Agronomy Research **15**(4), 1795–1814, 2017
https://doi.org/10.15159/AR.17.040

Weed community trajectories in cereal and willow cultivations after termination of a willow short rotation coppice

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Abstract. According to guidelines for willow short rotation coppice (SRC), weeding is needed during establishment, while weed populations which develop later under a well-established willow canopy do not require control. However, farmers are concerned that weeds which develop in SRC may result in long-lasting weed infestations in succeeding crops after SRC termination. We assessed the effects of two SRC-termination methods (with shallow and deep soil cultivation) on the development of the weed flora in a cereal system (CS) and in SRC during six seasons. Richness, ground cover, life-cycle strategy and composition of the weed species, and their environmental requirements (inferred from Ellenberg index) were evaluated.

SRC-termination method had no effect on the weed community trajectories in the succeeding SRC and CS. However, cropping system and growing season had significant impacts on species richness, ground cover and composition of the weed flora.

Differences in weed communities over time and between cropping systems were related to the impact of cropping systems on factors such as light, soil moisture, nitrogen level, and soil reaction, as inferred from the Ellenberg index. After termination of the old willow cultivation, the weed flora of the SRC and CS rapidly diverged and approached the weed flora characteristic for old willow stands and non-weeded old cereal plot, respectively. We conclude that willow stands can be converted, regardless of termination method, either into willow or cereal cultivations without additional risk of weed infestations other than those specific for their respective cropping systems. Furthermore, willow cultivations in agriculture contribute to floristic diversity at the landscape scale.

Key words: crop, diversity, Ellenberg index, flora, life cycle, *Salix* spp., short rotation forestry, termination method, weed outbreak, weed species composition, weed species ground cover, weed species richness.

INTRODUCTION

Biomass from willow (*Salix* spp.) short rotation coppice (SRC) is used as a renewable energy source in several European countries (Mola-Yudego, 2010) and overseas (Volk et al., 2004). Willow SRC has an economically productive life span of 20 to 25 years and is commonly harvested in winter every 3 to 4 years. Stem dry matter biomass in a well-established commercial field can exceed 10 Mg $ha^{-1}yr^{-1}$. After this period, SRC biomass production declines and the willow SRC can be terminated (Rahman et al., 2014). Land regained after termination of willow SRC is usually incorporated back into conventional agricultural production with annual crops, but may also be replanted again with willow SRC (Norberg & Nordh, 2012).

During establishment, willows are very susceptible to weeds which develop faster and efficiently outcompete young willow plants (Abrahamson et al., 2010). A survey among Swedish farmers showed that weeds were the most important cause for premature termination of willow stands (Helby et al., 2006). Weed control during the first year is essential (Albertsson et al., 2016), and both mechanical weed control and use of herbicides are recommended in planting instructions described in 'Manual för Salixodlare' (Gustafsson et al., 2007), 'Short Rotation coppice willow – best practice guidelines' (Caslin et al., 2010), and 'Handbok för Salixodlare' (Hollsten et al., 2012). After establishment, which takes 1 to 1.5 growing seasons, willows form a dense canopy which suppresses growth of weeds in the understorey, and no further weed control is required (Verwijst et al., 2013).

When weed control in a willow SRC after canopy closure is ceased, a spontaneous development of a weed flora occurs and contributes to floristic diversity in the agricultural landscape (Gustafsson, 1986, Baum et al., 2012a). Previous land-use has been found to affect the initial development of the ground vegetation after conversion, former grasslands leading to a larger share of long-lived perennials compared to former arable land (Cunningham et al., 2006). However, Baum et al. (2013) found a poor coherence of seed bank versus actual vegetation in SRC, suggesting that recent vegetation composition is mainly due to the species pool of the adjacent vegetation and site conditions. Baum et al. (2012c) and Stjernquist (1994) found that the influence of the previous vegetation decreases with cultivation age. These findings apply to conversion of conventional agricultural cropping systems into willow SRC. However, very little is known about the flora development after reconversion of willow SRC into annual cropping systems. At present, farmers are concerned that weeds which develop in willow SRC may result in long-lasting weed infestations in succeeding crops after willow SRC termination, and this necessitates studies on reconversion of willow SRC.

In this context, the main aim of our study was to compare the development of the weed flora in crops established after termination of long-term willow SRC. As noted by Pučka et al. (2016), such an assessment of the vegetation dynamics should preferably be performed for several years in sequence. We assessed the effects of two SRC-termination methods (with deep or with shallow soil cultivation after termination of SRC, respectively) on the development of the weed flora in SRC and cereal system (CS) in during six growing seasons. Both cropping systems were established on one and the same site and thus shared the same management history and the same seed bank.

We hypothesized that: 1) deep soil cultivation during willow termination will initially and in both cropping systems reduce weed species richness and cover compared to shallow soil cultivation, because deep soil cultivation may act as a weed control method, 2) weed species richness and cover will initially be similar in both cropping systems, as they share the same management history and seed bank, 3) weed species composition in the different cropping systems will diverge over time, and 4) this divergence is due to the inherent impact of the cropping systems on their environment, as inferred from Ellenberg index.

MATERIALS AND METHODS

Site description

The experiment was performed at Ultuna near Uppsala, Sweden (59°48’N, 17°39’E, altitude 5 m) on a 2.7 ha field with a neutral ($pH_{H2O} = 7.4$) Vertic Cambisol (Olsson & Samils, 1984) and a willow short rotation coppice (*Salix viminalis*, clone 77683) that was grown for 25 years (1984–2009), with an initial density of 20,400 plants ha^{-1} which had decreased to 2,900 plants ha^{-1} in 2009, predominantly due to self-thinning (Willebrand & Verwijst, 1993). The 25-year-old willow short rotation coppice is named ‘old willow’ (OW) below.

Two areas of 100 m × 100 m each were divided into blocks of 50 m × 100 m, and these further into 25 m × 100 m subplots in a split-plot design to accommodate cropping system (willow or cereals) in each main plot and termination method (with deep or shallow soil cultivation, see below) in the split plots (Fig. 1). Within the main plots in each of the four blocks, termination method was randomly assigned to the subplots.

After inventory of the weed flora (see below) on 20–21 June 2009, a tank mixture of herbicides (glyphosate ‘Roundup Bio’, 360 g active ingredient (a.i.) L^{-1}, Monsanto, dose: 6 L ha^{-1} and dimethylamine salt ‘MCPA 750’, 750 g a.i. L^{-1}, Nufarm, dose: 0.8 L ha^{-1}) was applied on 26 June 2009 to kill willows and weeds before mechanical termination. On 27 and 29 July 2009, willows were mechanically terminated using two methods: deep termination (TD) method using a multi mulcher (Seppi M. Multiforst), which removed above- and belowground part of stumps with soil cultivation to a depth of about 13 cm, or shallow termination (TS) method using a flail mower (Berti 250ECF/DT), which removed aboveground parts of stumps without soil cultivation (Norberg & Nordh, 2012). Within a few weeks after termination, weeds started to germinate in all plots where both TD and TS were applied.

Plots dedicated to CS on which TS was applied underwent disc harrowing on 3 September 2009. Winter wheat (*Triticum aestivum* L.) was sown on plots dedicated to cereals and on a nearby reference plot (see below) on 17 September 2009. Plots dedicated to SRC were planted with *Salix schwerinii* × *Salix viminalis*, clone ‘Tora’ (Svalöf-Weibull AB) on 18 May 2010 using a Woodpecker (Norberg & Nordh, 2012). During the growing seasons 2011, 2012 and 2014, spring barley (*Hordeum distichon* L.) was cultivated while spring wheat (*Triticum aestivum* L.) was sown in 2013 and 2015. Winter wheat and spring barley were sown with a density of 350–400 seeds m^{-2} and spring wheat with 500 seeds m^{-2}. Plots dedicated to cereals were disc harrowed in 2009 and 2010, and in subsequent years ploughed to a depth of 20–25 cm, either during autumn or spring, and prior to sowing the seed bed was prepared by harrowing. From 2012 on, mineral fertilization was applied annually with NPK 21-4-7 (YARA) at an N-supply of 80 kg ha^{-1}, about two weeks after sowing.

In spring 2009, a reference plot for cereal cultivation was established, at about 600 m distance from the experimental field. The reference plot had a size of 2,450 m^2 and had been cultivated with annual crops (mainly cereals) during the five preceding years, without any mean of the weed control. During summer 2009, the site was in fallow by performing rotary cultivation five times during the growing season. The reference plot is named ‘old cereal’ (OC) below.

