable farm systems

Modelling the ability of legumes to suppress weeds

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Summary

The ability of different legume cover crops to suppress annual weeds during the early establishment phase was compared using a simulation model of inter-plant competition and field observations. Height, partitioning parameters, extinction coefficients, crop density and time of emergence were recorded for 11 species sown in monocultures. A naturally occurring population of fat hen (*Chenopodium album*) was present on the experiment. The competition model was run to compare the expected suppressive ability of the different species on this weed. Samples of *C. album* were also taken from each plot immediately prior to cutting to provide some empirical observations. Predicted suppressive ability was correlated with seed size and height with large seeded, tall species such as white sweet clover being the most competitive. However, these species may recover poorly from mowing compromising their potential to suppress perennial weeds and a mixture of contrasting species may provide the optimum weed control.

Key words: Competition, *Chenopodium album*, traits

Introduction

It is likely that, as the cost of bagged fertiliser increases, legume cover crops will play an increasingly important role in conventional as well as low input systems. These are most commonly made up of a mix of red or white clover either under-sown with a cereal or used as a clover/grass ley. It has been found, however, that there is a danger of significant N losses occurring post incorporation of these green manures (Francis *et al*., 1994) and that the risk is related to residue composition (Cadisch *et al*., 1998). It may be possible to improve the synchrony between the demands of a following crop and the supply from the green manure by including legume species with a more complex residue structure potentially in mixtures of several species. Although the primary function of these crops would be nitrogen fixation, they are also required to deliver a number of other services including weed suppression. This paper reports on part of a larger project ("Using legume-based mixtures to enhance the nitrogen use efficiency and economic viability of cropping systems") that is screening the relative performance of a range of legume species in monocultures and mixtures in relation to a number of functions. Specifically, data are presented here on the relative ability of the different legumes to suppress annual weeds prior to cutting.

Materials and Methods

Field experiment

The following legume species were sown on 15 April 2009 in monocultures in a fully randomised block design with three replicates and a plot size of 2 m × 5 m: alsike clover (*Trofolium hybridum*), birdsfoot trefoil (*Lotus corniculatus*), black medick (*Medicago lupulina*), crimson clover (*Trifolium incarnatum*), large birdsfoot trefoil (*Lotus pedunculatus*), lucerne (*Medicago sativa*), red clover (*Trifolium pratense*), sanfoin (*Onobrychis viciifolia*), sweet white clover (*Melilotus alba*), white clover (*Trifolium repens*) and winter vetch (*Vicia sativa*). The species were chosen because of their contrasting growth habits and availability as commercially produced cultivars. In addition, there were two dummy plots in each replicate with no crop sown. Before sowing, the seed were inoculated with the appropriate inoculums (Table 1); for some species none was available. The seeds were broad cast onto a pre-prepared seed bed and raked in by hand. Emergence was recorded every 2–3 days in a fixed 0.25 m^2 quadrat and finally establishment recorded on 2 June 2009 in six 0.25 m^2 quadrats. As well as counting the sown crop, all weed species in each quadrat were also recorded. The experiment was repeated at six sites but this paper reports on a sub set of data that were only collected at Rothamsted Research (Hertfordshire, UK).

Approximately every 2 weeks after emergence, five individual plants were sampled from each plot and divided into stems, leaves and flowers. Stem and leaf area was measured using a 'WinDias' leaf area meter (Delta-T Devices, Cambridge, UK) and the dry weight of the different plant parts measured after drying at 80°C overnight. In addition, plant height was also measured at approximately the same time as the biomass samples. In the spring of 2010, a small pot experiment was done following the protocol of Storkey (2004) to paramaterise seedling relative growth rate. The data on all these eco-physiological traits were input into the competition model. No herbicides, fertilisers or pesticides were used on the experiment which had a naturally occurring population of fat hen (*Chenopodium album*). The opportunity was taken to quantify the relative ability of the legumes to suppress this annual weed by sampling five individuals of *C. album* from each plot on 15 July 2009 and measuring the dry weight after drying at 80°C overnight. These measurements were taken immediately prior to the first cut.

