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Impacts of cropping system and management practices on the assembly of weed communities

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Summary

Understanding how weed communities assemble as a function of biotic and abiotic filters and transform through time has important implications for the sustainable management of agronomic systems. In a three-year study, we evaluated weed community responses to lucerne (*Medicago sativa*, perennial) vs. continuous spring wheat (*Triticum aestivum*, annual, CSW) and weed management practices where weeds in the CSW system were managed with three contrasting approaches (herbicide, tillage or sheep grazing). Our results indicated no differences in weed diversity between the perennial and annual crops or across the different management practices in CSW. However, there were differences in weed community composition. Lucerne, with the exception of the establishing year, impeded the growth and reproduction of several annual weeds, including *Amaranthus retroflexus*, *Thlaspi arvense*, *Lamium amplexicaule* and *Chenopodium album*, but favoured perennial broad-leaved weeds such as *Taraxacum officinale* and *Cirsium arvense*. The replacement of herbicide treatments in pre-plant and post-harvest in CSW with soil tillage or sheep grazing selected for different weed communities beyond the second year of establishment. The weed species driving the differences in CSW systems were *Androsace occidentalis*, more common in CSW managed chemically; *Asperugo procumbens*, more common in CSW managed with tillage; and *T. officinale* and *Lactuca serriola*, more common in CSW managed with sheep grazing. Understanding how cropping systems modify weed communities is a necessary step to shift from reactive weed control programmes to predictive management strategies.

Keywords: lucerne, diversity, community assembly, spring wheat, weed management, sheep grazing, soil tillage, herbicides, annual crops, perennial crops.

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Introduction

Farmers have known for thousands of years that crop rotation and management practices modify weed abundance, pressure and community characteristics. Despite this empirical knowledge, only recently have scientists begun to formally evaluate the mechanisms responsible for such changes and their implications in the development of ecologically based weed management practices (Zimdahl, 1999). Within this framework, Booth and Swanton (2002) proposed that community assembly theory could provide a template

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to explain spatio-temporal changes occurring in weed communities as a function of management practices and species availability.

Community assembly theory (Diamond, 1975) explains how communities are built from a regional pool of species and get shaped by constraints acting as abiotic (e.g. environmental conditions, management practices) or biotic (e.g. competition, insect abundance, pathogen pressure) ecological filters. The net effect of these filters determines changes in the assembly dynamics of a community. From an applied perspective, determining how ecological filters modify community assembly dynamics can help explain shifts in weed communities as a function of management practices, such as time of tillage, organic vs. conventional practices and crop rotation (Ryan *et al*., 2010; Fried *et al*., 2012).

Perennial forage crops such as lucerne (*Medicago sativa* L.) are characterised by reduced soil disturbances, due to the absence of soil tillage, increased aboveground disturbances caused by repeated cuttings, extended competition throughout the year and a deep root system. (Bagavathiannan *et al*., 2012). In contrast, annual crops such as wheat (*Triticum aestivum* L.) require repeated disturbances, such as seedbed preparation, precisely timed inputs and management, and have comparatively less extensive root systems (Thorup-Kristensen, 2006). Consequently, these two systems might act as contrasting ecological filters, impacting the assembly trajectory of weed communities. This differential impact can be further modified by the specific weed management practices applied to each cropping system. For example, increased use of glyphosate has led to a decline in *Elymus repens* (L.) Gould., a perennial weed that invades non-ploughed fields (Salonen *et al*., 2013). Similarly, a reduction in tillage has been associated with increased abundance of annual grass weeds and perennial grass and broad-leaved weeds (Thomas *et al*., 2004). Finally, organic systems have been associated with an overall increase in weed abundance and diversity (Menalled *et al*., 2001; Pollnac *et al*., 2009).

While many farmers rely on herbicides or tillage to reduce weed pressure (Smith *et al*., 2007), increased awareness of the ecological and environmental impacts of intensive reliance on these management practices has driven interest in identifying alternative cropping systems. The re-integration of crop and livestock production offers the potential to improve the sustainability of farming systems by managing weed and insect pest populations, improving soil quality, increasing yield, augmenting pollinator populations and improving land use efficiency (Hilimire, 2011). While effects of mixed crop and livestock systems on farm productivity and profitability have been documented (Tracy & Davis, 2009; Miller *et al*., 2014), the role that animal grazing could have as a filtering factor conditioning the assembly of weed communities is largely unknown. The goal of this study was to evaluate the impact of cropping system (a perennial [lucerne] vs. an annual (continuous spring wheat, CSW) and contrasting weed management practices in CSW (mechanical, chemical and sheep grazed) on weed abundance, diversity and community composition.