Monthly mean temperature of growing season (May to September) was 14.3 °C(2009), 18.8 °C(2010), 13.8 °C(2012), 15.2 °C(2013), 14.6 °C(2014), and 13.8 °C(2015). Average monthly rainfall during the growing season (May to September) was 69.6 mm (2009), 58.6 mm (2010), 83.5 mm (2012), 37.6 mm (2013), 60.3 mm (2014), and 63.0 mm (2015) (Anonymous, 2016).

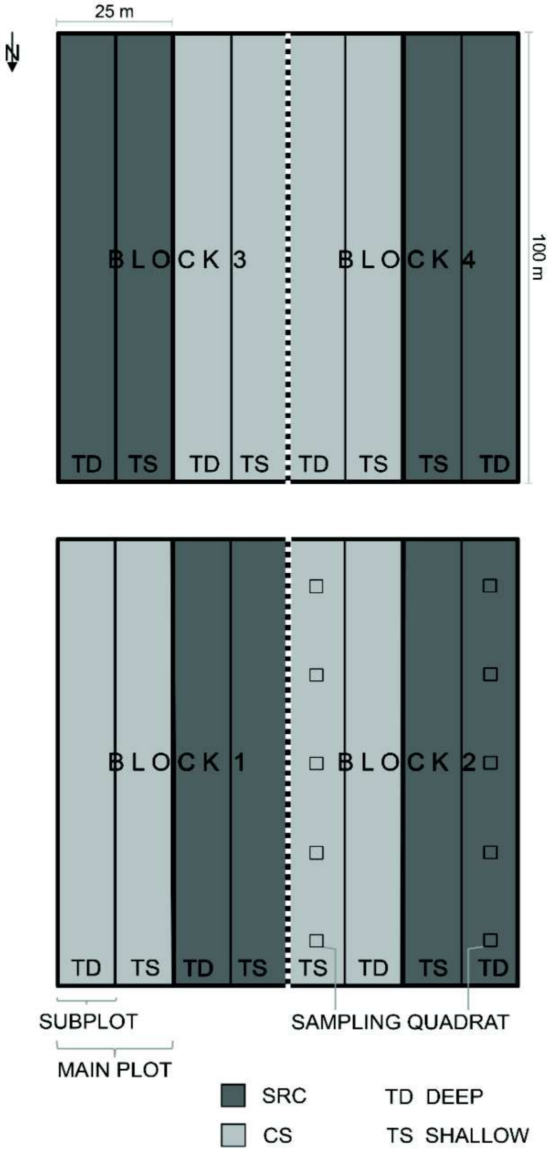

Figure 1. Design of the field experiment at Ultuna, Sweden. Bold lines indicate main treatments [crop: willow (SRC), dark grey; cereal (CS), light grey]; thin lines indicate split plots (subplots) [termination method: with deep soil cultivation (TD) or with shallow soil cultivation (TS)]. Dotted lines separate the blocks. The sampling quadrants (2 m × 2 m) indicate where the weed flora was recorded, however, for clarity of the figure, sampling quadrants are drown only on two subplots.

Inventory of the weed flora

All plant species different from the cultivated crops were considered as weeds. The weed flora was recorded within five 4 m^2 sampling quadrants located 10, 30, 50, 70 and 90 m from the subplot's headland, distributed along a transect centrally located in each subplot (Fig. 1). The first inventory of the flora was performed in June 2009 on the entire area of OW cultivation (16 subplots predesigned to be planted anew with SRC or converted to CS) and in July 2009 on the OC plot, also using five sampling quadrants of 4 m^2. Thereafter, the inventories were performed on 26 July 2010, 28 June 2012, 14–15 July 2013, 28 and 30 July 2014, and 27 July 2015 in SRC and CS (no inventory was performed in 2011). These dates coincided with the phenological stage of spike ripening (Bleiholder et al., 1997) of *Dactylis glomerata* L. in SRC and were used to minimize differences between growing seasons with regard to the phenological development of the flora. The weed flora inventory included taxonomic identification of the weeds to the species/genus (Lid & Lid, 2005), classification to the life forms (Raunkiær, 1934), habitat type, growth forms (Chapin et al., 1996) and life-cycle strategy and Grime's strategy (Grime et al., 2007). The nominal transformation (van der Maarel, 2007) of Braun-Blanquet scale (Braun-Blanquet, 1932; Braun-Blanquet, 1964) was used to assess the ground cover of the species in sampling quadrants.

Analyses of weed species richness and diversity

The PROC MIXED procedure in SAS 9.4 (SAS Institute Inc., Cary, NC, USA) was used to investigate differences in weed species richness and weed ground cover between and within growing seasons and in different life-cycle strategy categories (i.e. 'annual', 'biennial', and 'perennial'). Weed species richness was also analyzed per group 'only SRC', 'only CS' and 'SRC + CS'. Cropping system and termination method and their interaction were used as explanatory variables. Block was modeled as a random variable. Termination method was statistically insignificant in the mixed-design ANOVA of weed species richness ($P = 0.92$) and weed ground cover ($P = 0.77$) and was therefore excluded as explanatory variable in the overall analyses of weed species richness in the groups 'only SRC', 'only CS' and 'SRC + CS' and in occurrence percentage and cover percentage of weed species richness in life-cycle strategy categories.

Lack of replicates and uneven number of measurements in OW ($n = 80$) and OC ($n = 5$) necessitated the use of one-way ANOVA and Tukey honestly significant difference test at 95% confidence level to assess differences between cropping systems.

Weed species composition

Gradients in weed species composition based on cover-abundance in SRC and CS (growing seasons 2010 and 2012–2015) were assessed by Non-metric Multi-Dimensional Scaling (NMDS) performed using the software package Canoco 5, Windows release (5.02) (ter Braak & Šmilauer, 1997–2012). The Bray-Curtis distance measure and NMDS solution was based on 3 axes without optimization and perturbations, and formula for stress type 2 (i.e. the sum of squared differences between individual distance values and their mean) were applied. Treatments of ties in distances were set as primary, i.e. different occurrences of the same distance value might be matched with different fitted values. The stress values (Clarke, 1993) and number of iterations for separate years ranged from 0.07 (2010) to 0.0005 (2015), and 43 (2010) to 353 (2015), respectively.

Indicator species analysis revealing association of weed species to cropping system was performed for separate growing seasons on cover-abundance datasets using RStudio v. 0.98.501©2009–2013, package ‘labdsv’ v. 1.6–1 (Roberts, 2010). Based on these data, indicator values, being multiplication of species specificity (the proportion of sites of type *j* with species *i*) and fidelity (the proportion of the number of individuals of species *i* that are in a *j* type of site) (Dufrêne & Legendre, 1997), were produced for all weed species, but only those which are statistically significant were tabulated.

Environmental conditions (inferred from Ellenberg index)

Based on cover-abundance data for each weed species composition within a sampling quadrant the Ellenberg index, calculated as weighted mean of Ellenberg values for light, soil moisture, soil nitrogen level and soil reaction, was produced as a proxy for environmental conditions (Ellenberg, 1992; Diekmann, 1995; Diekmann & Lawesson, 1999; Grandin, 2004). Differences in environmental conditions inferred from the Ellenberg index as dependent on crop, growing season and their interaction were analyzed with PROC MIXED procedure in SAS 9.4 (SAS Institute Inc., Cary, NC, USA).

RESULTS AND DISCUSSION

Weed species characterization: richness and ground cover

Number of weed species and their life forms

For all growing seasons and crops, including OW and OC, a total number of 86 weed species was identified (Table 1). After conversion, 77 species were recorded during growing season 2010 and 2012–2015 in SRC while the corresponding number for CS was 30 species. Hemicryptophytes constituted 51% and 20% of the weed species detected in OW and OC, respectively. The average proportion of hemicryptophytes (all growing seasons) was 63% and 28% in SRC and CS, respectively. In 2010 a proportion of 52% and 55% in SRC and CS, respectively were hemicryptophytes. They increased from 63% to 66% in SRC but decreased in CS from 31% to 0% over a period 2012–2015. Therophytes constituted 10% and 60% of the weed species detected in OW and OC, respectively. On average for all growing seasons, 8% and 31% of the weed species detected in SRC and CS, respectively were therophytes. They decreased from 15% to 5% in SRC and increased from 7% to 67% in CS during growing season 2010 and 2012–2015 (Table 1). This change over time in proportion of therophytes is associated to the disturbance frequency inherent to the cropping system. The high frequency of soil cultivation in the CS primarily allows for weed species which can complete their life cycle within one growing season. Likewise, the abundant occurrence of hemicryptophytes in SRC is indicating a lower frequency of soil disturbance.

