AGRICULTURAL AND FOOD SCIENCE

Vol. 20(2011): 245–261.

Composition of weed flora in spring cereals in Finland – a fourth survey

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The weed flora in conventionally and organically grown spring cereals was investigated in southern and central Finland during 2007–2009. The survey was conducted in 16 regions, 283 farms and 595 fields (72 organically cropped and 523 conventionally cropped fields, of which 503 were treated with herbicides). The occurrence of weeds was assessed in late July–early August. Altogether 148 weed species were identified, of which 128 were broad-leaved and 20 grass species. In organically cropped fields, the average species number per field was 21 and the most frequent species were *Chenopodium album* 96%, *Stellaria media* 94%, *Viola arvensis* 94% and *Elymus repens* 89%. In conventionally cropped fields, the average species number was 12 and the most frequent weed species were *Viola arvensis* 83%, *Stellaria media* 65%, *Galeopsis* spp. 59% and *Galium spurium* 59%. The average density of weeds was 160 m^{-2} (median = 112) in sprayed conventional fields and 519 m^{-2} (468) in organic fields. The average air-dry biomass of weeds was 167 kg ha^{-1} (median = 82) and 775 kg ha^{-1} (563), respectively. *Elymus repens,* the most frequent and abundant grass species, produced the highest proportion (about 30%) of the total weed biomass in both cropping systems. The frequency of *Galium spurium* in conventional cropping and *Fumaria officinalis* in organic cropping had increased substantially since the previous survey in 1997–1999. The average size of the weed seedbank in the 5 cm surface layer was about 1 700 seeds m^{-2}, the most predominant seeds being of *C. album*. Although the weed flora in Finnish spring cereal fields consists of numerous species, only a fraction of them severely threaten crop production in terms of their frequency and abundance. Weeds in conventional cropping were effectively controlled with available herbicides whereas weed management in organic cropping calls for urgent measures such as direct mechanical weed control in crop stands, which was not practised at all in survey fields.

Key-words: weeds, spring cereals, biodiversity, conventional farming, organic farming, crop protection, seedbank, *Elymus repens*, *Viola arvensis*, *Galium spurium*

Manuscript received November 2010

Introduction

Three extensive surveys of weeds in spring cereal fields have been carried out in Finland since the 1960s, the first in 1961–1964 (Mukula et al. 1969), the second in 1982–1984 (Erviö and Salonen 1987) and the third in 1997–1999 (Salonen et al. 2001a). In addition to conventionally cropped fields, organically cropped fields were included in the survey protocol in the 1990s.

Similar comprehensive weed surveys have been conducted earlier in many countries, but new surveys and follow-up monitoring have been realized to a lesser extent. Nonetheless, recent information on composition of weed floras and factors affecting weed floras in cereal fields is available, e.g. from Bulgaria (Milanova et al. 2009), Denmark (Andreasen and Stryhn 2008, Andreasen and Skovgaard 2009), France (Fried et al. 2008), Hungary (Novak et al. 2010), the UK (Potts et al. 2010) and the US (Conn et al. 2011). In Finland, a small-scale survey of weeds in organically cropped spring cereals in coastal regions was carried out in the early 2000s (Riesinger and Hyvönen 2006a). Recently, the EWRS (European Weed Research Society) established a working group on weed mapping to facilitate communication among research groups monitoring weeds in arable habitats in Europe (http://www.ewrs.org/weedmapping/default.asp).

Since the previous extensive weed survey in Finland (Salonen et al. 2001a), which was conducted in 1997–1999, agri-environment policy has influenced the preconditions for cereal production. Some measures originating from EU regulations, such as restricted use of fertilizers, demand for over-wintering plant cover, reduced tillage and uncultivated buffer zones along watercourses have been extensively implemented in Finnish farms. Furthermore, several studies have demonstrated that organic farming clearly promotes weed floras, both in terms of diversity and abundance (e.g. van Elsen 2000, Salonen et al. 2001b, Hyvönen et al. 2003a, Hyvönen 2007, Romero et al. 2008).

In the present study, we report the results of the fourth extensive weed survey of Finnish spring cereals, conducted in 2007–2009. We expected that continuous changes in cropping practices affect the species composition of the weed flora and the level of weed infestation, as discussed for instance by Andreasen and Streibig (2010). This report focuses on the composition of weed flora in spring cereals in 2007–2009. The changes in weed occurrence over the decades will be reported in detail separately.

