LEGUME BASED PLANT MIXTURES FOR DELIVERY OF MULTIPLE ECOSYSTEM SERVICES: WEED DIVERSITY AND WEED CONTROL

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SUMMARY

Legume-based leys offer multiple benefits to ecosystem service provision, e.g. protecting soil and supporting pollinators. While weeds can play an antagonistic role during ley establishment, little is known about weed communities in these leys or about the optimal solutions for weed control in the establishment phase. To determine if the choice of ley species affects weed levels, we conducted field trials at six locations in the UK, measuring weed cover and biomass in monoculture plots of 12 legume and 4 grass species, plus an all species mix over two years. In these trials and in additional on-farm trials, weed cover and diversity were lower in the second than in the first year, owing to a decrease of annual weeds over time. The ability of a diverse species mixture to suppress weed development was higher than the average of its component legume and grass species. This might in part be attributed to the complementary effects of species with different growth patterns in the mixture.

INTRODUCTION

In organic rotations, legume-based leys are an essential component for fertility building (Watson *et al*., 2002). In addition, legumes are increasingly being included in conventional rotations as costs for mineral nitrogen fertilizer are increasing. Underpinning high ley performance, and subsequent provision of nutrients to the following crops, is clearly the successful establishment of the ley. Ideally, plants need to cover the ground quickly, establish well in a range of environmental conditions and be highly persistent until incorporation into the soil. During the establishment period, weeds can interact antagonistically with the ley as they compete for light, nutrients, and water. Also, annual weeds that exploit the space left by failed ley plants are more likely to contribute to the weed seed bank in the soil and may therefore become a problem later after the ley is incorporated.

However, despite their potentially negative effects in leys, weeds are essential for a wide range of ecosystem services. They constitute part of the farm's biodiversity and provide resources for invertebrates and other wildlife (Gabriel and Tscharntke, 2007), thereby helping to regulate the agro-ecosystem in terms of ecological pest control. In addition, certain weed species in leys can be seen as a welcome source of mineral nutrients for livestock (Harrington *et al*., 2006). Currently, however, little is known about weed communities in leys or about the optimal approaches for weed management in the establishment phase. Ecological research on the function and diversity of weeds in organic farming systems has so far mainly concentrated on weeds occurring in arable crops, especially wheat (Gabriel *et al*., 2006; Clough *et al*., 2007). In contrast, knowledge about weed diversity and weed control in organic leys is limited.

In order to characterise the response of the weed community to a range of legume and grass species and their mixture (the 'all species mix', or ASM) we conducted replicated plot trials at six locations across the UK, measuring weed cover and biomass in ASM plots and in monoculture plots of 12 legume and 4 grass species over 24 months. In addition, we monitored weed communities in leys on 21 organic and non-organic farms across the UK. Specifically, we asked: (1) Which legume and grass species used in the leys suppress weeds most successfully?; (2) Which are the dominating weed species in typical organic leys in the UK?; (3) What is the typical diversity of weeds (as measured by species richness) on organic leys?; and (4) Can key factors be identified that affect problem weeds, total weed burden and weed biodiversity?

MATERIALS AND METHODS

Field Trials

The study was conducted over two years, starting in spring 2009 and consisting of two main parts. In part (A), we set up replicated field trials at six sites across the UK, evaluating various legume and grass species in monocultures and in a mixture (details see Döring *et al*., 2012). In part (B), a multi-species mixture of legumes and grasses (ASM) was sown on 21 farms in the UK as non-replicated 0.5 ha strips alongside farmer-chosen control leys (Table 1). In the following text we refer to part (A) as "replicated trials" and to the part (B) as "on-farm trials". In the on-farm trials the species composition of the control ley was chosen by each farmer individually, and at a given farm, the management for the ASM and the control ley were identical. Most farmers sowed the leys in spring 2009, while some delayed sowing until autumn 2009.

Weed and Crop Assessments

In five of six replicated trials above ground dry matter of weeds and crop were determined in one 0.25 m^2 sectioned quadrat per plot in late summer of the first trial year and again in the following spring. At the remaining site (Barrington Park), weed and crop species were assessed for percentage cover four times during the trial duration. Cover estimates were performed either on a per plot basis or with two 0.25 m^2 sectioned quadrats per plot.

In the on-farm trials, all weed and crop cover assessments were carried out with a 0.25 m^2 sectioned quadrat. Four such areas were assessed within each treatment, i.e. both in the ASM strip and in an adjacent strip of the control ley, resulting in eight assessment points per farm and sample date. At least 10 m were left between any two assessment points. Two assessments were carried out per farm, one several weeks after sowing in 2009, and another one in the following year at a similar time.

