Designing high-yielding, high-diversity and low-input temporary grasslands

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Abstract. Species-rich swards have received increasing interest due to their focus on ecosystem services, animal welfare and product quality. However, in high-yielding swards the proportion of herbs is often limited and there is little knowledge of their management. Seed mixture composition, cutting frequency, fertilization and grazing/cutting strategies were examined over 4 years in 3 experiments to quantify their effects on herbage yield and botanical composition. Inclusion of herbs in the sward gave similar or higher annual yields but swards established with 100% herbs depended on the presence of a driver species. The effects of management differed between species. Herb content in the sward was significantly related to the proportion of herbs in the seed mixture, whereas botanical composition was related to defoliation frequency. Continuous grazing with heifers reduced the proportion of herbs, relative to cutting, and reduced the competitiveness of ribwort plantain, caraway and lucerne, whereas chicory was unaffected. Fertilization with cattle slurry reduced the proportion of legumes and increased most of the non-leguminous species. Herb proportions changed over the 4 years, with plantain decreasing and caraway increasing. Growing weak competitors together, such as salad burnet and dandelion, with one legume showed possibilities for improving the proportion of these species in the sward. In general, it was possible to maintain diversity in the swards but with changing botanical composition over years. However maintaining weak competitors requires a special planting design.

Keywords: Temporary grasslands, multi-species, biodiversity, herbs, management.

Introduction

High yielding temporary grasslands are composed of highly competitive grass and clover species such as perennial ryegrass (*Lolium perenne* L.), festulolium (*Festulolium braunii* K.A.), red clover (*Trifolium pratense* L.) and white clover (*T. repens* L.). In such grasslands there is usually a low proportion of unsown species. However, there is in general a high focus on increasing biodiversity in grasslands with the aim of increasing ecosystem services. Increasing diversity by including other species necessitates that they are competitive and able to find their specific niches in the sward. Alternatively, weak species could be grown in separate smaller areas with lower competition from companion species.

In this paper we present results from 3 experiments with different management of herbs (non-traditional grassland species) sown together with traditional grassland seed mixtures. We hypothesize that it is possible to obtain high plant diversity in high-yielding temporary grasslands (up to 4 years) by tailored management. Lucerne (*Medicago sativa* L.) is here considered as a herb, as it is normally grown in pure stands.

Materials and methods

Three plot experiments (Experiment 1, Experiment 2 and Experiment 3) were established at the Research Centre Foulum, Denmark (9°34'59 E, 56°29'22 N) with different seed mixtures (Table 1). In Experiment 1, 4 mixtures were established in 2008 and cutting frequency (4 vs. 6 cuts) was compared at 2 fertilizer levels (0 and 200 kg total N/ha in cattle slurry). In Experiment 2, 3 mixtures were established in each of 4 years (2007-10) and a 4-cut regime was compared with heifers grazing continuously to 5 cm at 2 fertilizer levels (0 and 100/200 kg total N/ha in cattle slurry in grazing/cutting). In Experiment 3, 6 mixtures were established in 2011 and the different seed mixtures were compared under management treatment consisting of 4 cuts and no fertilizer. A total seeding rate of 25-26 kg/ha was used, and the mixtures were under-sown in spring barley that was harvested at maturity. The following years are denoted as 1-yr-old, 2-yr-old etc. Dry matter (DM) yield and botanical composition were determined. Plots were harvested with a Haldrup plot harvester to a stubble height of 7 cm. Measurements in the grazed plots in Experiment 2 were made in subplots fenced off in the same growth periods as cuts 1 and 3. Botanical composition was determined at each cut by oven-drying the harvested material after it had been separated by hand into the individual sown and unsown species. Plots were irrigated during short-term drought periods. Experiments 2 and 3 used a completely randomized block design, while Experiment 1 used a split-split-plot design with fertilization treatments in the main plots, seed mixtures in subplots

Table 1. Seed rates (weight %) of the individual species for different mixtures in Experiments 1-3.