Table 1. *Seed rates, emergence times and establishment of legume species used in study*

Species	Inoculum type	Seed rate (m^{-2})	50% Emergence (DAS)	Establishment (m^{-2})
Alsike clover	Clover	1099	11	110
Birdsfoot trefoil	None	863	16	138
Black medick	Lucerne	429	9	193
Crimson clover	None	395	7	170
Large birdsfoot trefoil	None	1644	27	82
Lucerne	Lucerne	952	8	362
Red clover	Clover	874	9	323
Sanfoin	None	368	9	121
Sweet white clover	Lucerne	638	8	134
White clover	Clover	1333	10	213
Winter vetch	Vetch	192	15	25

Competition model

The model of inter-plant competition was based on INTERCOM (Kropff & Spitters, 1992; Storkey & Cussans, 2007). The version of the model used in this study uses the relationship between seedling growth and thermal time to predict establishment before the onset of competition for resources, which is taken to begin at total green area index 0.75. Competition for light was modelled using functions that divide the canopy into five layers and calculate the fraction of incident radiation captured by each species in the canopy from data on extinction coefficients and vertical distribution of foliage. The rate of assimilation was calculated from the relationship between photosynthesis and leaf traits (Storkey, 2005) and carbohydrate allocated to different plant organs using the partitioning parameters measured on the field experiment. All the parameters required by the model were measured on the field experiment described above and, in addition, data were input on *Chenopodium album* from a previous experiment to allow the competition of the different legumes against this weed to be predicted. The relative ability of the legume cover crops to suppress *C. album* was simulated by fitting a Cousens hyperbolic function (Cousens, 1985), Equation 1, to the model output from several runs using different densities of legume (10, 20, 40, 80, 160, 320, 640 and 1280 plant m^{-2}) and a fixed weed density, 28 plants m^{-2} (corresponding to the average density recorded on the field experiment). The response variable used was the percent reduction in weed dry weight. The competitive balance between species in a canopy is particularly sensitive to the relative time of emergence. Therefore, actual data on differences in emergence times of the legumes in the field experiment were used in the model (Table 1). The parameter, *i*, was correlated against a number of plant traits to identify the causes of the differences between the species after log transforming *i* and seed weight.

$$\%\ reduction\ \ in\ weed\ \ weight\ = \frac{i.D}{(1+i.D/A)}$$

where, D = legume density, A = asymptotic reduction in weed weight at very high legume densities, i = reduction in weed weight as legume density approaches zero.

Results

The competition model generated realistic output in that as legume densities increased, the proportional reduction in weed weight per legume plant decreased as intra-specific competition became more important (Fig. 1). The hyperbolic function fitted well to the output from all the species with the exception of white clover, alsike clover, birdsfoot trefoil, black medick and large birdsfoot trefoil. In these cases, the legumes were predicted to be very uncompetitive and it was not possible to fit the asymptote to the model; a simple linear model with one parameter was, therefore, used.

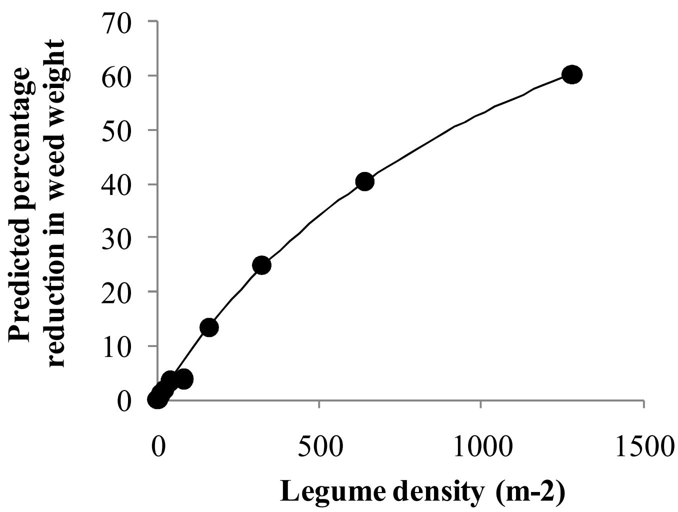

Fig. 1. Example of model output for series of simulation runs using crimson clover at increasing densities with fixed weed density of 28 plants m^{-2}. Fitted hyperbolic equation: y = 0.095 * legume density /(1+ 0.095 * legume density / 119.66).