Materials and methods

Site description and history

This study was conducted over 3 years (2009–2011) at the Fort Ellis Research and Extension Center, Montana State University, near Bozeman, Montana (45°40′N, 111°2′W, altitude 1468 m). Soils at the site are a Blackmore silt loam (a fine-silty, mixed, superactive, frigid Typic Arguistoll) with 0–4% slopes and consists of a 1:1:2 mixtures of sand, clay and silt by weight. Soils at the area generally contain sufficient levels of plant available P and K (>16 and 250 ppm for P and K respectively) and only require N fertilisation. Soil pH ranges from moderately acidic to slightly alkaline (5.5–7.5). Historical mean monthly temperatures (120 years) vary from −5.7°C in January to 19.0°C in July and annual precipitation averages 453 mm.

Between 1994 and 2004, the entire site was used for pasture and consisted of a mixture of perennial grasses including *Bromus inermis* L., *Thinopyrum intermedium* (Host) Barkwiorth & DR Dewey and *Poa compressa* L. Between 2004 and 2008, wheat was grown at this site in a randomised split-plot design with three blocks and different weed management practices (sheep grazing, herbicide treatment and tillage) applied to main plots, and crops (CSW, spring wheat-fallow, and winter wheat-fallow) assigned to subplots.

Experimental design

Based on the design used by Sainju *et al*. (2011), this study had main plots as weed management practice (sheep grazing, herbicide treatment and tillage) and subplots as crop (CSW, var. Vida and lucerne, var. Shaw). Hereafter, the combination of weed management practice and crop will be referred to as ‘cropping system.’ Main plots, replicated three times, were 0.34 ha (45 × 75 m) and had five 0.07 ha (45 × 15 m) subplots. To minimise the potential impacts of crop legacies from the previous study, subplots in this study were assigned based on previous cropping system and management practices. Specifically, in 2009, subplots that were CSW since 2004 were continued as CSW, and subplots that had been in the spring wheat phase of a spring wheat-fallow rotation were assigned to lucerne. Our research was conducted on the CSW subplots where weeds were managed chemically (CSW-C), mechanically (CSW-T) or by sheep grazing (CSW-G). Only the lucerne subplots in the main plots that were chemically managed were included in this study. This experimental design allowed us to assess the impact of two different monocultures [spring wheat (annual species) vs. lucerne (perennial species)] and weed management practices (chemical, tillage and grazing) on weed communities.

Management practices

All CSW subplots were fertilised based on residual nitrogen and projected yield goals (Dinkins & Jones, 2007). Prior to planting, CSW subplots were fertilised to 202 kg ha^{-1} of nitrogen (based on soil sample analyses) as granular urea using a Gandy spreader and tilled with a John Deere 100 field cultivator fitted with 15-cm-wide sweeps for seedbed preparation. Planting dates were 19 May 2009, 17 May 2010 and 16 May 2011. Spring wheat was seeded at 15-cm row spacing at seeding rates of 89.7 kg seed ha^{-1}. Lucerne was seeded in 2009 at 40 kg seed ha^{-1} and mowed twice per year in 2009 and 2010, and once in 2011 when stem height reached 40 cm and basal regrowth was evident. Mowing dates were 10 and 21 July and 15 August for the first cut in 2009, 2010 and 2011, and 12 August and 4 October for the second cut in 2009 and 2010 respectively.

In the CSW subplots, different management practices were used for both pre-planting and post-harvest weed control and residue management (Table 1). As pre-planting practices, CSW-C subplots received a herbicide application (glyphosate at 416 g a.i. ha^{-1} and dicamba at 281 g a.i. ha^{-1}) 0–4 days before seeding. In CSW-G subplots, pre-planting weed management was achieved through grazing by white-faced sheep during a one- to two-week period prior to seeding, although this practice was not conducted in 2009 due to low weed pressure. Stocking rates (mean of 260 sheep days ha^{-1}) varied slightly depending on weed pressure and precipitation. Sheep grazing continued until weed biomass was reduced below 5% ground cover, based on visual assessment. Sheep grazing was also used post-harvest in these subplots for residue reduction, except in 2009. CSW-T subplots did not receive additional pre-plant weed management, but additional soil tillage with an EZ off-set disk was conducted in late September 2010 and 2011. Finally, wheat straw in CSW-C and CSW-T subplots was windrowed and bailed following harvest, and residues were incorporated with an EZ-off set disk.