As a supplement to previous weed surveys, sampling of soil seed banks was included in the present survey. The seed density data provide information on the potential of germinating weed seedlings in the soil. Reference mapping of soil seed banks in cultivated soils in Finland dates back to the 1960s (Paatela and Erviö 1971). Since then factors like the use of herbicides (Hyvönen and Salonen 2003), crop rotations (Sjursen 2001) and changes in tillage practices (Yenish et al. 1992) have been of central importance in determining the amount of seeds in the soil seed bank.

Weed surveys in spring cereal fields in Finland are important in terms of crop dominance as spring cereals account for more than half of the total cropped area of around 2 million hectares (Niemi and Ahlstedt 2009). In addition to biodiversity aspects (species richness, high-value species, findings of new alien species etc.), the updated information on weed infestation is aimed at farmers, advisory services and the chemical industry, with a view to promoting specific weed control measures. Weed shift is of agronomic interest primarily as regards the most abundant weeds species.

Material and methods

Study regions, farms and fields

The weed survey was carried out in southern and central Finland in 2007–2009 (Fig. 1). The highest number of fields (N = 369) was studied in southern Finland (Table 1), where spring cereals are grown on more than 50% of the arable area and annual spring-sown crops are predominant. The number of study fields decreased towards the east and north,

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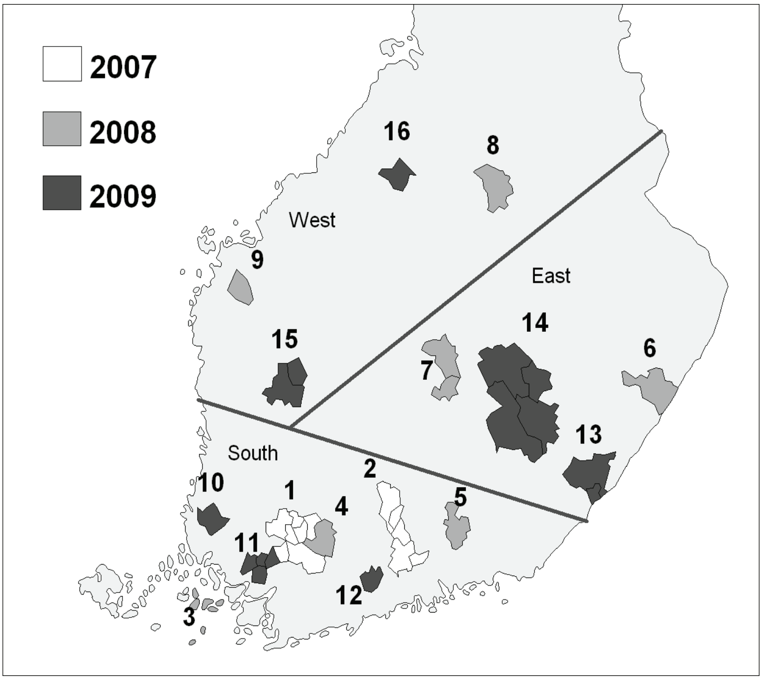

Fig.1. Weed survey regions (1-16) in three zones in 2007-2009. Key to region numbers: 1 = Jokioinen, 2 = Lammi, 3 = Nauvo/Korppoo, 4 = Tammela, 5 = Iitti, 6 = Kitee, 7 = Laukaa/Toivakka, 8 = Vieremä, 9 = Laihia, 10 = Laitila, 11 = Lieto/Paimio, 12 = Nurmijärvi, 13 = Ruokolahti, 14 = Mikkeli, 15 = Kihniö/Parkano, 16 = Nivala.

where spring cereals account for less than 50% of the cultivated area, and many farms include grassland in their crop rotation.

The number of farms visited was 283, of which 243 were engaged in conventional and 40 in organic farming. Three survey regions, Nauvo/Korppoo (region number 3), Tammela (4) and Laihia (9), were study regions without organically cultivated survey fields. The proportion of organic survey fields was highest, 30–35%, in eastern Finland (regions 6, 7 and 13) and in Kihniö/Parkano (15). The difference in cropping systems between survey regions is reflected to some extent in the results on overall weed occurrence.

One to five spring cereal fields were examined on each farm, giving a total of 595 fields: 267 under barley (*Hordeum vulgare* L.), 175 under oats (*Avena sativa* L.), 148 under wheat (*Triticum aestivum* L.) and 5 under oat/pea or spring-sown rye cultivation. Altogether 523 study fields were cultivated conventionally and 72 organically.

The average area of the study fields was 5.7 ha (range 0.3 ha– 35.6 ha) and the total area surveyed, 3 378 ha. In the largest fields the investigated area was restricted to a maximum of 25 ha and in some fields the surveyed field area was adjusted according to previous surveys. The same 16 regions were surveyed ten years ago and altogether 443 out of the 595 surveyed fields were the same as in 1997–1999 (Salonen et al. 2001a).