There were large differences in the predicted suppressive ability of the legumes as measured by the parameter, *i*, in the hyperbolic equation (the proportional reduction in weed biomass per legume plant at low legume densities), Table 2. The most competitive species were winter vetch, white sweet clover and sanfoin with the trefoils predicted to perform particularly poorly against the weed. The variability in *i* was significantly correlated with maximum weed height and seed size (which was negatively related to seedling relative growth rate), Fig. 2, with large seeded, tall species predicted to be the most suppressive. The intention was to validate the model predictions against the reduction in weed biomass observed in the field (Fig. 3). However, there was a non-significant correlation between observed and predicted results (results not shown). In particular, the large reductions in *C. album* dry weight on the birdsfoot trefoil and black medick plots was unexpected. As much information as possible was input into the model including relative densities and emergence dates of the legumes and *C. album*, however, it was not possible to account for the impact of other weed species on the plots and it is likely, given the poor competitive ability of some of the legumes that other species, such as *Fallopia convolvulus* (which were patchily spread across the experiment) were having a large effect.

Table 2. *Parameters from hyperbolic yield loss equation with trait information for the legume species ranked in order of suppressive ability*

Species	*i*	Seed weight (mg)	Maximum height (cm)	Seedling relative growth rate
Winter vetch	1.69	51.9	79.7	0.007
White sweet clover	0.57	2.8	102.9	0.011
Sanfoin	0.16	21.8	93.2	0.007
Crimson clover	0.095	4.6	53.9	0.01
Lucerne	0.03	2.1	73.9	0.009
Red clover	0.019	2.1	59.2	0.012
Black medick	0.0069	3.5	41.3	0.011
Alsike clover	0.0056	0.9	50.5	0.011
White clover	0.003	0.8	28.4	0.013
Birdsfoot trefoil	0.0011	1.4	45.5	0.012
Large birdsfoot trefoil	<0.001	0.7	14.4	0.011

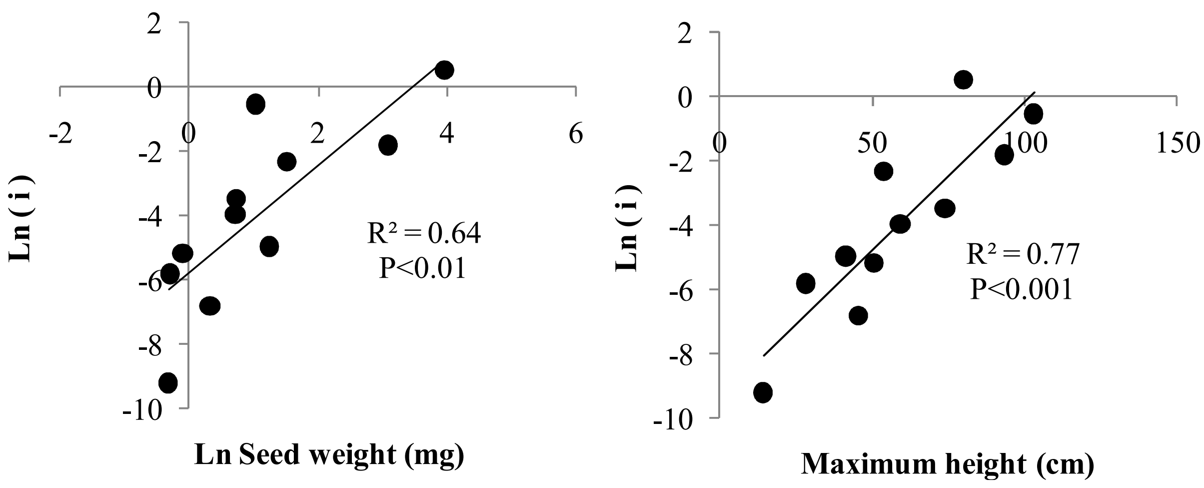

Fig.2. Relationship between ability of legumes to suppress weeds during early growth and seed weight and maximum height.