Based on weed pressures, lucerne and CSW crops received post-emergence in-crop herbicides. Lucerne subplots were treated with ammonium salt of imazethapyr (63 g a.i. ha^{-1}) on 7 July 2009 and received no additional herbicide in 2010 and 2011. In 2010, all CSW subplots were sprayed with a tank-mixture of dicamba and pinoxaden (140 g a.i. ha^{-1} + 30 g a.i. ha^{-1}) 4 weeks after seeding, and in 2011, they were sprayed with pinoxaden (73 g a.i. ha^{-1}) 6 weeks after seeding.

Table 1 Summary of cropping systems and management practices applied to continuous spring wheat (CSW) and lucerne subplots

Cropping systems	Managements practices	Pre-plant agronomic practices	Post-emergence agronomic practices	Post-harvest agronomic practices
CSW	Chemical	Glyphosate and dicamba tank mix applied at 416 g a.i. ha^{-1} and 281 g a.i. ha^{-1}	Pinoxaden applied at 74 g a.i. ha^{-1} (2011) Tank-mixture of dicamba and pinoxaden at 140 g a.i. h^{-1} + 30 g a.i. ha^{-1} (2010)	Residues incorporated with tillage
	Mechanical	Tilled with a John Deere 100 field cultivator fitted with 15-cm-wide sweeps (shallow tillage)	Pinoxaden at 74 g a.i. ha^{-1} (2011) Tank-mixture of dicamba and pinoxaden at 140 g a.i. h^{-1} + 30 g a.i. ha^{-1} (2010)	Residues incorporated with tillage Soil tillage post-harvest with an off-set disk
	Graze	Grazing*:176–344 sheep days ha^{-1}	Pinoxaden at 74 g a.i. ha^{-1} (2011) Tank-mixture of dicamba and pinoxaden at 140 g a.i. h^{-1} + 30 g a.i. ha^{-1} (2010)	Grazed residues* 659–806 sheep days ha^{-1}
Lucerne	Chemical	Glyphosate and dicamba applied in the first year (2009)	Ammonium salt of imazethapyr at 63 g a.i. ha^{-1} (2009)	

*Practice not applied in 2009.

Data collection

Weed percentage cover by species in all subplots was estimated at approximately two-week intervals from June to late August in 2009, and from May to late August during the 2010 and 2011 growing seasons. For each sampling date, three 1-m^2 quadrats were randomly placed in each subplot. Within each quadrat, visual estimates of percentage cover per species were recorded and values were averaged per species within subplots and across sampling dates to provide a comprehensive measure of the impact of cropping systems on weed community characteristics.

Statistical analysis

Weed species abundance and diversity Species richness (total species number, SR) and Simpson's diversity index (D) were calculated in each subplot. Simpson's diversity index was calculated as:

$$D = 1 - \sum\nolimits_{i=1}^{S} p_i^2 \quad (1)$$

where $p_i = n_i/N$, n_i was the percentage cover m^{-2} accounted for by species *i,* and N the sum of percentage cover over all species (Molnar & Precsenyi, 2000). These indices and weed abundance values, estimated as the sum of the percentage cover of the different species, were compared across the four cropping systems using repeated measures ANOVA for a nested (split-plot) design with cropping system as fixed factor, block as random factors and year as repeated measure. Tukey's honest significant difference test was used to determine differences between cropping systems. Analyses were carried out using R version 3.0 and the TukeyC package (R Development Core Team, 2013).

Weed community composition A non-metric multidimensional scaling (NMS) ordination analysis (Clarke, 1993) was conducted to identify the impact of cropping systems on weed community composition with the Sorensen (Bray–Curtis) distance measure, 50 runs with real data, 2 axes and 250 maximum number of interactions. Each year, weed species relative abundances (RA) were calculated to determine the species included in the weed community composition analysis (NMS and the two analyses described below) as in equation 2:

$$\text{RA} = \frac{\text{AAA per species present in all cropping systems} \times 100}{\sum_{i=1}^{n} \text{AAA per species present in all cropping systems}} \quad (2)$$

where, AAA was the average absolute abundance and n the number of species. Species that were present in just one subplot (frequency $\leq$0.09) and at very low densities (RA < 2%, Appendix 1) were removed from any further analysis, as they may unduly influence results (Kenkel *et al*., 2002). A multiresponse permutation procedure (MRPP) based on the squared Euclidean distance was used to test the null hypothesis of no difference in weed community composition among systems (Mielke & Berry, 2001). The MRPP statistic (A) is a descriptor of within-group homogeneity, with A = 1 indicating that all items within groups are identical, A = 0 indicating that the heterogeneity within groups equals the expectation observed by chance and A < 0 indicating less agreement within groups than expected by chance. Although 1 is the highest possible value for A, in community ecology, values for A > 0.3 are usually considered as fairly high (McCune & Mefford, 2006).