Table 1. Botanical characterization of the weed species identified in different cropping systems during growing seasons 2009–2010 and 2012–2015. Growth habit is not specified for *Epilobium* sp. L. and *Galium* sp. L. (apart from *E. angustifolium*, *E. montanum*, *G. aparine,* and *G. odoratum*) due to a great diversity in growth habit of these genera. The main habitat type preferred by each weed species in Scandinavia is given. Abbreviated names of plant species are used in Fig. 5

No.	Name of plant species	Abbreviation	Occurrence per growing season						Raunkiær's life form[1]	Life-cycle strategy categories[2]	Grime's strategy[3]
			2009	2010	2012	2013	2014	2015			
1	*Acer platanoides* L.	A pla	OW	-	-	SRC	-	-	M	P	S
2	*Achillea millefolium* L.	Ach mil	-	-	-	-	-	SRC	H	P	C-S-R
3	*Alopecurus pratensis* L.	Alop prat	-	-	-	SRC	SRC	-	H	P	C-S-R / C
4	*Anthemis arvensis* L.	Ant arv	-	-	-	-	-	SRC	G	A	R
5	*Anthriscus sylvestris* Hoffm.	Ant sylv	OW	SRC, CS	SRC, CS	-	-	SRC	H	A	C / C-R
6	*Arctium tomentosum* Mill.	Arct tom	-	-	SRC	-	-	-	H	B	ns
7	*Arrhenatherum elatius* (L.) P. Beauv. ex J. & C. Presl	Arrh elat	OW	-	-	-	-	-	H	P	C
8	*Artemisia absinthium* L.	Art abs	-	-	SRC	SRC	SRC	-	C	P	C / C-S-R
9	*Bromus secalinus* L.	Brom sec	-	-	-	CS	-	-	T	A	ns
10	*Bunias orientalis* L.	Bun orient	OW	SRC, CS	SRC	SRC, CS	SRC	SRC	H	B	ns
11	*Capsella bursa-pastoris* (L.) Medik.	Cap bur	-	-	CS	-	-	-	T	A	R
12	*Carum carvi* L.	Car car	-	-	-	SRC	SRC	SRC	H	B	ns
13	*Cerastium arvense* L.	Cer arv	OW	-	-	-	-	-	C	B	S-R / C-S-R
14	*Chelidonium majus* L.	Chel maj	-	-	SRC	SRC	SRC	-	H	P	C-R / C-S-R
15	*Chenopodium album* L.	Chen alb	OC	SRC	CS	SRC, CS	CS	CS	T	A	C-R
16	*Cirsium arvense* (L.) Scop.	Cir arv	OW, OC	SRC, CS	SRC, CS	SRC, CS	SRC, CS	SRC, CS	G	P	C
17	*Cirsium vulgare* (Savi) Ten.	Cir vulg	-	-	-	SRC, CS	-	-	H	P	C-R
18	*Convulvulus arvensis* L.	Conv arv	-	SRC, CS	SRC, CS	SRC, CS	SRC, CS	SRC	G	P	C-R
19	*Cornus sanguinea* L.	Cor san	-	-	-	-	-	SRC	M	P	S-C
20	*Crataegus monogyna* Jacq.	Cra mon	OW	-	-	-	-	SRC	M	P	S-C
21	*Dactylis glomerata* L.	Dac glom	OW	CS	SRC	SRC	SRC	SRC	H	P	C-S-R / C
22	*Deschampsia cespitosa* (L.) P. Beauv.	Des ces	OW	-	-	-	SRC	SRC	H	P	C-S-R / S-C
23	*Elymus repens* (L.) Gould	El rep	OW, OC	SRC, CS	SRC, CS	SRC, CS	SRC, CS	SRC, CS	G	P	C / C-R
24	*Epilobium angustifolium* (L.)	Epil ang	-	SRC	-	-	SRC	-	H	P	C
25	*Epilobium montanum* L.	Epil mon	-	-	-	SRC	-	-	H	P	R / C-S-R
26	*Epilobium* sp. L.	Epil sp.	-	-	SRC	SRC	SRC	SRC	ns	ns	ns
27	*Erodium cicutarium* (L.) L`Her.	Ero cic	-	-	-	SRC	SRC	-	H	B	S-R

Table 1 (continued)

28	*Festuca pratensis* Huds.	Fes prat	OW	SRC	SRC	SRC	SRC	SRC	H	P	C-S-R
29	*Festuca rubra* L.	Fes rub	OW	SRC	SRC	SRC	SRC	SRC	H	P	C-S-R / C / S-C / S
30	*Filipendula ulmaria* (L.) Maxim.	Filip ulm	-	-	-	SRC	SRC	-	H	P	C / S-C
31	*Fragaria vesca* L.	Fra ves	OW	-	SRC	SRC, CS	SRC	SRC	H	P	S / C-S-R
32	*Fumaria officinalis* L.	Fum off	OW, OC	SRC	CS	CS	-	CS	T	A	R
33	*Galeopsis tetrahit* L.	Gale tet	-	SRC, CS	SRC, CS	-	-	SRC, CS	T	A	C-R
34	*Galium aparine* L.	Gal apar	OW	SRC, CS	SRC, CS	SRC, CS	SRC, CS	SRC, CS	T	A	C-R
35	*Galium odoratum* (L.) Scop.	Gal odor	-	-	-	SRC	SRC	SRC	G	P	S-C / C-S-R
36	*Galium* sp. L.	Gal sp.	OW	SRC, CS	SRC	-	-	-	ns	ns	ns
37	*Geranium robertianum* L.	Ger rob	OW	SRC, CS	SRC	SRC	SRC	SRC	H	B	R / C-S-R
38	*Geum urbanum* L.	G urb	OW	SRC, CS	SRC, CS	SRC, CS	SRC	SRC	H	P	C-R / C-S-R
39	*Glechoma hederacea* L.	Glech hed	-	CS	-	-	-	-	G	P	C-R / C-S-R
40	*Hypericum perforatum* L.	Hyp perf	-	-	-	SRC	SRC	SRC	H	P	C-R / C-S-R
41	*Juncus effusus* L.	Junc eff	-	-	-	SRC	SRC	-	H	P	C / S-C
42	*Lactuca serriola* L.	Lac serr	-	-	CS	-	SRC, CS	-	T	B	ns
43	*Lamium album* L.	Lam alb	-	SRC	-	-	-	-	H	P	C-R
44	*Lamium purpureum* L.	Lam purp	-	-	-	CS	SRC	-	H	P	R
45	*Lathyrus pratensis* L.	Lath prat	OW	SRC	SRC	-	-	SRC	H	P	C-S-R
46	*Leucanthemum vulgare* Lam.	Leu vul	-	-	SRC	-	-	-	H	P	C-S-R / C-R
47	*Lonicera tatarica* L.	Lon tat	OW	-	-	-	-	-	N	P	ns
48	*Lonicera xylosteum* L.	Lon xyl	OW	SRC	SRC	-	-	-	N	P	ns
49	*Matricaria inodorata* L.	Mat inod	OC	-	-	-	-	-	T	A	R
50	*Medicago lupulina* L.	Med lup	OW	-	SRC	SRC	SRC	SRC	H	A	R / C-S-R
51	*Melilotus albus* Medik.	Mel alb	-	-	-	SRC	-	SRC	H	B	C-R
52	*Myosotis arvensis* (L.) Hill	Myos arv	OW	-	SRC	SRC	SRC	SRC	H	P	R
53	*Phleum pratense* L.	Ph prat	OW	-	-	-	-	-	H	P	C-S-R
54	*Poa pratensis* L.	P prat	-	-	SRC	SRC, CS	SRC	SRC	H	P	C-S-R
55	*Poa trivialis* L.	P triv	OW	-	SRC	-	-	SRC	H	P	R / C-S-R
56	*Potentilla arenaria* Borkh.	Pot are	-	-	-	SRC	SRC	-	H	P	ns
57	*Prunus padus* L.	Pru pad	OW	SRC	-	SRC	-	SRC	M	P	S-C
58	*Ranunculus repens* L.	Ran rep	OW	SRC, CS	SRC, CS	SRC	SRC	SRC	H	P	C-R
59	*Roegneria canina* (L.) Nevski	Roe can	-	-	-	-	SRC	-	H	P	ns