In some cases, plants could not be identified to species level and were assessed as a species-group. For example, docks (*Rumex spec*.), could not always be assigned to *R. crispus*, *R. obtusifolius* or the hybrid *R. crispus* x *obtusifolius*. In such cases, all docks were summarized under *Rumex spec*.. However, where differentiation was possible, *R. obtusifolius* was the most dominant taxon. Volunteer crops, such as potato (*Solanum tuberosum*), wheat (*Triticum* *aestivum*) and oats (*Avena sativa*), which were encountered in weed assessments were excluded from further data analysis.

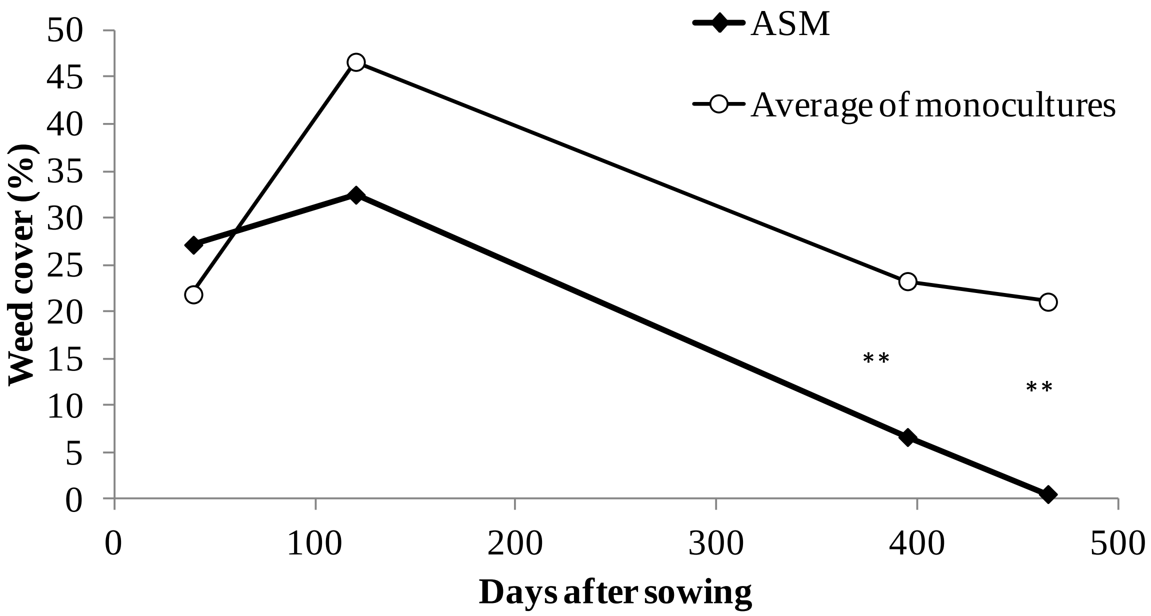
Table 1: Details of participatory trials: geographic coordinates and soil properties

Farm no.	North	West	Elevation (m)	Soil texture	Soil pH
1	52°21'36.7"	-1°21'9.2"	51	Clay	7.4
2	52°37'50.2"	-0°20'42.7"	1	Clay	7.6
3	52°8'28.2"	0°2'57.2"	45	Clay Loam	8.2
4	52°31'17.4"	0°9'46.4"	0	Clay Loam	6.7
5	51°29'47.9"	1°3'30.2"	52	Clay Loam	6.0
6	51°27'1.7"	1°9'39.6"	99	Clay Loam	7.2
7	52°22'1.6"	1°24'47.4"	73	Clay	6.6
8	51°31'5.7"	1°27'25.9"	162	Clay Loam	8.0
9	51°18'56.3"	1°31'9.3"	170	Clay Loam	7.6
10	51°22'49.1"	1°32'3.7"	125	Clay Loam	7.4
11	51°26'28.0"	1°54'5.7"	164	Silty Loam	7.1
12	51°43'56.3"	1°56'21.4"	135	Silty Clay	7.7
13	57°16'52.6"	2°7'56.9"	97	Sandy Loam	5.5
14	57°11'5.6"	2°12'45.1"	109	Sandy Loam	5.8
15	57°33'3.0"	2°18'0.5"	120	Clay Loam	5.7
16	57°18'38.4"	2°18'29.9"	194	Clay Loam	6.2
17	57°40'16.5"	3°16'30.7"	20	Loamy Sand	6.3
18	53°0'38.7"	3°38'48.1"	309	Silty Loam	4.9
19	52°37'45.6"	4°5'1.0"	56	Sandy Loam	6.2
20	52°2'44.3"	4°35'59.4"	70	Silty Clay	4.9
21	51°48'22.5"	5°4'5.4"	85	Clay Loam	5.9

RESULTS

Weed Suppression by Individual Legume and Grass Species and the All Species Mixture in Replicated Trials

When cover estimates at the Barrington Park site were analysed, weed cover was significantly lower in the All Species Mix (ASM) than in the average of the monocultures of the ASM component species on the two later assessment dates (Figure 1), and there was a similar trend for the second assessment date ($p<0.1$). The ASM was also among the highest best ranking trial entries regarding the weed biomass as a proportion of total biomass (Table 2). While red clover (*Trifolium pratense*), white clover (*T. repens*) and black medic (*Medicago lupulina*) showed good abilities to suppress weeds, large birdsfoot trefoil (*Lotus pedunculatus*), white sweet clover (*Melilotus alba*), meadow pea (*Lathyrus pratensis*) and winter vetch (*Vicia sativa*) performed poorly regarding this parameter. The advantage of the ASM in terms of weed suppression increased over time (Table 2, Figure 1).