Indicator species analysis (ISA; Dufrene & Legendre, 1997) was used to identify weed species associations with cropping systems. Indicator values (IV) were calculated for each species and cropping system. Indicator values vary between 0 when species are absent from all subplots of a given practice and 100 when species are present with the highest abundances in all subplots, thus reflecting 'perfect indication'. Indicator values were tested for statistical significance among cropping systems and years using a Monte Carlo technique based on 6000 randomisations. All weed community composition analyses were performed using the PC-ORD multivariate analysis software program v. 5.1 (McCune & Mefford, 2006).

Results

Weed species abundance and diversity

Weed cover was affected by cropping system and the interaction between cropping system and year (Table 2, Fig. 1A). In 2009, weed cover in lucerne was greater than in all CSWs regardless of management practice ($P < 0.001$). This was due mainly to the presence of volunteer *T. aestivum* that accounted for 62.3% (±14.3) of the total weed abundance sampled in lucerne. In 2010, there were no differences in weed cover across cropping systems ($P > 0.05$) and estimates were the lowest of all 3 years. In 2011, weed cover values were intermediate compared with the previous years, with the highest values observed in CSW-G, although this cropping system did not differ from the others. In CSW-G subplots that year, *Taraxacum officinale* F.H. accounted for 45.9% (±1.85) of the total relative weed cover. During this study, cropping system had no significant impact on weed species richness (Table 2, Fig. 1B) and minimal impact on diversity

Table 2 ANOVA table of the impact of cropping systems [lucerne, continuous spring wheat (CSW) chemically managed, CSW mechanically managed and CSW managed with sheep grazing] on weed cover, species richness and Simpson's diversity index

	d.f.	Sum Sq.	Mean Sq.	*F*-value	*P*-value
Weed cover					
Error: Block					
Residuals	2	96.2	48.1		
Error: Block: Cropping system					
Cropping system	3	647.1	215.68	9.552	0.011
Residuals	6	135.5	22.58		
Error: Block: Cropping system: Year					
Year	2	449.4	224.72		
Cropping system: Year	6	1772.1	295.34	16.660	<0.001
Residuals	16	283.6	17.72		
Species richness					
Error: Block					
Residuals	2	25.18	12.59		
Error: Block: Cropping system					
Cropping system	3	17.52	5.840	1.734	0.259
Residuals	6	20.21	3.368		
Error: Block: Cropping system: Year					
Year	2	27.43	13.71		
Cropping system: Year	6	26.29	4.382	2.949	0.039
Residuals	16	23.78	1.486		
Simpson's diversity index					
Error: Block					
Residuals	2	0.042	0.021		
Error: Block: Cropping system					
Cropping system	3	0.140	0.047	3.418	0.094
Residuals	6	0.082	0.014		
Error: Block: Cropping system: Year					
Year	2	0.045	0.023		
Cropping system: Year	6	0.245	0.041	2.243	0.092
Residuals	16	0.291	0.018		