Table 1 (continued)

60	*Rhamnus cathartica* L.	Rha cath	-	-	-	SRC	SRC	-	N	P	S-C
61	*Rosa* sp.	Rosa sp.	OW	-	-	SRC	SRC	SRC	N	P	ns
62	*Rubus idaeus* L.	Rub idae	OW	-	-	SRC	SRC	SRC	N	P	S-C
63	*Rubus saxatilis* L.	Rub sax	-	-	-	SRC	-	-	N	P	S / C-S-R
64	*Rumex crispus* L.	Rum cris	OW	SRC, CS	SRC, CS	SRC	SRC	SRC	H	P	C-R / C-S-R
65	*Sambucus racemosa* L.	Samb rec	OW	-	SRC	SRC	SRC	SRC	N	P	ns
66	*Senecio vulgaris* L.	Sen vul	-	-	-	-	SRC	-	H	P	R
67	*Sinapis arvensis* L.	Sin arv	OW, OC	SRC	CS	SRC, CS	CS	-	T	A	R / C-R
68	*Solanum dulcamara* L.	Sol dunc	-	-	-	SRC	SRC	-	C	P	C-S-R / C
69	*Sonchus arvensis* L.	Son arv	OC	-	-	-	-	-	H	P	C-R
70	*Sonchus asper* (L.) Hill	Son asp	OW	SRC	-	-	-	-	T	A	R / C-R
71	*Sorbus aucuparia* L.	Sorb auc	OW	-	-	-	-	-	M	P	S-C
72	*Stellaria media* (L.) Vill	Stell med	OC	CS	SRC	SRC	-	-	T	B	R
73	*Symphoricarpos albus* (L.) S. F. Blake	Sym alb	OW	-	-	-	-	SRC	N	P	C / S-C
74	*Taraxacum officinale* F. H. Wigg.	Tar off	OW, OC	SRC, CS	SRC, CS	SRC, CS	SRC, CS	SRC	H	P	R / C-S-R
75	*Thlaspi arvense* L.	Thl arv	OW, OC	SRC, CS	CS	CS	CS	-	T	A	R
76	*Tragopogon pratensis* L.	Trag prat	-	-	SRC	-	-	-	T	B	C-R / C-S-R
77	*Trifolium pratense* L.	Trif prat	-	CS	-	SRC	SRC	-	H	P	C-S-R
78	*Trifolium repens* L.	Trif rep	OW	SRC	SRC	-	-	SRC	H	P	C-S-R / C-R
79	*Tussilago farfara* L.	Tuss far	-	-	SRC	CS	-	-	G	P	C / C-R
80	*Ulmus glabra* Huds.	Ul glab	OW	SRC	SRC	-	-	-	M	P	C / S-C
81	*Urtica dioica* L.	Urt dioi	OW	SRC, CS	SRC	SRC, CS	SRC	SRC	H	P	C
82	*Urtica urens* L.	Urt uren	-	SRC	-	-	-	-	T	A	R / C-R
83	*Veronica arvensis* L.	Ver arv	OW, OC	-	SRC	-	SRC	-	T	A	S-R
84	*Veronica chamaedrys* L.	Ver cham	-	-	-	SRC	SRC	SRC	H	P	C-S-R / S
85	*Vicia cracca* L.	Vicc crac	-	SRC	SRC	SRC	SRC	-	H	P	C / C-S-R
86	*Viola reichenbachiana Jord*	Vio reich	-	-	-	-	SRC	SRC	H	P	S

Occurrence per growing season: Weed species present in old willow (OW, 2009); willow short rotation coppice (SRC, 2010, 2012–2015); old cereals (OC, 2009); cereal system (CS, 2010, 2012–2015), or absent in any cropping system (-); **Raunkiær's life form**: Chamaephyte (C); Geophyte (G); Hemicryptophyte (H); Megaphanerophyte (M); Nanophanerophyte (N); Terophyte (T); (ns) not specified in the literature used due to a great diversity in growth habit of these genera; **Life-cycle strategy categories**: Annual (A); Biennial (B); Perennial (P); (ns) not specified in the literature used; **Grime's strategy**: Competitor (C), Ruderal (R), Stress tolerator (S); (ns) not specified in the literature used. [1] Raunkiær, 1934; [2] Lid & Lid, 2005; [3]Grime et al., 2007.

Grime's strategy

Following the triangular plane of which the corners represent a defined strategy (Grime et al., 2007), weed species which are able to tolerate stress, i.e. stress tolerators (S), stress tolerant ruderals (S–R) and stress tolerant competitors (S–C), were observed in both OW and OC in growing season 2009, and then during growing seasons 2010 and 2012–2015 predominantly in SRC (3–21%). Ruderals (R) > competitive ruderals (C–R) > intermediate between competitor (C), stress tolerators (S) and ruderals (C–S–R) constituted the majority (each around 20%) of weed species in OW. In OC, in contrast the order was R > C > C–R (each around 30%). Weeds in SRC and CS belonged predominantly to the C–R (22–60%), C (15–40%) or C–S–R (5–29%) category during all growing seasons (Table 1). The relative high share of ruderals is likely related to both disturbance frequency and nutrient levels inherent to the cropping systems. Gustafsson (1988) also found that ruderal species became increasingly common during succession in willow SRC. As described earlier by Baum et al. (2012b), mostly common species, typical for disturbed and anthropogenic environments, were found both in cereal and willow SRC.

Weed species richness and weed ground cover

Cropping systems OW and OC differed in the weed species richness and ground cover ($P = 0.0061$, $F = 9.51$ and $P = 0.0000$, $F = 108.94$, respectively).

The average weed species richness and average weed ground cover was affected by crop ($P < 0.0001$), growing season ($P < 0.0001$) and crop × growing season ($P < 0.0001$) (Fig. 2), but not by termination method. In our first hypothesis we postulated that deep soil cultivation during termination of OW, initially and in both crops would reduce weed species richness and ground cover compared to shallow soil cultivation, due to that deep soil cultivation during OW would act as a weed control method. However, no effect of this one-time action was found, likely because the disturbance regime associated with SRC establishment and the disc harrowing in 2009 and 2010 in CS overruled a possible effect of termination method.

With regard to weed species richness, statistically significant differences were observed for the groups 'only SRC', 'only CS' and 'SRC + CS' within but not between growing seasons (Fig. 3). Weed species found in both SRC + CS were rare, decreased from 4.63 (2010) to 3.13 (2015). These were mostly weeds of wide distribution and common in many cropping systems (e.g. *Cirsium arvense*, *Elymus repens*, *Taraxacum officinalis*, Håkansson (2003)). SRC-specific species already dominated during the establishment year and over time continued to enlarge their share in SRC. Weed species richness in the CS however, already deviated from the richness in the SRC during the first growing season after termination, and was lower. Thereby we did not find support for our second hypothesis that seed bank and site history would result in similar weed species richness and ground cover of SRC and CS. This indicates that the seed bank typical for SRC could not be expressed in the CS, probably due to the high frequency of soil disturbance, or that historical effects on the seed bank generally are of short-term (Bohan et al., 2011). Weed flora richness and diversity was higher in SRC compared to CS. This is in accordance with previous work of Baum et al. (2012a) and Weih et al. (2003) who found that species richness was higher in fields grown with woody perennials such as willow and poplar than in cereal cultivations.