A great majority of study fields had been sown by mid-May (mainly during weeks no. 18–20) and sprayed with herbicides by the end of June (weeks no. 24–26).

The permission to investigate weeds in survey fields was asked from farmers only in early July with the aim that all cropping practices influencing the weed infestation, including the level of fertilization or choice of herbicide product, dose and time of application, were realized according to “house-style”. At the sampling time, information on cropping measures was recorded by interviewing the farmers.

Herbicides had been applied in 503 out of 523, i.e. 96%, conventionally cultivated fields. A common reasoning for not using chemical weed control

Table 1. Number of fields surveyed by region, production type and cereal species.

Region			Number of fields					
				Production type		Cereal species[7]		
Year Municipality	No	Zone[5]	Total	Conventional [6]	Organic	Barley	Oat	Wheat
2007								
Jokioinen[1]	1	S	43	37 (36)	6	23	14	5
Lammi[2]	2	S	50	45 (42)	5	18	15	17
2008								
Nauvo/Korppoo	3	S	28	28 (26)	0	9	10	9
Tammela	4	S	40	40 (40)	0	20	14	6
Iitti	5	S	35	31 (27)	4	13	12	8
Kitee	6	E	20	13 (10)	7	8	10	2
Laukaa/Toivakka	7	E	35	32 (30)	3	12	19	3
Vieremä	8	W	26	24 (20)	2	18	6	2
Laihia	9	W	41	41 (41)	0	24	1	16
2009								
Laitila	10	S	48	43 (42)	5	27	14	7
Lieto/Paimio[3]	11	S	66	60 (60)	6	18	7	40
Nurmijärvi	12	S	59	52 (52)	7	24	11	24
Imatra/Ruokolahti	13	E	23	15 (15)	8	9	10	4
Mikkeli[4]	14	E	25	17 (17)	8	9	13	3
Kihniö/Parkano	15	W	26	18 (18)	8	10	16	
Nivala	16	W	30	27 (27)	3	25	3	2
Total			595	523 (503)	72	267	175	148

[1] including Humppila, Jokioinen, Koski Tl, Loimaa municipality, Somero, Ypäjä
[2] including Hämeenkoski, Kärkölä, Lammi, Mäntsälä, Pukkila
[3] including Lieto, Marttila, Paimio, Tarvasjoki
[4] including Joroinen, Juva, Jäppilä, Mikkeli, Pertunmaa
[5] S = South, E = East, W = West
[6] number of sprayed fields in parentheses
[7] added to this 5 fields with either cereal/pea or spring-sown rye

was either rainy weather conditions, particularly in 2008, or undersown clover/grass mixture. Four major types of active ingredients were used: pure MCPA (4-chloro-2-methylphenoxyacetic acid) in 7% of treated fields, phenoxy acid mixtures (22%), sulphonylureas (50%) and phenoxy acids + sulphonylurea tank mixtures (20%).

Weed sampling

The weed survey was carried out in 2007–2009 during a 4-week period starting in mid-July (weeks no. 28–29), by which time the spring cereals had reached their heading stage and in most cases around one month had elapsed since herbicide treatment.

The weed sampling protocol was exactly the same as in the previous survey in 1997–1999 (Salonen et al. 2001a). The occurrence of weeds was assessed from 10 sample quadrats randomly placed in each field. For this purpose, each field was split into a 10 x 10 cell grid in which the positions of sample quadrats were set with a random number calculator. The size of grid cells varied among fields according to the area of each field.

Weed density was determined by counting the number of plants or shoots of grass weeds by spe-

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cies in a rectangular frame measuring 0.1 m^2 (25 cm × 40 cm), which was a corner area within a larger quadrat measuring 1.0 m^2 (1.0 m × 1.0 m). The larger quadrat was used for observations on the presence/absence of each species. The results presented in the tables and figures derive from data collected from the 0.1 m^2 quadrats and pooled over the 10 samples in each field. A complete list of the additional weed species found in the presence/absence observation (1 m^2) is given in Appendix 1 as a supplement to the 40 most frequent species presented in the tables.

In four out of ten small sample quadrats, weeds and cereals were cut at the soil surface and their biomass was weighed by species after the samples had been dried in an air-flow dryer at 40°C for several days. The air-dry biomass results are presented in kg ha^{-1} which is the equivalent of 10 × g m^{-2}.