Experiment	1 (2009-11)				2 (2007-10)			3 (2012)					
Mixture	1.1	1.2	1.3	1.4	2.1	2.2	2.3	3.1	3.2	3.3	3.4	3.5	3.6
Traditional species													
Perennial ryegrass (PRG)	81	68	42	0	82	66	28						
Festulolium (FES)							31						
White clover (WC)	14	12	8	0	15	12	5						
Red clover (RC)					4	3	1			2			2
Herbs													
Lucerne (LU)	0.4	2	5	10			15		6			6	
Melilot (ME)	0.4	2	5	10									
Birdsfoot trefoil (BT)	0.8	4	5	10		2	2	50			50		
Caraway (CA)	0.4	2	5	10		3	3						
Chicory (CHI)	0.4	2	5	10		3	3						
Chervil (CHE)	0.4	2	5	10		2	2						
Dandelion (DA)											50	94	98
Fenugreek (FEN)	0.8	1.4	10	20									
Ribwort plaintain (PL)	0.4	0.8	2.4	5		3	3						
Sainfoin (SA)						3	3						
Salad burnet (SB)	0.8	4	5	10		3	3	50	94	98			
% herb of total	5	20	50	100	0	25	35						

Table 2. Yield and botanical composition of mixture components in Experiment 2 (mean of 1-4 year old swards): (a) comparing N treatments; and (b) comparing cutting vs. grazing effects. See Table 1 for abbreviations. PRG includes *Festulolium* in mix 2.3

Mixture	Treatment	Yield (t DM/ha)	Botanical composition (% of DM)									
			PRG	WC	RC	LU	CHI	PL	CA	SB	BT	Unsown spp
Yearly mean (4 cuts per year)												
Mix 2.1	0N	11.7 c	44 b	26 a	29a							2 b
	200N	12.8 b	60 a	19 ab	19b							3 a
Mix 2.2	0N	11.7 c	24 c	22 ab	26a		8 b	13 a	6 a	0.2	0.7 a	0.7 c
	200N	13.3 ab	38 b	14 bc	18b		11 a	10 b	7 a	0.1	0.2 b	2 b
Mix 2.3	0 N	12.7 b	21 c	12 c	10c	38a	5 c	9 b	4 b	0.2	0.5 ab	0.9 c
	200N	13.7 a	38 b	8 c	6c	25b	8 b	7 c	6 a	0.4	0.2 b	2 b
Mean of cut 1 and cut 3												
Mix 2.1	Cut	4.2 b	45 b	21	33 a							1
	Grazing	4.5 a	55 a	24	20 b							1
Mix 2.2	Cut	4.1 b	24 b	15	29 a		9	15 a	6 a	0.3	0.8	0.5
	Grazing	4.6 a	48 a	17	17 b		7	8 b	2 b	0.3	0.6	0.4
Mix 2.3	Cut	4.4 b	27 b	9 b	11	30 a	6	11a	4 a	0.4	0.5	0.3 b
	Grazing	4.8 a	49 a	16 a	12	4 b	8	7b	3 b	0.3	1	0.7 a

Different letters within columns and within mix show significant differences (P<0.05).