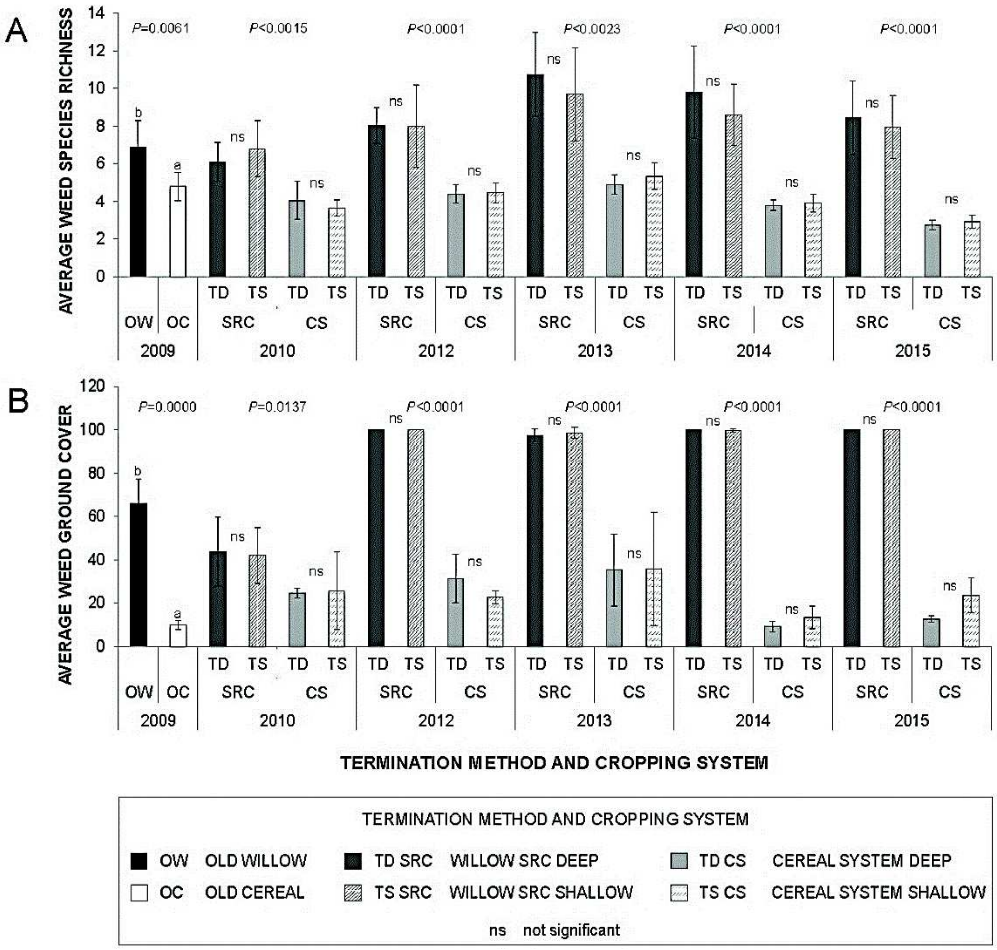

Figure 2. The average weed species richness (A) and average weed species ground cover (B) during growing seasons 2009–2010 and 2012–2015 presented for different crops: old willow (OW, black bar), old cereal (OC, white bar), willow SRC established after application of termination method with: deep soil cultivation (TD SRC, dark grey bars) andshallow soil cultivation (TS SRC, dashed bars), and cereal CS established after application of termination method with: deep soil cultivation (TD CS, light grey bars), and shallow soil cultivation (TS CS, stripped bars). Values are means (OW: *n* = 80, OC: *n* = 5, TD SRC, TS SRC, TD CS and TS CS: *n* = 20) of species richness and ground cover within blocks (± standard deviation). *P*-values indicate statistically significant differences between willow and cereal crop within growing season. An abbreviation 'ns' indicates that there were no significant differences between TD and TS within growing season.

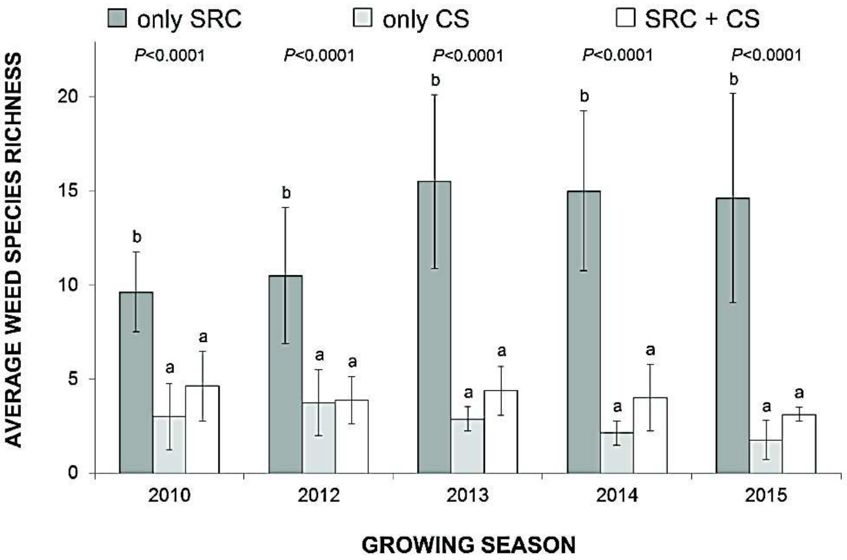

Figure 3. The average richness of weed species within groups 'only SRC' (dark grey bars), 'only CS' (light grey bars) and 'SRC + CS' (white bars) during growing seasons 2010 and 2012–2015. Values are means ($n = 4$) of weed species richness for block and within a crop (± standard deviation). Different letters and *P*–values indicate statistically significant differences between different groups of weed species within growing season. There were no significant differences within separate groups between growing seasons.

Life-cycle strategy categories

Average occurrence percentage of weed species in different life-cycle strategy categories in OW and OC, SRC and CS during all growing seasons (except 2015 for SRC) was perennials > annuals > biennials (Fig. 4, A). Average occurrence percentage of biennials fluctuated more in SRC than in CS until they were absent in SRC in 2015. An increase in the average occurrence percentage of annuals was recorded between 2013 and 2014 in SRC. This was attributed to an increase in the occurrence percentage of *Galium aparine*, *Medicago lupulina* and *Veronica arvensis* in the weed flora. The reason of this increase could not be specifically explained.

In OW and OC the average ground cover percentage of weed species in different life cycle categories was perennials > annuals > biennials. This structure remained the same during 2010 and 2012–2015 in CS but varied in SRC (Fig. 4, B) where the most pronounced change was observed for biennials. As the growing season proceeded, they were eliminated from the weed assemblages in SRC from perennials > biennials > annuals (2012), perennials > biennials = annuals (2013), perennials > annuals > biennials (2014), perennials > annuals (2015). Predominance of annuals in CS and perennials in SRC is determined mostly by the frequency of disturbances associated with management practices in specific cropping system (Håkansson, 2003). Furthermore, conversions from annual to perennial crops are known to lead to a shift from annual to perennial weed species (Andersson & Milberg, 1998) while annual weed species become dominant on arable land (Majekova et al., 2010), attributed to an increase in disturbance frequency inherent to the cropping system. Similarly, we demonstrated that a conversion from a woody perennial to an annual crop led to a shift from perennial to annual weeds.

Woody perennials disappeared rapidly after conversion to CS, while they gradually got foothold in SRC. This category also included some garden escapes like *Symphoricarpos albus* (L.) S. F. Blake and *Lonicera tatarica* L. and other native species such as *Cornus sanguinea* L., *Crataegus monogyna* Jacq., *Lonicera xylosteum* L., *Prunus padus* L., *Rhamnus cathartica* L., *Sambucus racemosa* L. and *Sorbus aucuparia* L., which all are disseminated by birds.

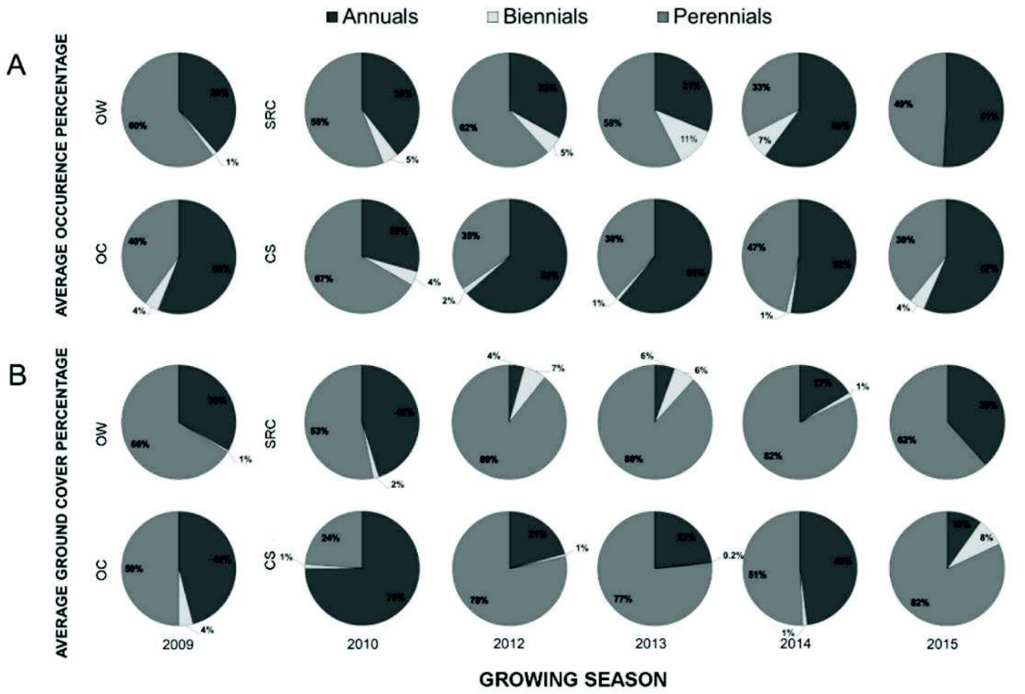

Figure 4. The average occurrence percentage in quadrants (A) and average ground cover percentage (B) of weed species per life-cycle category (% annuals, dark grey; % biennials, light grey; % perennials, grey) during growing seasons 2009–2010 and 2012–2015 presented for different crops: old willow (OW), old cereal (OC), willow short rotation coppice (SRC) and cereal system (CS).