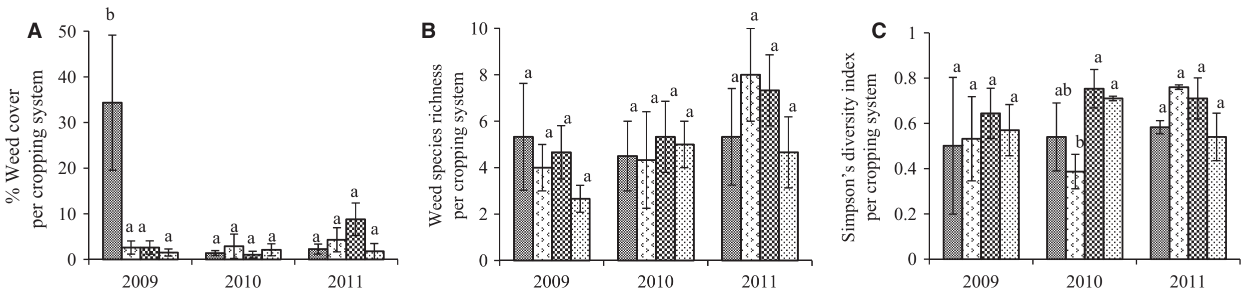


Fig. 1 Weed cover (A), species richness (B), and Simpson diversity index (C), in lucerne (▒), chemically managed continuous spring wheat (▒), sheep-grazed continuous spring wheat (▒), and tillage-based continuous spring wheat (▒) cropping systems. Bars indicate means and whiskers standard deviations. Within year, different letters on the bars indicate statistical significance ($P < 0.05$).

(Fig. 1C), with CSW-C having lower diversity than CSW-G and CSW-T in 2010.

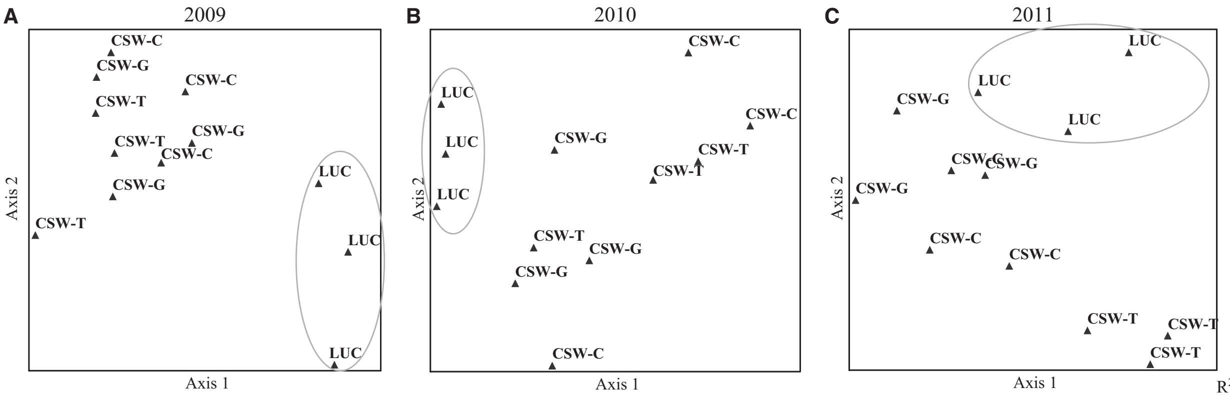
Community composition

Summing across all cropping systems, a total 13, 14 and 17 weed species were identified in 2009, 2010 and 2011, respectively, including one unidentified species in 2010 and in 2011 (Appendix 1). Fourteen weed species were annual broadleaves, three were perennial broadleaves and three were annual grasses. After species with very low frequency (≤0.09) and relative abundance (<2%) were removed from the analysis, the species number decreased to 5, 9 and 10 in 2009, 2010 and 2011 respectively.

In 2009, the first NMS axis separated weed communities sampled in lucerne from those observed in the CSW cropping systems, regardless of the pre-plant and post-harvest management practice applied (Fig. 2A). This tendency was further confirmed by the MRPP analysis (Table 3) with differences between lucerne and CSW-G, CSW-T and CSW-C ($P < 0.05$). According to ISA (Table 4), in 2009 volunteer *T. aestivum* and *Amaranthus retroflexus* L. were the two weed species driving the differences observed across systems. Both species were more abundant in lucerne than in CSW, regardless of the weed management practice employed. Particularly, *A. retroflexus* was over seven times more abundant in lucerne than in CSW, whereas *T. aestivum* was recorded as a weed only in lucerne. In this first year of our study, weed communities in CSW were similar across the three different management practices.

In 2010, the NMS and MRPP analyses showed tendencies similar to the previous growing season (Fig. 2B, Table 3) with the first NMS axis separating weed communities associated with lucerne from those in CSW-G, CSW-T and CSW-C. As in 2009, no clear differentiation occurred among CSW systems with different weed management practices. In accordance, the MRPP test indicated differences between lucerne and CSW-G, CSW-T ($P < 0.05$) and marginally significant difference between lucerne and CSW-C ($P = 0.054$). Results of the ISA showed that these differences were driven by *T. officinale,* which was over five times more abundant in lucerne than in the CSW subplots.