Seed bank sampling

The seed sampling was conducted by taking one soil sample (10 × 10 cm in size, around 5 cm depth) from every weed sampling quadrat (0.1 m^2, see above). The ten samples were mixed in the bucket and one 4 deciliter soil sample was taken for the final sample. Soil samples were taken to the laboratory and dried at room temperature. Seeds were separated from soil with tweezers and identified by species.

Nomenclature and data analysis

All weed species found in sampling areas were assessed. Nevertheless, some genera or taxa, e.g. *Galeopsis* spp. and *Lamium* spp., were pooled since they could not be unequivocally identified to species level at the small seedling stage.

The plant species nomenclature follows Hämet-Ahti et al. (1998), and the abbreviations of species names are according to the EPPO code system (formerly BAYER codes) available at the EPPO web site (www.eppo.org). The full scientific names with attribution are given to the 40 most frequent species (Table 2).

The term frequency indicates the proportion of fields where the species was found. Differences between frequency values were tested with Fisher's Exact Test. For each field, the total weed density and biomass were summed, and the averages, standard deviations and median values are presented by survey regions. Differences between the regions were tested with log-transformed values using the MIXED procedure of SAS 9.2 (SAS Institute Inc, Cary, NC, USA). If not mentioned otherwise, the specific results concerning the weed occurrence in conventional cropping derive from the 503 fields treated with herbicides, i.e. the 20 non-sprayed fields were excluded.

The similarity of species composition between zones was compared using Jaccard's similarity coefficient S_j (Jaccard 1912) (S_j=c/(A+B-c), where c = number of species common to both samples A and B, A = number of species in sample A, B = number of species in sample B). The data were pooled over all fields of each zone before the analysis.

The diversity of weed species was described by species richness. The number of species was used as a measure of species richness. Since the number of species depends on the sample size and since the number of sampled fields varied among zones, regions and production types total species numbers could not be compared directly. Therefore, the expected number of species $E(S_n)$ was calculated for each zone, region and production type using rarefaction:

$$E(S_n) = \sum_{i=1}^{S} \left(1 - \frac{\binom{N - N_i}{n}}{\binom{N}{n}} \right)$$

where $E(S_n)$ = expected number of species in a random sample of n individuals, S = total number of species in the entire collection, N_i = number of individuals in species i, N = total number of individuals in the collection, n = sample size (number of individuals) chosen for standardization (see Heck et al. 1975).