Weed species dynamics

Weed species abundance and composition

As deduced from the direction and length of the weed species vectors, the abundance of weed species changed over time and the composition of the weed flora became progressively more crop-specific as the growing seasons proceeded (Fig. 5). From growing seasons 2010 and 2012–2015, the weed flora composition diverged along the first NMDS axis, which represents cropping system. Along the second NMDS-axis, the weed flora composition showed a separation of subplots on basis of their spatial distribution and termination method.

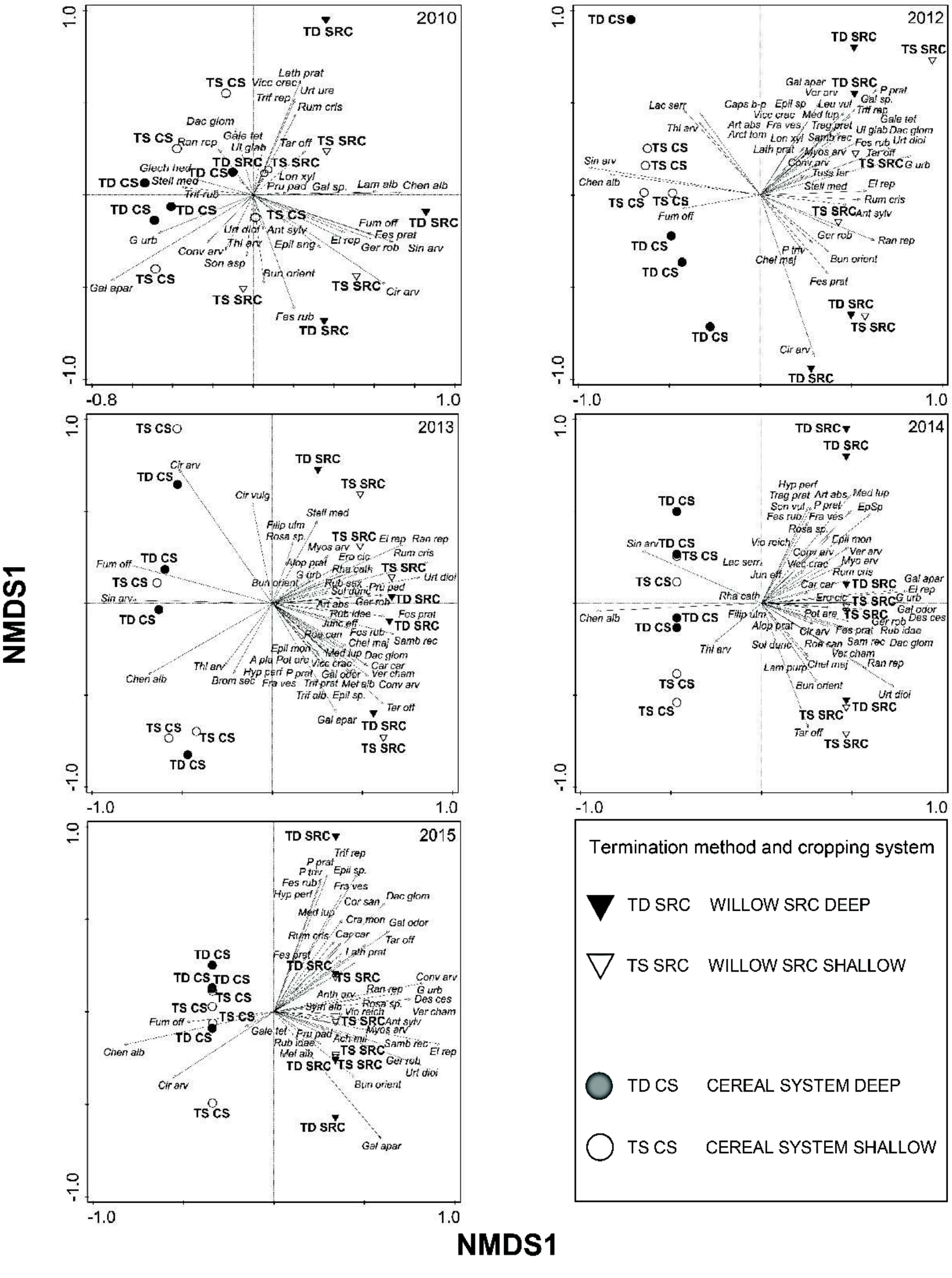

Figure 5. Gradients in the weed species composition in willow short rotation coppice (SRC) and cereal system (CS) during growing seasons 2010 and 2012–2015 assessed by Non-metric Multi-Dimensional Scaling (NMDS). NMDS axis 1: cropping system, NMDS axis 2: weed flora composition. Each point represents one subplot of willow established after application of: deep termination method (TD SRC, black triangles), and shallow termination method (TS SRC, white triangles), and cereal system established after application of: deep termination method (TD CS, light grey circles), and shallow termination method (TS CS, white circles). Identities of the weed species are encoded according to Table 1.

In SRC the abundance of *Urtica dioica* L., *Geum urbanum* and *Galium aparine* L. increased while the abundance of *Cirsium arvense* (L.) Scop. decreased during growing season 2012–2015. In CS, *Sinapis arvensis* and *Chenopodium album* were abundant weed species, whereas the abundance of *Thlaspi arvense* L. decreased during growing season 2012–2015. The weed flora in CS during 2010 contained *Geum urbanum*, *Dactylis glomerata* and *Ranunculus repens* L., which were abundant in the OW. However, the abundance of these species declined rapidly when the cultivation of CS was continued (Fig. 5). This once again stresses the importance of the cropping system specific disturbance frequency, which favours therophytes and prohibits forest species to get a foothold in cereal systems.

Divergence of the weed flora

The divergence of the weed flora during 2010 and 2012–2015, a change in specificity of a certain weed species to a certain cropping system was observed (Table 2). The indicator species analysis showed that the weed species *Sinapis arvensis*, *Chenopodium album* and *Fumaria officinalis*, were indicative weed species for SRC in growing season 2010 while only one weed species, *Elymus repens* (L.) Gould, was indicative for CS. This is likely due to the fact that willow is not a competitive crop in an early stage, thereby giving these summer annuals the opportunity for a rapid development during initial willow establishment.