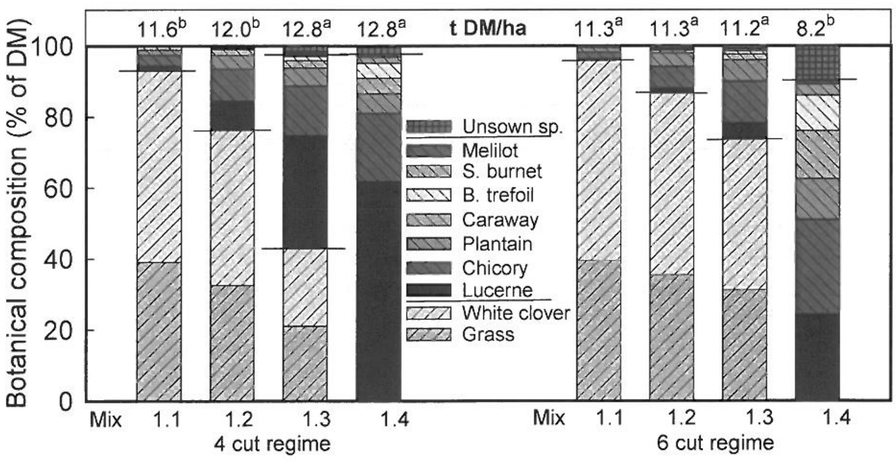

Figure 1. Mean botanical composition (% of DM) and annual yield (t DM/ha) of mixture components in Experiment 1. Different letters in yield data within each cutting frequency show significant differences (P<0.05).

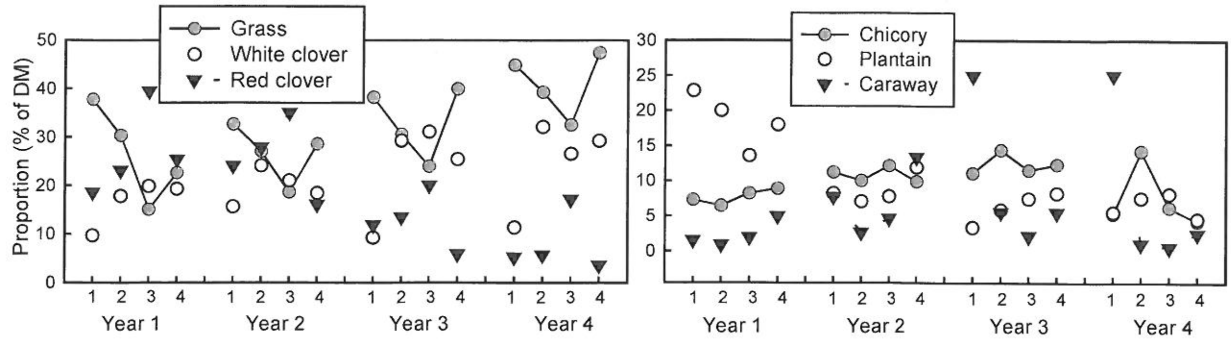

Figure 2. Botanical composition throughout the season (cuts 1-4) over 4 years in mix 2.2 of Experiment 2. Annual yields were 13.5, 12.9, 10.9 and 10.6 t DM/ha for Years 1, 2, 3 and 4, respectively.

and cutting regimes in sub-sub-plots. There were 2 replicates in Experiments 1 and 2, and 3 replicates in Experiment 3.

Results and discussion

The experiments showed a clear grouping in competitive strength of the examined plant species. Strong competitors (drivers) included perennial ryegrass, festulolium, white clover, red clover and lucerne. Moderate competitors included chicory (*Chicorium intybus* L.), ribwort plantain (*Plantago lanceolata* L.) and caraway (*Carum carvi* L.). Weak competitors included birdsfoot trefoil (*Lotus corniculatus* L.), dandelion (*Taraxacum officinale* agg.), melilot (*Melilotus officinalis* L.) and salad burnet (*Sanguisorba minor* Scop.), while very weak competitors included (*Anthriscus cerefolium* L.), fenugreek (*Trigonella foenum-graecum* L.) and sainfoin (*Onobrychis viciifolia* Scop.).

The herbs, without lucerne, mostly competed with grasses under cutting, with grass proportion decreasing from 52% to 31% of DM and red and white clover combined decreasing from 47% to 40% of DM (Table 2a). Inclusion of lucerne suppressed the clovers more than the grasses (Table 2a).

Sowing rate and cutting frequency

Increasing the proportion of herbs in the seed mixture increased their proportion in the herbage (Fig. 1). In the 4-cut regime the proportion of herbs in the herbage was similar to that in the seed mixture, whereas in the 6-cut regime herbage proportion was significant lower, particularly for lucerne. This compares with the 4-cut regime, where lucerne was a driver with high competitive strength (Fig. 1, Table 2). This was reflected by DM yield, as inclusion of lucerne increased the 4-cut regime yield of plots with 50% and 100% herbs, whereas yield was lower in the 100% herb plots in the 6-cut regime, where no driver species were present.