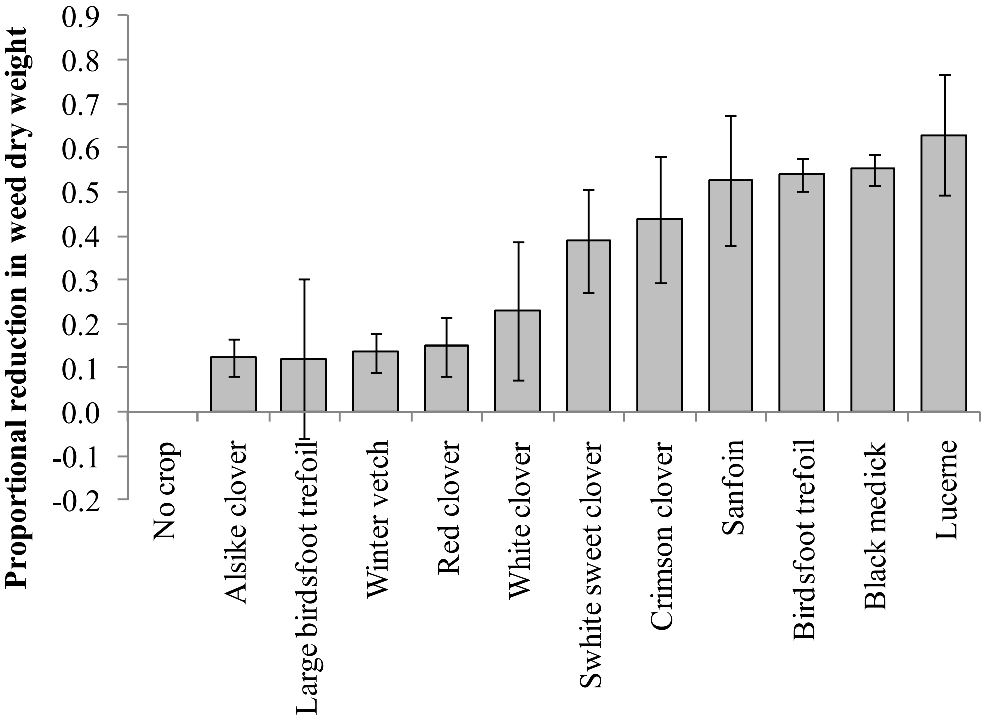

Fig. 3. Observed suppression of Fat hen (*Chenopodium album*) by different legume cover crops immediately prior to the first cut. It is not possible to make a direct comparison with the competitive rankings in Table 2 because the legumes are present in different densities but white sweet clover, crimson clover and sanfoin were generally more competitive with the three other clovers less so.

Discussion

With the increasing pressure on land to deliver both productivity and a healthy environment, there is a need to design cropping systems that are more environmentally sustainable and legumes will have an increasingly important role to play in meeting this goal. The work presented in this paper is part of a larger collaborative effort to design mixes of legume species that are multi-functional and, therefore, optimise the efficiency of the system. As well delivering the crucial function of nitrogen fixation, they are an important resource for pollinators (Pywell *et al.*, 2006) and can be useful for controlling weeds, the focus of this paper. The primary driver for recommending which combination of legumes to grow in a rotation will be agronomic performance in terms of productivity and the behaviour of the composition of the residue which will determine the breakdown characteristics of the green manure. However, information on the ability of different species to suppress weeds will also be an important consideration. The focus of the model used in this study was on the early growth phase before cutting. During this period, species such as winter vetch and white sweet clover with a larger seedling and tall canopy were predicted to be the most competitive. It is well known that height is an important trait driving suppressive ability (Gaudet & Keddy, 1988; Kropff *et al.*, 1992) but this analysis also emphasised the importance of initial seedling size in determining the outcome of competition later in the season. This effect could be compensated for with smaller seeded species by increasing the densities and one application of the model will be to optimise sowing rates of different legume mixtures.

The competition model is currently being improved to predict the growth and competition following mowing. It is likely that the taller species will recover less well from being cut as they lose a greater proportion of their biomass and it was observed that species, such as white sweet clover which were very competitive early in the season had more open canopies post-cutting as they grew back slowly. While being useful for suppressing annual weeds, therefore, the optimum system for also controlling perennials will include a mixture of species with contrasting patterns of growth over the whole season. The competition model will be used to optimise these mixtures. While providing a useful insight into the performance of the different legumes, the empirical measurements of weed suppression from the field experiment were limited in that the crop and weed densities were very variable. A more structured weed competition experiment with standard crop densities and sown weed populations would provide a better validation of the model.

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