Table 2. *P*-values of indicator values of weed species specific for a given category (SRC, dark grey; CS, light grey; both SRC + CS, white) during growing seasons 2010 and 2012–2015. Only statistically significant values at 95% confidence level within growing season are presented

	Growing season				
	2010	2012	2013	2014	2015
Weed species					
Sinapis arvensis	0.001	0.001	0.003	0.029	
Chenopodium album	0.001	0.002	0.002		0.001
Elymus repens	0.006	0.003	0.001	0.001	0.001
Fumaria officinalis	0.001	0.038	0.004		
Geranium robertianum		0.023	0.003	0.002	0.001
Geum urbanum		0.001	0.001	0.001	0.001
Dactylis glomerata			0.019	0.004	0.005
Ranunculus repens		0.001	0.003		0.001
Rumex crispus		0.006	0.003		
Poa pratensis		0.030		0.029	
Deschampsia cespitosa				0.001	0.002
Galium odoratum				0.019	0.007
Galium aparine				0.001	0.022

In 2012 *Geranium robertianum* and *Poa pratensis* L. were indicative for SRC, and *Sinapis arvensis* and *Chenopodium album* – for CS. A few weed species (i.e. *Elymus repens*, *Fumaria officinalis*, *Geum urbanum*, *Ranunculus repens* and *Rumex crispus* L.) were found in both cropping systems. Indicative weed species for SRC in 2013 were *Geranium robertianum*, *Geum urbanum*, *Dactylis glomerata*, *Ranunculus repens*, and *Rumex crispus*. In the same growing season only *Fumaria officinalis* was indicative species for CS. Three weed species (i.e. *Sinapis arvensis*, *Chenopodium album* and *Elymus repens*) occurred in both cropping systems. Weed species *Geranium robertianum*, *Geum urbanum*, *Dactylis glomerata*, *Poa pratensis*, *Deschampsia cespitosa* and *Galium odoratum* (L.) Scop. were indicative for SRC in 2014. S*inapis arvensis* was the only indicative weed species for CS in 2014, whereas *Elymus repens* and *Galium aparine* occurred in both cropping systems. In 2015 *Geranium robertianum*, *Geum urbanum*, *Dactylis glomerata*, *Ranunculus repens*, *Deschampsia cespitosa* and *Galium odoratum* were indicative weeds for SRC. CS had only one indicative weed species, *Chenopodium album* and *Elymus repens* and *Galium aparine* was present in both cropping systems.

Similarly to the average occurrence percentage of weed species in different life-cycle strategies, also the differences in weed species indicative for SRC and CS are likely to be determined by the frequency of disturbances associated with management practices in specific cropping system. Disturbance-sensitive weeds such as e.g., *Geum urbanum* L., *Geranium robertianum* L., *Dactylis glomerata* L., and *Deschampsia cespitosa* (L.) P. Beauv. were indicative for willow SRC in our study and also commonly found in other willow SRC (Gustafsson, 1988; Augustson, 2004) in which management was ceased. In contrast, indicators of CS which is frequently disturbed were *Chenopodium album* L., *Fumaria officinalis* L. and *Sinapis arvensis* L. which are competitors and ruderals completing their life-cycle within one growing season (Håkansson, 2003).

CS harbored annual weed species such as e.g. *Chenopodium album*, *Fumaria officinalis* and *Sinapis arvensis* during growing seasons 2012–2015, but these were also indicative for SRC in the growing season 2010. This is likely due to the fact that the old willow stand had developed many gaps in the canopy (Verwijst, 1996), thereby providing niches in which light-demanding species could maintain a seed bank. While some traces of site history were present in the form of some species (e.g. *Anthriscus sylvestris, Bunias orientalis, Fragaria vesca*, *Geum urbanum, Urtica dioica*) during the first year in CS, the divergence in weed species composition between cropping systems was immediate, which supports our third hypothesis.

NMDS analyses employed cover-abundance data (based on nominal transformation of the Braun–Blanquet methodology) which provide the information about the ground cover percentage of a given weed species in a given cropping system. The analyses revealed thus the changes in gradients of ground cover of weeds in SRC and CS over time (Fig. 5). In contrast, indicator values in indicator species analysis (Table 2) are multiplication of weed species' specificity (i.e. abundance relative to other weed species in the same weed assemblage) and their fidelity (i.e. the proportion of the ground percentage of a given species in a given crop) in a given crop. Thus, the difference between these two approaches is that NMDS revealed exclusively how much ground cover percentage is occupied by a given weed species and in a given crop, whereas indicator values showed how large is the ground cover of a given weed species (in relation to other weed species in the same assemblage) and how strongly it affiliates to a given cropping system.

Environmental conditions (inferred from Ellenberg index)

The Ellenberg index (light, soil moisture, soil N level and soil reaction) was affected by cropping system ($P < 0.0015$), growing season ($P < 0.0059$, except soil reaction) and cropping system × growing season ($P < 0.0001$). Light regime was significantly affected by cropping system in growing season 2012 and 2014 ($P < 0.0079$; Table 3). Apart from growing season 2010, soil moisture was significantly affected by the cropping system ($P < 0.0071$). The impact of the cropping system on the soil N level was significant for growing season 2012, 2014 and 2015 ($P < 0.0001$). Soil reaction was significantly affected by the cropping system for growing seasons 2012–2015 ($P = 0.0017$). This supports our fourth hypothesis that divergence of the weed species composition in SRC and CS is due to the inherent impact of the cropping systems on their environment, as inferred from the significance for the Ellenberg indices during most of the growing seasons. Soil moisture may be retained under willow, due to its litter layer and shading canopy. Also, the top soil (1–10 cm) is known to become more acid under willow SRC (Jug et al., 1999), which partly explains the divergence of the weed flora in our cropping systems (Fig. 5) towards a more acidophilus weed assemblage under the willow crop.

Table 3. *P*-values of Ellenberg index for light, soil moisture, N concentration and soil reaction during growing seasons 2010 and 2012–2015. Values statistically significant at 95% confidence level within growing seasons are presented

	Growing season				
	2010	2012	2013	2014	2015
Ellenberg index					
Light		0.0079		< 0.0001	
Soil moisture		< 0.0001	0.0071	< 0.0001	< 0.0001
Soil N level		< 0.0001		< 0.0001	< 0.0001
Soil reaction		0.0011	0.0002	< 0.0001	0.0017

CONCLUSIONS

We conclude that: 1) method of termination of willow SRC had no effect on weed species richness and ground cover, 2) the cropping system, but neither the initial seed bank nor site management history, had prevalent impact on the expression of seed bank in SRC and CS, 3) divergence in weed species composition between SRC and CS was immediate as was observed already in the first growing season after termination of old willow cultivation, and 4) the divergence in weed species composition in SRC and CS was affected by the cropping system and its inherent environmental conditions as inferred from the Ellenberg index.

Willow stands can be converted, regardless of termination method, either into cereal cultivations or willow SRC without additional risk of weed infestations other than those specific for their respective cropping systems. Winter cereals already may be sown in the growing season of willow termination. As both the SRC and CS systems harboured cropping system specific species, willow cultivations in an agriculture landscape contribute to floristic biodiversity, although their flora mainly consist of specific ruderal species which are characteristic for an anthropogenic environment.

REFERENCES

Abrahamson, L.P., Volk, T.A., Smart, L.B. & Cameron, K.D. 2010. Shrub willow biomass producer's handbook. Syracuse, New York. State University of New York, https://blogs.cornell.edu/willow/files/2014/10/ProducersHandbook-2enkbl7.pdf. Accessed 17 January 2017.

Albertsson, J., Verwijst, T., Rosenqvist, H., Hansson, D., Bertholdsson, N.O. & Åhman, I. 2016. Effects of mechanical weed control or cover crop on the growth and economic viability of two short-rotation willow cultivars. *Biomass and Bioenergy* **91**, 296–305.

Andersson, T.N. & Milberg, P. 1998. Weed flora and the relative importance of site, crop, crop rotation, and nitrogen. *Weed Science* **46**, 30–38.

Anonymous 2016. Ultuna climate station. SLU, Uppsala, Sweden. http://grodden.evp.slu.se/slu_klimat/slu_files/dygn.html. Accessed 20.06.2016.

Augustson, Å.S. 2004. Flora of vascular plants in *Salix* cultivations compared with traditional arable crops (Kärlväxtfloran i odlingar av *Salix* jämfört med traditionella jordbruksgrödor). Department of Short Rotation Forestry, Swedish University of Agricultural Sciences, Uppsala. Report 72, pp. 18 (In Swedish).

Baum, S., Bolte, A. & Weih, M. 2012a. High value of short rotation coppice plantations for phytodiversity in rural landscapes. *Global Change Biology Bioenergy* **4**, 728–738.

Baum, S., Bolte, A. & Weih, M. 2012b. Short Rotation Coppice (SRC) plantations provide additional habitats for vascular plant species in agricultural mosaic landscapes. *Bioenergy Research* **5**, 573–583.

Baum, S., Weih, M. & Bolte, A. 2012c. Stand age characteristics and soil properties affect species composition of vascular plants in short rotation coppice plantations. *BioRisk* **7**, 51–71.

Baum, S., Weih, M. & Bolte, A. 2013. Floristic diversity in Short Rotation Coppice (SRC) plantations: Comparison between soil seed bank and recent vegetation. *Landbauforschung Völkenrode* **63**, 221–228.