In 2011, the second NMS axis separated lucerne from CSW-C and CSW-T, but results showed less separation between lucerne and CSW-G than those observed in the previous 2 years (Fig. 2C). In contrast with the results observed in 2009 and 2010, the first axis separated the differently managed CSW cropping systems. In accordance, the MRPP analysis showed that the weed community in lucerne was different from the weed community sampled in CSW-G and CSW-T ($P < 0.05$), but in contrast with the patterns observed in 2009 and 2010, we did not detect differences in weed community composition between lucerne and CSW-C



R^2 Axis 1: 0.729; R^2 Axis 2: 0.136; Final stress: 4.93 R^2 Axis 1: 0.460; R^2 Axis 2: 0.305; Final stress: 11.84 R^2 Axis 1: 0.386; R^2 Axis 2: 0.361; Final stress: 6.99

Fig. 2 Non-metric multidimensional scaling analysis (NMS) showing the relative position of the cropping systems (lucerne (LUC), continuous spring wheat (CSW) chemically managed (CSW-C), CSW with tillage (CSW-T) and CSW with sheep grazing (CSW-G), with respect to the weed species (species are not represented in the graph). (A) 2009, (B) 2010 and (C) 2011. The grey ellipse highlights the position of lucerne subplots. The variance explained (R^2) by each axis, and the final stress of each ordination is described at the bottom of each graph.

Table 3 Within-year pairwise comparison by multiresponse permutation procedures (MRPP) of weed communities among the cropping systems [lucerne (LUC), continuous spring wheat (CSW) chemically managed (CSW-C), CSW mechanically managed (CSW-T) and CSW managed with sheep grazing (CSW-G)]

	2009		2010		2011	
Cropping Systems	A*	*P*-value	A	*P*-value	A	*P*-value
LUC vs. CSW-C	0.327	0.026	0.211	0.054	0.031	0.204
LUC vs. CSW-G	0.324	0.026	0.284	0.025	0.203	0.049
LUC vs. CSW-T	0.346	0.025	0.331	0.027	0.231	0.023
CSW-C vs. CSW-G	−0.087	0.734	0.110	0.165	0.160	0.059
CSW-C vs. CSW-T	0.035	0.331	0.035	0.316	0.190	0.028
CSW-G vs. CSW-T	0.008	0.334	0.021	0.308	0.382	0.026

**A*: Statistic of the MRPP.

Table 4 Indicator values (IV) of the indicator species analysis for each year and cropping system combinations [lucerne (LUC), continuous spring wheat (CSW) chemically managed (CSW-C), CSW mechanically managed (CSW-T) and CSW managed with sheep grazing (CSW-G)]. IV > 20 shaded in light grey, IV > 40 shaded in dark grey. Significant *P*-values (<0.05) indicate differences in the weed species across cropping systems (significant *P*-values are bolded)

Weed species	Cropping systems LUC	CSW-C	CSW-G	CSW-T	*P*-value
Year 2009					
Triticum aestivum	100	0	0	0	**0.017**
Amaranthus retroflexus	72	9	13	4	**0.016**
Thlaspi arvense	52	23	15	10	0.094
Lamium amplexicaule	28	2	1	5	1.000
Amaranthus blitoides	22	1	20	0	1.000
Year 2010					
Taraxacum officinale	76	3	11	0	**0.020**
Lactuca serriola	31	0	0	19	0.357
Avena fatua	0	52	1	10	0.227
Tragopogon dubius	7	29	0	0	1.000
Amaranthus retroflexus	7	2	33	49	0.069
Capsella bursa-pastoris	7	9	32	27	0.669
Thlaspi arvense	2	15	27	55	0.209
Malva neglecta	0	2	9	33	0.372
Year 2011					
Cirsium arvense	22	0	11	0	1.000
Androsace occidentalis	2	63	1	0	0.284
Amaranthus retroflexus	0	18	18	17	1.000
Taraxacum officinale	15	6	75	0	**0.035**
Lactuca serriola	0	26	72	0	**0.036**
Capsella bursa-pastoris	10	33	56	0	0.079
Thlaspi arvense	2	31	47	19	0.784
Bromus tectorum	15	1	34	0	0.365
Chenopodium album	0	8	29	0	1.000
Asperugo procumbens	0	6	9	78	**0.016**

($P = 0.204$) (Table 3). In accordance with NMS, MRPP showed that the weed community was different between the different CSW management practices ($P < 0.05$), although only marginally between CSW-G and CSW- C ($P = 0.059$) (Table 3). The ISA indicated that these results were driven by the higher presence of *T. officinale* and *Lactuca serriola* L. in CSW-G and *Asperugo procumbens* L. in CSW-T (Table 4). Specifically, *T. officinale* was five times more abundant in the CSW-G than in lucerne, over seven times more abundant in CSW-G than in CSW-C and was not present in CSW-T. *Lactuca serriola* was over 2.5 times more abundant in CSW-G than in CSW-C and was not present in lucerne or CSW-T. Finally, *A. procumbens* was not present in lucerne and was over six and 8.5 times more abundant in CSW-T than in CSW-G and CSW-C respectively.