Table 2. Frequencies (%) of weed species by regions

Species / Taxon	Year / Region 2007		2008							2009							Average 2007–09
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
Achillea millefolium L	0	8	0	0	9	20	9	0	2	2	2	8	17	4	8	0	5
Alopecurus geniculatus L.	5	0	0	0	3	5	6	12	2	0	8	7	4	4	8	10	4
Artemisia vulgaris L.	0	10	0	3	0	20	0	0	0	21	0	14	17	4	8	0	6
Brassica rapa L. ssp. *oleifera* (DC.) Metzg.	9	4	4	3	3	10	3	0	10	4	0	3	4	24	4	3	5
Capsella bursa-pastoris (L.) Medik.	23	14	25	23	34	60	37	35	15	42	9	22	35	56	19	30	27
Cerastium fontanum Baumg.	7	6	0	5	11	60	0	27	0	0	0	12	9	12	12	0	8
Chenopodium album L.	65	56	57	60	63	90	66	62	78	44	64	31	70	48	35	83	59
Cirsium arvense (L.) Scop.	26	52	4	20	37	40	9	19	24	19	44	32	35	24	12	23	28
Elymus repens (L.) Gould	30	50	46	63	51	80	63	85	54	46	45	44	96	72	69	63	56
Epilobium angustifolium L.	0	6	0	8	9	0	14	12	0	2	2	0	4	4	12	13	5
Equisetum arvense L.	16	18	32	5	9	5	11	19	5	13	30	20	9	8	8	7	15
Erysimum cheiranthoides L.	19	38	39	20	40	80	69	96	29	19	18	15	39	44	46	27	35
Fallopia convolvulus (L.) À. Löve	51	62	39	68	54	45	26	8	78	38	70	68	96	28	12	63	53
Fumaria officinalis L.	58	64	39	43	63	60	66	42	29	35	53	69	65	36	27	17	49
Galeopsis L. spp.[a]	72	72	29	70	74	80	60	58	51	50	76	54	70	48	85	70	64
Galium spurium L.[b]	77	48	71	78	77	20	31	19	76	52	71	64	74	16	23	13	55
Gnaphalium uliginom L.	5	36	0	30	37	75	66	88	2	25	0	8	43	64	58	17	29
Juncus bufonius L.	0	0	0	3	14	20	0	23	0	2	0	0	0	16	12	0	4
Lamium L. spp.[c]	42	28	93	35	54	10	14	0	20	60	68	56	48	24	8	7	39
Lapsana communis L.	51	78	71	65	91	70	86	8	20	79	41	68	91	80	19	3	58
Matricaria matricarioides (Less.) Porter	16	20	7	25	29	55	57	58	17	21	12	19	52	52	58	47	29
Myosotis arvensis (L.) Hill	42	58	32	38	66	70	69	54	39	40	44	39	57	76	38	33	48
Persicaria lapathifolia (L.) Gray	21	36	14	43	26	50	46	31	17	15	44	34	57	48	62	60	36
Phleum pratense L.	2	6	0	3	3	25	3	12	12	4	2	5	0	12	15	7	6
Plantago major L.	5	18	7	5	11	55	31	42	5	8	5	14	13	24	4	10	14
Poa annua L.	12	14	14	25	14	45	71	65	29	33	21	20	9	44	62	60	31
Poa pratensis L.	2	14	0	5	3	35	11	19	7	13	8	2	0	12	4	3	8
Polygonum aviculare L.	35	40	36	53	57	65	57	58	44	60	61	59	26	40	62	73	52
Ranunculus repens L.	7	26	7	8	29	65	40	69	7	4	9	19	26	24	50	20	22
Sonchus arvensis L.	40	66	54	53	49	30	46	31	27	27	21	37	48	36	35	33	39
Sonchus asper (L.) Hill	7	10	0	5	0	0	0	0	5	0	20	5	0	0	0	0	5
Spergula arvensis L.	16	46	32	53	34	85	71	62	22	44	24	17	78	56	88	43	43
Stellaria media (L.) Vill.	86	54	50	83	66	80	57	58	78	73	82	47	78	60	73	80	69
Taraxacum Weber spp.	53	64	14	40	60	70	17	81	32	6	24	63	57	24	8	17	39
Thlaspi arvense L.	14	16	11	5	26	15	0	0	10	0	2	3	22	4	12	10	8
Trifolium L. spp.[d]	35	54	7	40	31	65	57	77	12	15	27	12	13	36	23	17	31
Tripleurospermum inodorum (L.) Sch. Bip.	63	62	57	40	60	30	43	19	17	23	53	42	43	12	31	30	41
Veronica L. spp.[e]	2	2	14	5	9	25	6	38	10	15	2	15	22	28	15	0	11
Vicia L. spp.[f]	12	32	11	18	17	15	9	4	7	10	14	10	26	32	12	3	14
Viola arvensis Murray[g]	79	98	89	85	89	100	91	92	83	98	70	69	83	96	88	83	85

[a]mainly *G. bifida* and *G. speciosa*, [b]incl. *G. aparine*, [c]mainly *L. purpureum*, [d]mainly *T. repens*, [e]mainly *V. serpyllifolia*, [f]mainly *V. cracca*, [g]incl. *V. tricolor*

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In rarefaction, the number of species of larger samples is scaled down to the given number of individuals, which permits the comparison of species numbers among samples differing in size. Since the lowest numbers of individuals observed were 23081, 5316 and 37403 for zone, region and production type, respectively, we scaled sample sizes down to 23000, 5000 and 37000, respectively. Data from the ten 0.1 m^2 sample quadrats were pooled before the calculation.

Results

Species richness

In total 175 weed species were found in the large (1.0 m^2) sampling quadrats and 148 in the small (0.1 m^2) quadrats (see Appendix 1 for the species recorded in large quadrats but not included in the list of 40 most frequent species). The majority (i.e. 110 species) of the observed species occurred in less than 5% of the fields studied. Altogether 104 species were observed in organically cropped fields (N = 72) and 133 species in conventionally cropped, herbicide-treated fields (N = 503).

The total number of observed species, S_{OBS}, in regions ranged from 48 to 76 (Table 3). In four regions (Jokioinen, Nauvo/Korppoo, Laihia and Laitila), the number of observed species was below 50 and in one region (Nurmijärvi) it exceeded 70. The same regions had the lowest and the highest expected number of species, $E(S_n)$, calculated by rarefaction analysis (Table 3). The total number of species was greatest in the southern and lowest in the western zone. The species composition of the southern zone was also most dissimilar among zones (Jaccard's similarity: east vs. south = 0.411, south vs. west 0.311 and east vs. west 0.59).

Surprisingly, the total species number for conventionally farmed fields exceeded that for organically farmed fields (Table 3). However, the average observed species number was higher in organically farmed fields, 21 (SD = 4.5, min 11, max 34), than in conventionally farmed fields, 12 (SD = 4.7., min 3, max 26).