Bleiholder, H., Feller, C., Hess, M., Meier, U., Van Der Boom, T., Lancashire, P.D., Buhr, L., Hack, H., Klose, R., Stauss, R., Weber, E. & Munger, P. 1997. *Compendium of growth stage identification keys for mono- and dicotyledonous plants. Extended BBCH scale. 2nd edition*.

Bohan, D.A., Powers, S.J., Champion, G., Haughton, A.J., Hawes, C., Squire, G., Cussans, J. & Mertens, S.K. 2011. Modelling rotations: can crop sequences explain arable weed seedbank abundance? *Weed Research* **51**, 422-432.

Braun-Blanquet, J. 1932. *Plant sociology (Transl. G. D. Fuller and H. S. Conrad)*. McGraw-Hill, New York.

Braun-Blanquet, J. 1964. *Plant sociology: Basic principles of vegetation science (Pflanzensoziologie: Grundzüge der Vegetationskunde)*. Springer-Verlag, Wien, Third edition, pp. 330 (In German).

Caslin, B., Larsson, S. & Mccracken, A. 2010. Short Rotation coppice willow - best practice guidelines. Teagasc, Crops Research Centre, Oak Park, Carlow, Ireland. http://www.seai/Renewables/Bioenergy/Willow_Best_Practice_Guide_2010.pdf. Accessed 17 January 2017.

Chapin, F.S., Bret-Harte, M.S., Hobbie, S.E. & Zhong, H. 1996. Plant functional types as predictors of transient responses of arctic vegetation to global change. *Journal of Vegetation Science* **7**, 347–358.

Clarke, K.R. 1993. Nonparametric multivatiate analysis och changes in community structure. *Australian Journal of Ecology* **18**, 117–143.

Cunningham, M.D., Bishop, J.D., Watola, G., Mckay, H.V. & Sage, R.B. 2006. The effect on flora and fauna of converting grassland to Short Rotation Coppice. Project report. http://webarchive.nationalarchives.gov.uk/+/http:/www.berr.gov.uk/files/file30621.pdf. Accessed 17 January 2017.

Diekmann, M. 1995. Use and improvement of Ellenberg's Indicator Values in deciduous forests of the Boreo-Nemoral zone in Sweden. *Ecography* **18**, 178–189.

Diekmann, M. & Lawesson, J. 1999. Shifts in ecological behaviour of herbaceous forest species along a transect from northern central to North Europe. *Folia Geobotanica* **34**, 127–141.

Dufrêne, M. & Legendre, P. 1997. Species assemblages and indicator species: the need for a flexible asymmetrical approach. *Ecological Monographs* **67**, 345–366.

Ellenberg, H. 1992. *Zeigerwerte von Pflanzen in Mitteleuropa*. E. Goltze (Göttingen).

Grandin, U. 2004. Dynamics of understory vegetation in boreal forests: experiences from Swedish integrated monitoring sites. *Forest Ecology and Management* **195**, 45–55.

Grime, J.P., Hodgson, J.G. & Hunt, R. 2007. *Comparative plant ecology: a functional approach to common British species.* Castelpoint Press, Kirkcudbrightshire, Great Britain, Second edition, pp. 762.

Gustafsson, J., Larsson, S. & Nordh, N.E. 2007. Manual för Salixodlare. http://www.bioenergiportalen.se/attachments/42/406.pdf. Accessed 17 January 2017.

Gustafsson, L. 1986. Vegetation and flora of short-rotation willow stands from a conservation viewpoint. Doctoral thesis. Swedish University of Agricultural Sciences, Uppsala, Sweden.

Gustafsson, L. 1988. Vegetation dynamics during the establishment phase of an energy forest on a riverside in south-western Sweden Swedish University of Agricultural Sciences, Faculty of Forestry Uppsala, Department of Ecology and Environmental Research, Studia Forestalia Suecica NO. 178.1988

Helby, P., Rosenqvist, H. & Roos, A. 2006. Retreat from Salix - Swedish experience with energy crops in the 1990s. *Biomass & Bioenergy* **30**, 422–427.

Hollsten, R., Arkelöv, O. & Ingelman, G. 2012. Handbok för Salixodlare. Jordbruksverket (Swedish Board of Agriculture), Jönköping, Sweden. http://www2.jordbruksverket.se/webdav/files/SJV/trycksaker/. Accessed 17 January 2017.

Håkansson, S. 2003. *Weeds and weed management on arable land: an ecological approach*. CABI Publishing, UK, pp. 288.

Jug, A., Makeschin, F., Rehfuess, K.E. & Hofmann-Schielle, C. 1999. Short-rotation plantations of balsam poplars, aspen and willows on former arable land in the Federal Republic of Germany. III. Soil ecological effects. *Forest Ecology and Management* **121**, 85–99.

Lid, J. & Lid, D.T. 2005. *The Norwegian flora* (*Norsk flora)*, Elven R. (editor). The Norwegian Publishing House (Det Norska Samlaget), Oslo, Norway, Seventh edition, pp. 808 (In Norwegian).

Majekova, J., Zaliberova, M., Sibik, J. & Klimova, K. 2010. Changes in segetal vegetation in the Borská nížina Lowland (Slovakia) over 50 years. *Biologia* **65**, 465–478.

Mola-Yudego, B. 2010. Regional potential yields of short rotation willow plantations on agricultural land in Northern Europe. *Silva Fennica* **44**, 63–76.

Norberg, I. & Nordh, N.-E. 2012. *Termination of a willow cultivation – fastest and cheapest by shallow cultivation* (Att avsluta en salixodling - snabbast och billigast med ytlig uppbrytning). JTI-Informerar, JTI:s Skriftserie 2012:2, pp. 2–12 (In Swedish).

Olsson, M.T. & Samils, B. 1984. *Site characterisation an energy forest production*. Report no 48, Department of Forest Soils, Swedish University of Agricultural Sciences, Uppsala, Sweden.

Pučka, I., Lazdiņa, D. & Bebre, I. 2016. Ground flora in plantations of three years old short rotation willow coppice *Agronomy Research* **14**, 1450–1466.

Rahman, M.M., B. Mostafiz, S., Paatero, J.V. & Lahdelma, R. 2014. Extension of energy crops on surplus agricultural lands: A potentially viable option in developing countries while fossil fuel reserves are diminishing. *Renewable and Sustainable Energy Reviews* **29**, 108–119.

Raunkiær, C. 1934. *The life-forms of plants and statistical plant geography being the collected papers of C. Raunkiær*. Oxford University Press, Oxford, Great Britain, pp. 632.

Roberts, D.W. 2010. Labdsv: Ordination and Multivariate Analysis for Ecology. R package version 14-1 http://CRAN.R-project.org/package=labdsv. Accessed 04 November 2016.

Stjernquist, I. 1994. An integrated environmental analysis of short rotation forests as a biomass resource. *Biomass and Bioenergy* **6**, 3–10.

Ter Braak, C.J.F. & Šmilauer, P. 1997–2012. Biometrics, Plant Research International.

Van Der Maarel, E. 2007. Transformation of cover-abundance values for appropriate numerical treatment - Alternatives to the proposals by Podani. *Journal of Vegetation Science* **18**, 767–770.

Weih, M., Karacic, A., Munkert, H., Verwijst, T. & Diekmann, M. 2003. Influence of young poplar stands on floristic diversity in agricultural landscapes (Sweden). *Basic and Applied Ecology* **4**, 149–156.

Verwijst, T. 1996. Cyclic and progressive changes in short-rotation willow coppice systems. *Biomass and Bioenergy* **11**, 161–165.

Verwijst, T., Lundkvist, A., Edelfeldt, S. & Albertsson, J. 2013. Development of Sustainable Willow Short Rotation Forestry in Northern Europe. In: *Biomass Now - Sustainable Growth and Use*, Matovic, M. D. (editor). Published jointly by CAB International and FAO, pp. 634, InTech, DOI: 10.5772/55072. Available from: https://www.intechopen.com/books/biomass-now-sustainable-growth-and-use/development-of-sustainable-willow-short-rotation-forestry-in-northern-europe

Willebrand, E. & Verwijst, T. 1993. Population dynamics of willow coppice systems and their implications for management of short-rotation forests. *The Forestry Chronicle* **69**, 699–704.

Volk, T.A., Verwijst, T., Tharakan, P.J., Abrahamson, L.P. & White, E.H. 2004. Growing fuel: a sustainability assessment of willow biomass crops. *Frontiers in Ecology and the Environment* **2**, 411–418.