Discussion

Our results supported the hypothesis that cropping systems act as ecological filters structuring weed communities. The conversion of an annual crop (spring wheat) to a perennial and less disturbed crop (lucerne) resulted in a shift from dominance by annual to perennial weed species. Similarly, in CSW, weed management influenced weed community with herbicide, tillage and grazing all leading to distinct weed communities by the end of this three-year study. The lack of differences in richness and diversity found indicated that while the weed community may change as a result of differential crops and crop management practices, the total number and relative abundance of weed species does not necessarily change. This is in accordance with previous authors working on different crops and across different management systems (Dorado & Lopez-Fando, 2006; Armengot *et al.*, 2013). However, in this study, the small number of repetitions produced, in some situations, low statistical power in the ANOVA (power < 0.8 – analysis, data not shown) that might have limited the ability to observe differences in SR and/or Simpson diversity index. Unfortunately, the size of the experimental plots and the labour required to perform this research prevented an increase in sample size.

The shift observed in the weed community in lucerne after the first year seemed to be driven by the competitive ability and characteristics of a perennial forage crop. Our results are in accordance with previous research that indicated lucerne as a suppressive crop of summer annuals weeds (Ominski *et al.*, 1999). Summer annuals, such as *Chenopodium album* L., volunteer *T. aestivum*, *T. arvense, A. retroflexus* and *Lamium amplexicaule* L., were very abundant in lucerne the first year, but were reduced in subsequent years. In accordance, Bellinder *et al.* (2004) observed *C. album* to be favoured by lucerne in the first year of its establishment and greatly reduced in subsequent years.

Within the annual CSW, management practices filtered out different weed species. For example, *T. officinale,* a perennial dicotyledonous species, was never present in the tillage-based subplots, but was selected in the herbicide and sheep grazed no-till systems. *Taraxacum officinale* populations are known to increase in reduced-tillage annual crop production (Froese & Van acker, 2003). Interestingly, *T. officinale* was even more dominant in the grazed system than in the herbicide-managed system. The large increase of its population in 2011 in the CSW-G subplots may be due to partial grazing due to this species' prostrate nature, allowing it to eventually recover and reproduce.

Applying the trait-based approach proposed in community assembly theory to understand how cropping systems modify weed communities can help shift from purely reactive weed control to proactive weed management programmes (Navas, 2012). In this context, our results showed first that as a perennial crop, lucerne impeded the establishment of annual weed species, but favoured perennial broad-leaved ones. Second, this study demonstrated that the replacement of herbicide with sheep grazing or tillage in the CSW systems was associated with changes in weed community composition, without significantly impacting weed abundance or weed diversity, suggesting that these practices act as differential filters. The inclusion of sheep grazing or soil tillage could represent biotic or abiotic filters to help producers manage herbicide resistant weeds, an emerging issue in cereal cropping systems (Thomas *et al.*, 2007), while driving weed communities toward a suite of relatively easy to manage species. Thus, producers considering the adoption of alternative cropping system programmes should evaluate the costs and benefits of increasing the abundance of certain weed functional forms and the associated environmental and economic consequences of the selected strategy.

In the differently managed annual CSW systems, general species traits (perennial vs. annual, or broad-leaved vs. grasses) were not sufficient to describe how species were filtered. More specific traits (seed size, germination depth, plant architecture, etc.) may be necessary to evaluate the filter effect of management practices and to lead to general principles that could be applied to other agronomic situations. While this study does not allow us to specifically test the extent to which sheep foraging preferences could act as an ecological filter of weed communities, it is possible to infer its importance. In grazed CSW, for example, prostrate architecture (e.g. *T. officinale*) or unpalatability (presence of spikes, e.g. *L. serriola*) seemed to be favoured, while other species traits such as upright architecture or palatability were filtered out (e.g. *A. fatua* before seed formation) (Sternberg *et al.*, 2000). Previous studies have shown that CSW managed with tillage impacts the composition of the soil seedbank (Dorado *et al.*, 1999) and could filter weed species unable to germinate from deeper soil (Gardarin *et al.*, 2010). In our study, tillage clearly favoured *A. procumbens*, but the specific trait by which that species was selected is unknown.