Frequency of weed species

The occurrence of the 40 most frequent weed species in the small 0.1 m^2 sample quadrats is presented by region (Table 2) and the remaining species observed from the larger 1.0 m^2 quadrats are listed by region (Appendix 1). The most common weeds were broad-leaved species, including

Table 3. Observed (SOBS) and rarefied (E(Sn) and SD) number of species by zone, region and production type.

	S_{OBS}	$E(Sn)$[a]	*SD*
Zone			
South	131	113	2.91
East	105	101	1.81
West	84	84	0.16
Region			
Jokioinen	49	48.4	0.69
Lammi	64	60.1	1.55
Nauvo/Korppoo	48	47.5	0.71
Tammela	63	59.1	1.60
Iitti	64	58.5	1.82
Kitee	63	61.3	1.18
Laukaa/Toivakka	63	55.5	2.01
Vieremä	57	57.0	0.17
Laihia	49	48.3	0.78
Laitila	49	45.7	1.44
Paimio/Tarvasjoki	62	56.2	1.86
Nurmijärvi	76	71.5	1.75
Imatra/Ruokolahti	64	60.6	1.42
Mikkeli mlk	65	62.9	1.28
Kihniö/Parkano	56	54.1	1.22
Nivala	51	50.6	0.64
Production type			
Organic	105	105	0.33
Conventional	135	123	2.63

[a]The number of individuals used in the analysis: zone 23000, region 5000 and production type 37000

Viola arvensis, *Stellaria media* and *Galeopsis* spp., which were frequently found both in conventionally and organically cropped fields. Nevertheless, there were evident differences in the ranking list of predominant weed species and their frequency levels between conventionally and organically cropped fields (Table 4).

With a frequency of 56%, *Elymus repens* was by far the most common grass weed (Table 4). The next most common grass species were *Poa annua* (31%), *Poa pratensis* (8%), *Phleum pratense* (6%) and *Alopecurus geniculatus* (4%). Altogether 23 grass species were identified in the sample quadrats (1.0 m^2).

Highly productive perennial broad-leaved weed species occurred more frequently ($p < 0.001$) in organic than in conventional farming; *Sonchus arvensis* had a frequency of 61% in organic and 35% in conventional fields and *Cirsium arvense* 46% and 25%, respectively. Typical grassland weed species such as *Achillea millefolium* 26% vs. 1% and *Ranunculus repens* 47% vs. 17% were more frequent ($p < 0.001$) in organic than in conventional farming.

Some weed species were characteristic of certain regions or zones in Finland; e.g. *Lamium* spp. and *Galium spurium* were most frequently found in southern regions, whereas the frequency of *Elymus repens*, *Gnaphalium uliginosum, Matricaria matricarioides, Poa annua* and *Spergula arvensis* increased towards the north. One of the most common species, *Lapsana communis*, was relatively rare in the regions of western Finland.

Weed density

The average density of weeds in all fields surveyed was 209 plants m^{-2} (SD = 211, median = 138, N = 595) (Table 5). However, the difference between the two cropping systems was considerable; the average density of weeds in sprayed conventional fields was 160 plants m^{-2} (SD = 155, median = 112,

Table 4. Frequency of ten most common weed species in two cropping systems and the change in frequency-% from 1997–1999 to 2007–2009. For comparison, additional four species from the other cropping system are included.

	Sprayed conventional (N = 503)			Organic (N = 72)		
Rank	Weed species	%	Change	Weed species	%	Change
1	*Viola arvensis*	83	+2	*Chenopodium album*	96*	0
2	*Stellaria media*	65	0	*Stellaria media*	94*	-1
3	*Galeopsis* spp.	59	-1	*Viola arvensis*	94*	+1
4	*Galium spurium*	59	+16	*Elymus repens*	89*	+8
5	*Lapsana communis*	57	+5	*Spergula arvensis*	89*	+6
6	*Fallopia convolvulus*	53	+5	*Galeopsis* spp.	88*	-5
7	*Chenopodium album*	52	-1	*Erysimum cheiranthoides*	86*	+4
8	*Elymus repens*	50	-9	*Myosotis arvensis*	72*	+12
9	*Fumaria officinalis*	48	+9	*Polygonum aviculare*	72*	+2
10	*Polygonum aviculare*	48	-2	*Persicaria lapathifolia*	68*	+15
	Spergula arvensis	34	-1	*Galium spurium*	39*	+2
	Erysimum cheiranthoides	25	-4	*Lapsana communis*	60	+3
	Myosotis arvensis	44	+4	*Fallopia convolvulus*	58	-5
	Persicaria lapathifolia	30	-3	*Fumaria officinalis*	58	+17