Fertilization

Slurry application increased yields but decreased the proportion of legumes (Table 2a). The proportion of chicory increased significantly with slurry and caraway also increased in mix 2.3, whereas plantain decreased. Fertilization had the same effects under grazing (data not shown). However, in contrast to Plantureux *et al.* (2005), fertilization did not reduce species number.

Grazing vs. cutting

Grazing with heifers considerably increased mean grass proportion compared to cutting (from 32% to 51% of DM), whereas red clover and lucerne were repressed by grazing (Table 2b). Grazing did not affect chicory, while the proportions of plantain and caraway decreased (Table 2b). In mix 2.2 (without lucerne) grazing decreased the herb proportion from 31% to 18% of DM.

Persistence and seasonal profile

Over the 4-year study period, cutting led to an increase in the proportions of grass and white clover and a decrease in red clover (Fig. 2). As expected for traditional grass/clover swards, the proportion of grass was high in spring and autumn and low in summer (the opposite of the clovers). Herb proportion did not change significantly, but persistence of the different herbs did. Plantain decreased with time, as found by Sanderson *et al.* (2003), and other weak competitors also decreased (data not shown), while chicory remained relatively constant, in contrast to findings by Li and Kemp (2005). Caraway, however, had a low proportion in 1-yr-old swards, but increased markedly in 3- and 4-yr-old swards, comprising up to 25% of herbage DM in spring (Fig. 2).

Improved conditions for weak competitors

To examine options for improving the conditions for weak competitors, dandelion and salad burnet were sown in mixtures with a legume without grass. The seeding rates of red clover and lucerne were kept low, in order to reduce competition. Highest yields were obtained with red clover as the companion legume, even with a seeding rate of only 0.5 kg/ha (Table 3). Birdsfoot trefoil was a weak competitor in mixtures, even with another weak competitor. Dandelion had high proportions in all cuts (17-39% of DM), while salad burnet decreased from 42% to 7% of DM over the season and was invaded by unsown species. The highest invasion was in mix 3.1 (birdsfoot trefoil + salad burnet), where the proportion of unsown species increased from 9% to 75% of DM (cuts 1-4). Mix 3.6 (red clover + dandelion) had the lowest invasion, with 2-4% of unsown species.

We hypothesized that it is possible to obtain high plant diversity in high-yielding short-term grasslands. Our hypothesis was confirmed for species richness, as very few species disappeared. However, only 4 species (CA, CHI, PL and LU) accounted for most of the herbage, whereas other species (BT, DA, ME, SB) only comprised a small part. This indicates that these species co-exist in an unstable manner, with no sign of recovery from their decline (Chesson 2000). To increase their proportion, an alternative field design could be developed with separate areas of low competition from companion species. However, such areas would decrease total yield of the field.

In general, a higher proportion of herb seeds in the seed mixtures increased their proportion in the sward. However, lucerne was a very strong competitor, even with a low amount of seeds, in the 4-cut regime. Therefore, the success of lucerne establishment would strongly affect the subsequent botanical composition of the pasture. Management factors such as fertilizer, cutting/grazing and cutting frequency influenced the herb species differently and the persistence and seasonal profile of the species was highly variable. Thus, achieving a sward with a constant proportion of the main species is difficult.

Conclusion

High-diversity short-term grasslands were obtained without compromising their annual dry matter production. However, the results reveal the importance of balancing dominant and non-dominant species during establishment. Designing grasslands with strong herb competitors (together with grass and clover) and weaker herbs (together with weak legumes or sparsely sown competitive legumes) in separate areas could introduce a significant proportion of herbs in the herbage. However, further testing of such mixtures is required before they can be recommended for commercial use.

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