To our knowledge, this is the first study assessing the relative impact of cropping system and management practices in structuring weed communities in the Northern Great Plains, an area where little information exists. Our results allowed us to assess the relative importance of biological and abiotic filters structuring weed communities. Further research in weed community assembly should combine manipulative and observational studies considering additional biological and agronomical meaningful traits to increase our knowledgebase on how weed community composition responds to management and crop systems. This ecological knowledge could, in turn, be applied to facilitate the displacement of the most problematic species by less problematic ones, while accepting that a certain weed community is going to be part of the agro-ecosystem.

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Appendix 1 Scientific name, common name, family, life cycle (LC) (A = Annual, P = Perennial) and morphotype (Mt) (d = dicotyledonous and m = monocotyledonous), and relative abundance per species, cropping system (Lucerne (LUC), Continuous Spring Wheat (CSW) chemically managed (CSW-C), CSW mechanically managed (CSW-T), and CSW managed with sheep grazing (CSW-G)), and year.

			2009				2010				2011			
Scientific name	Family	LC & Mt	LUC	CSW-C	CSW-G	CSW-T	LUC	CSW-C	CSW-G	CSW-T	LUC	CSWC	CSW-G	CSW-T
Amaranthus blitoides	Amaranthaceae	Ad	1.58	0.09	0.72	0	0	0	0.21	0	0	0	0	0
Amaranthus retroflexus	Amaranthaceae	Ad	15.8	2.07	2.88	1.22	0.64	0.21	1.49	2.23	0	0.84	1.69	0.52
Androsace occidentalis	Primulaceae	Ad	0	0	0	0	0	0	0	0	0.19	6.57	0.14	0.09
Asperugo procumbens	Boraginaceae	Ad	0	0	0	0	0	0	0	0	0	0.23	0.33	1.97
Avena fatua	Gramineaceae	Am	0	0.63	0.36	0	0	28.94	0.85	7.66	0	0	0	5.44
Bromus tectorum	Gramineaceae	Am	0	0	0	0	0	0	0	0	2.11	0.14	2.35	0
Capsella bursa-pastoris	Brassicaceae	Ad	0	0	0	0	0.64	1.28	1.49	1.28	1.08	3.66	6.19	0.09
Chenopodium album	Chenopodiaceae	Ad	0.99	0.32	0.09	0	0	0	0	0	0	0.42	3.10	0
Cirsium arvense	Asteraceae	Pd	0.18	0	0	0	1.60	0	0.21	0	1.97	0	0.99	0
Lamium amplexicaule	Labiatae	Ad	5.59	0.36	0.18	0.45	0	0.21	0.43	0	0	3.10	0	0
Lactuca serriola	Asteraceae	Ad	0.09	0	0	0	1.60	0	0	0.96	0.14	2.67	7.36	0.09
Malva neglecta	Malvaceae	Ad	0	0	0	0.36	0	0.43	1.70	4.15	0	0.56	0	0
Silene latifolia	Caryophyllaceae	Pd	0	0	0	0	0	0	0	0	0.94	0.09	0.28	0
Sisymbrium altissimum	Brassicaceae	Ad	0	0	0	0	0	0	0	0	0.28	0	0	0
Solanum triflorum	Solanaceae	Ad	0.59	0.09	0.23	0.50	0	0	0	0	0	0	0	0
Taraxacum officinale	Asteraceae	Pd	0.36	0	0.09	0	9.89	1.06	2.13	0	4.78	3.10	23.9	0
Thlaspi arvense	Brassicaceae	Ad	6.17	2.79	1.80	1.17	0.64	2.77	5.11	10.2	0.28	3.80	5.68	2.35
Tragopogon dubius	Asteraceae	Ad	0	0	0	0	0.32	2.13	0	0	0	0	0	0
Veronica persica	Scrophulariaceae	Ad	0.9	0	0	0	1.60	0	0	0	0	0	0	0
Triticum aestivum	Graminaceae	Am	51.4	0	0	0	0.32	0	0	0	0	0	0	0
Unknown			0	0	0	0	1.60	1.70	0.43	1.91	0.09	0.28	0.05	0.05