* indicates significant difference in species frequencies between cropping systems (Fisher's Exact Test, $p < 0.05$)

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Table 5. Weed density (plants m^{-2}) by regions. + indicates < 1 plant m^{-2}

Species / Taxon	Year / Region																Average
	2007		2008							2009							2007–09
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
Achillea millefolium	0	+	0	0	+	2	+	0	+	+	+	1	+	+	+	0	+
Alopecurus geniculatus	+	0	0	0	+	1	2	2	+	0	2	+	+	+	+	+	+
Artemisia vulgaris	0	+	0	+	0	+	0	0	0	+	0	+	+	+	+	0	+
Brassica rapa ssp. *oleifera*.	+	+	+	+	+	+	+	0	+	+	0	+	+	1	+	+	+
Capsella bursa-pastoris	+	+	2	1	4	13	7	2	+	2	+	+	7	7	+	4	3
Cerastium fontanum	+	+	0	+	+	3	0	+	0	0	0	+	1	+	+	0	+
Chenopodium album	15	30	26	27	12	39	11	8	36	32	19	10	39	55	7	27	23
Cirsium arvense	+	2	+	1	1	+	+	+	+	+	3	+	1	+	+	+	+
Elymus repens	8	17	16	15	27	21	18	27	16	10	11	13	73	32	51	17	20
Epilobium angustifolium	0	+	0	+	+	0	+	+	0	+	+	0	+	+	+	+	+
Equisetum arvense	+	1	2	+	+	+	+	+	+	+	+	1	1	+	+	+	+
Erysimum cheiranthoides	+	2	4	+	5	19	7	9	1	2	2	+	6	8	15	3	4
Fallopia convolvulus	6	4	2	7	4	2	1	+	5	2	5	6	6	2	+	4	4
Fumaria officinalis	4	3	2	3	7	3	9	2	1	2	6	7	17	+	1	1	4
Galeopsis spp.	7	9	11	8	13	8	7	9	9	8	13	21	5	13	8	12	11
Galium spurium	20	12	14	13	12	1	2	2	12	18	8	9	5	1	+	+	9
Gnaphalium uliginosum	+	3	0	8	21	40	16	14	+	+	0	2	3	5	8	+	6
Juncus bufonius	0	0	0	+	3	3	0	+	0	+	0	0	0	3	+	0	+
Lamium spp.	7	3	28	6	6	+	8	0	2	6	24	5	4	+	+	+	7
Lapsana communis	13	16	9	11	34	16	22	+	1	26	2	11	50	10	3	+	13
Matricaria matricarioides	+	2	+	1	7	7	18	7	+	+	+	3	12	9	5	4	4
Myosotis arvensis	2	4	+	1	22	21	7	2	1	1	3	2	9	6	2	4	5
Persicaria lapathifolia	2	8	12	4	6	3	16	1	+	+	6	2	5	2	8	7	5
Phleum pratense	+	1	0	+	+	2	+	2	+	+	+	+	0	4	+	2	+
Plantago major	+	+	+	+	+	7	5	2	+	+	+	3	+	3	+	+	1
Poa annua	5	2	+	18	6	4	56	16	7	27	3	2	+	12	8	17	11
Poa pratensis	+	1	0	+	+	3	6	+	+	2	+	+	0	+	+	+	+
Polygonum aviculare	+	+	+	2	4	3	2	1	2	1	4	3	1	1	2	3	2
Ranunculus repens	+	+	+	+	+	3	2	4	+	+	+	+	+	+	21	+	2
Sonchus arvensis	2	5	4	6	5	+	6	4	3	5	1	1	12	4	+	+	4
Sonchus asper	+	+	0	+	0	0	0	0	+	0	+	+	0	0	0	0	+
Spergula arvensis	3	8	15	7	16	12	28	27	1	2	3	4	42	29	60	13	13
Stellaria media	13	4	14	22	7	12	5	7	13	19	22	4	14	11	10	14	12
Taraxacum spp.	6	3	2	1	11	3	+	4	+	+	+	5	4	2	+	1	3
Thlaspi arvense	2	+	+	+	5	2	0	0	+	0	+	+	8	+	+	2	1
Trifolium spp.	4	4	+	2	1	2	2	7	+	+	+	+	+	2	5	1	2
Tripleurospermum inodorum	3	3	3	2	11	4	4	+	+	+	2	1	9	+	+	+	3
Veronica spp.	+	+	2	+	+	1	+	2	+	4	+	1	1	2	+	0	+
Vicia spp.	+	2	1	1	+	+	+	+	+	2	+	+	4	3	+	+	+
Viola arvensis	17	18	20	24	34	41	36	22	23	50	10	13	28	21	30	33	25
Mean total, plants m^{-2}	150	175	199	204	293	311	319	193	143	228	158	140	387	266	257	177	209
Median total, plants m^{-2}	114	118	104	159	199	301	200	130	110	153	109	90	324	185	182	86	138

