Diversity of perennial legume-grass mixture influences the delivery of ecosystem services in organic arable cropping systems

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1 Introduction

Integration of perennial forage legume- and grass-based grasslands into arable cropping systems has demonstrated a great potential to enhance sustainable production and multifunctionality of agricultural systems [1]. However, cropping systems in Europe are largely dominated by cereals, and perennial crops are rarely included in intensive stockless cropping systems even though they may be highly valuable in a bio-based economy, e.g. for biorefining of proteins and sustainable production of bioenergy carriers [2]. We performed a three-year field experiment with perennial forage legume and grass mixtures integrated in an organic arable cropping system, with the aim to determine how species choice and composition of perennial forage legumes and grasses, other than those commonly used in forage production, and cutting frequency would influence dynamics of biomass production, weed abundance and pre-crop value to a subsequent cereal crop.

2 Materials and Methods

The field experiment was carried out in an arable organic cropping system in Alnarp, Sweden (55°13′ N, 13°4′ E). The experiment was initiated in the spring 2010 by under-sowing four forage legume species; *Medicago sativa* (MS), *Melilotus officinalis* (MO), *Lotus corniculatus* (LC) and *Trifolium repens* (TR), and four grass species; *Phleum pratense* (PP), *Dactylis glomerata* (DG), *Festuca pratensis* (FP) and *Lolium perenne* (LP) as pure stands and mixtures of varied composition (Table 1) in oat (*Avena sativa*). The species mixtures were established in a replacement design, based on equal proportions relative to each species sowing density in pure stand. The oat was harvested in September 2010 and species mixtures were investigated in the first and second production years (2011 and 2012) under low (two cuts in both years) and high (four cuts in 2011 and three cuts in 2012) cutting frequencies. At each cut, above-ground biomass was manually sampled, sorted into legume, grass and unsown (weed) functional groups, dried at 60 ˚C and weighed. Finally, pre-crop value of the species and mixtures (without distinguishing between cutting frequencies) was determined in terms of grain yield of a subsequent spring wheat crop sown in spring 2013. The effects of species identity and mixture composition and cutting regime on measured variables was determined with analysis of variance (ANOVA) and TukeyHSD function in the R open source software.

3 Results

The total biomass yield, summed up for all cuts during the two years, was as high in mixtures as in the most productive legume or grass pure stand (Table 1). Weeds were suppressed in mixtures compared to most legume pure stands, especially under high cutting frequency. A six species mixture composed of three forage legumes and three grasses showed promising yield under both cutting strategies, reflecting a positive effect of diverse legume-grass mixtures in utilizing above-and below-ground resources. The species mixtures appeared to be more tolerant to high cutting frequency, especially when compared to pure stands of legumes (except LC). Yields of subsequent spring wheat ranged from 4 to 6 t grain ha^{-1} yr^{-1} (Table 1). Pure stands of legumes had higher pre-crop value to spring wheat than pure stands of grass and legume-grass mixtures, with the highest grain yield after pure stand of LC. The MS+PP, LC+PP and the four species mixture also showed a good pre-crop effect, comparable to most legume pure stands (with the exception of LC).

Table 1: Total biomass yield and weed biomass in pure and mixed stands of legumes and grasses in a two-year sequence (sum of all cuts in 2011 and 2012), and grain yield of subsequent spring wheat in 2013. Values are means of four replicates. Within each column, values followed by the same letter are not significantly different ($p<0.05$)

Species composition	Biomass production (ton DM ha^{-1})		Weed biomass (ton DM ha^{-1})		Wheat grain yield (ton ha^{-1})
	2 cuts/yr	3 or 4 cuts/yr	2 cuts/yr	3 or 4 cuts/yr	
Legume pure stands					
Medicago sativa (MS)	18.3 def	11.5 acd	1.9 ab	5.2 de	5.2 bcde
Melilotus officinalis (MO)	6.7 a	7.4 a	5.0 c	5.5 e	5.5 cde
Lotus corniculatus (LC)	14.2 cde	12.8 bcd	2.7 abc	3.6 bcde	6.2 e
Trifolium repens (TR)	6.9 ab	9.1 ac	4.2 bc	3.9 cde	5.7 de
Grass pure stands					
Phleum pratense (PP)	13.1 cd	13.9 bcd	2.8 abc	3.2 abcde	4.3 ab
Dactylis glomerata (DG)	12.8 bcd	13.0 bcd	0.3 a	0.7 a	4.2 a
Festuca pratensis (FP)	13.9 cde	13.5 bcd	1.9 ab	2.5 abcd	4.6 abc
Lolium perenne (LP)	11.6 abc	12.9 bcd	1.3 ab	1.9 abc	4.6 abc
Mixtures					
MS + DG	19.2 ef	16.1 bd	0.2 a	0.4 a	4.8 abcd
MS + PP	21.2 f	16.1 bd	0.8 a	1.9 abc	5.1 abcd
MO + PP	14.8 cde	14.3 bd	1.4 ab	1.8 abc	4.6 abc
LC + PP	17.4 cdef	16.8 b	1.7 ab	1.8 abc	5.0 abcd
TR + PP	16.4 cdef	16.0 bd	1.6 ab	1.6 abc	4.9 abcd
MO + MS + DG + PP	18.7 def	16.0 bd	1.6 ab	2.2 abc	5.0 abcd
MO + MS + TR + DG + FP + PP	19.2 ef	17.7 b	0.6 a	0.8 ab	4.4 ab
LC + MO + MS + TR + DG + FP + LP + PP	17.4 cdef	16.1 bd	0.6 a	0.7 a	4.7 abcd

4 Discussion and conclusions

Species mixtures had different effects on the evaluated ecosystem services, with the advantage of species diversity for biomass production and weed reduction being most pronounced in the six-species legume-grass mixture under both cutting strategies. However, when considering the pre-crop value, the two- four- and eight-species mixtures appeared more promising. This is an important insight about tradeoffs between different ecosystem services that need to be considered when designing diversified forage mixtures as multifunctional components of arable cropping systems. The study also highlights possibilities to optimize plant diversity for soil fertility build-up via legume N_2 fixation, resource-efficient biomass production, and weed reduction. These findings are in line with principles of agroecology, *e.g.* promoting crop diversity and multifunctionality while considering synergies and tradeoffs between different ecosystem services provided by diverse legume-grass mixtures in arable organic cropping systems.

References

1. Lüscher, A., et al., Potential of legume-based grassland–livestock systems in Europe: a review. *Grass and Forage Science, 2014.* ***69****(2): p. 206-228.*
2. Jensen, E.S., et al., Legumes for mitigation of climate change and the provision of feedstock for biofuels and biorefineries. A review. *Agronomy for Sustainable Development, 2012.* ***32****(2): p. 329-364.*