** Indicate where the difference between ASM and average of monocultures is significant (p<0.01). Trial details see Döring *et al*. (2012).

Figure 1: Weed cover assessments the All Species Mix (ASM) and the average of the monocultures at the Barrington Park trial site

Weed Community Composition in On-farm Trials

In the first year of the ley (2009), the most frequently encountered weed species were chickweed (*Stellaria media*), sowthistle (*Sonchus arvensis*), and field speedwell (*Veronica persica*). These very common species, as well as the majority of other weed species found on the farms, are typical annual weeds of arable fields. In the second year of the ley, almost all annual species decreased in frequency and cover. Conversely, some perennial species slightly increased in frequency from the first to the second year, e.g. dandelion (*Taraxacum officinale agg*) was present on 7.7% and 13.1% of sampled quadrats in 2009 and 2010 respectively

Weed Diversity in On-farm Trials

In total, 63 weed species were recorded on the organic leys. With a total of 56 weed species found in the first year of the ley, the species richness was twice as large as in the second year, when only 28 species were recorded. Similarly, the number of weed species per farm was 11.9±1.6 and 3.8±0.7 in the first and second year respectively (average ± standard error). The total number of weed species found on each farm, in both years combined, ranged from 3 to 27. Weed species numbers between the first and the second years of the study were uncorrelated (Adjusted R^2=0.079, p=0.137), i.e. farms with a higher number of weed species in the first year did not necessarily tend to have a higher species number in the second year as well.

Geographic, Soil and Management Factors Affecting Weeds in On-farm Trials

In the replicated plots as well as the on-farm trials, weed cover was lower in the second year than in the first year, owing to a decrease of annual weeds over the two years. On the farms, weed diversity did not correlate with the crop species diversity in the ley (Adjusted R^2=0.007, p=0.247), indicating that increasing the number of species within in a ley mixture does not compromise the conservation of wild farmland plants. Interestingly, on farms where soil samples showed relatively high organic matter contents (i.e. values above the average of 5.3%), a significantly lower number of weed species was found than on farms with below-average organic matter contents (9.2±1.6 vs. 20.0±2.6 species, p<0.01, df=10). The number of weed species was lower in the more Northern farms than further South.

Table 2: Weed suppression ranks determined by weed dry matter as a proportion of total dry matter (crop + weed), determined over five trial sites. Low ranks mean low proportions of weed biomass. ND = not determined

	Species	Rank	
		Late summer year 1	Spring year 2
ASM	Inoculated ASM	2	1
	Non-inoc. ASM	3	2
Legumes	Alsike Clover	12	12
	Black medic	4	5
	Birdsfoot trefoil	10	13
	Crimson Clover	11	11
	Large birdsfoot trefoil	18	15
	Lucerne	8	6
	Meadow pea	17	ND
	Red clover	5	4
	White sweet clover	16	16
	Sainfoin	13	14
	White clover	7	3
	Winter vetch	15	ND
Grasses	Italian ryegrass	1	7
	Meadow fescue	9	10
	Perennial ryegrass	6	8
	Timothy	14	9

DISCUSSION

This study addresses two contrasting aspects of weeds in the rotation, namely weed control and weeds as constituents of farm biodiversity. It highlights, therefore, the potential conflict between agronomic and biodiversity aspects of agricultural production.

Our results show that using species mixtures in the ley phase can help to improve weed control. Importantly, mixing species with phenological complementarity can simultaneously provide benefits for pollinators (Brown *et al*., 2012). At the same time, our analysis shows that there is a degree of redundancy in the ASM, where some species (such as meadow pea) perform too poorly to warrant an inclusion in the mixture. Thus, mixtures with fewer species, but with complementary functions, may optimise weed management in leys.

On the other hand, our on-farm trials show that weed diversity as a component of farm biodiversity does not suffer from including more crop species in the ley. Weed diversity in the ley is more likely to be influenced by the history and geography of any particular site. In the first year of establishment, leys may be seen to provide a niche for arable weeds. For the later stages of the ley, whilst annual weed numbers decline, the challenge remains to control problem perennial weeds such as creeping thistle (*Cirsium arvense*) and docks (*Rumex spp*.). These species are again mostly influenced by site history as well as farm management and are likely to be relatively unaffected by the choice of species in a ley mixture.

As we have shown, leys can be designed through species mixes for optimizing weed control while protecting weed diversity. Further research is needed to show how far additional functions can be integrated in the choice of species.

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