Table 6. Weed biomass (kg ha^{-1}) by regions. + indicates < 1 kg ha^{-1}

Species / Taxon	Year / Region																Average
	2007		2008							2009							Average
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	2007–09
Achillea millefolium	0	3	+	0	+	2	0	0	0	0	0	6	+	0	0	0	+
Alopecurus geniculatus	0	0	0	0	+	2	3	1	2	0	2	3	+	0	+	+	1
Artemisia vulgaris	0	+	0	0	0	+	0	0	0	+	0	1	0	0	0	0	+
Brassica rapa ssp. *oleifera*	0	0	0	0	+	2	0	0	1	+	0	0	1	10	0	3	+
Capsella bursa-pastoris	+	0	+	+	3	2	2	6	+	3	0	+	2	4	+	4	1
Cerastium fontanum	0	0	0	0	+	+	0	0	0	0	0	+	0	0	0	0	+
Chenopodium album	11	25	17	46	37	60	8	5	51	29	12	8	31	104	4	40	27
Cirsium arvense	8	6	0	7	29	1	2	0	7	3	18	5	8	23	+	2	8
Elymus repens	19	63	34	95	72	50	65	102	79	45	38	49	217	127	196	61	72
Epilobium angustifolium	0	0	0	0	0	0	+	0	0	0	0	0	0	0	0	+	+
Equisetum arvense	+	6	7	+	1	0	+	+	+	1	3	11	9	+	0	+	3
Erysimum cheiranthoides	+	+	+	1	1	12	4	2	1	3	+	+	+	4	4	2	2
Fallopia convolvulus	3	3	2	7	7	4	1	0	5	3	2	5	9	3	+	4	4
Fumaria officinalis	2	2	1	2	7	3	9	+	3	1	3	7	19	1	0	3	4
Galeopsis spp.	8	11	2	32	21	20	12	11	30	32	9	20	9	20	13	13	17
Galium spurium	14	17	16	10	10	+	3	+	13	17	4	4	1	0	10	+	8
Gnaphalium uliginosum	+	+	0	+	+	+	+	0	0	+	0	0	+	+	3	+	+
Juncus bufonius	0	0	0	+	2	5	0	+	0	0	0	0	0	+	0	0	+
Lamium spp.	3	+	10	2	7	0	10	0	1	3	6	3	2	+	0	+	3
Lapsana communis	4	12	4	11	12	12	10	0	1	16	+	6	53	8	1	0	8
Matricaria matricarioides	+	+	0	+	5	2	7	1	+	+	+	+	2	6	+	4	2
Myosotis arvensis	1	+	+	+	4	8	3	+	+	+	+	+	2	1	+	1	1
Persicaria lapathifolia	+	14	3	11	14	4	11	1	+	+	9	2	6	5	11	22	7
Phleum pratense	0	12	0	0	0	2	1	0	8	0	13	1	0	3	4	0	4
Plantago major	+	+	0	0	+	5	+	0	0	+	0	+	+	4	0	1	+
Poa annua	+	0	0	6	3	+	11	9	12	21	+	2	+	5	2	24	6
Poa pratensis	0	+	0	+	0	3	+	4	1	+	+	+	0	+	0	+	+
Polygonum aviculare	+	+	+	5	7	6	3	+	1	+	8	4	+	2	+	8	3
Ranunculus repens	0	+	+	+	0	2	+	2	0	0	+	+	+	0	+	+	+
Sonchus arvensis	3	9	0	29	27	+	40	13	7	15	2	2	32	14	4	1	12
Sonchus asper	+	+	0	+	0	0	0	0	0	0	+	+	0	0	0	0	+
Spergula arvensis	1	3	31	8	16	15	33	65	3	1	2	7	44	50	89	13	18
Stellaria media	4	+	7	25	8	12	2	4	8	34	9	5	7	23	19	14	11
Taraxacum spp.	+	3	+	+	3	4	+	+	+	0	+	6	4	+	0	+	1
Thlaspi arvense	+	0	0	0	3	5	0	0	+	0	0	+	6	+	+	+	+
Trifolium spp.	+	+	0	+	3	+	+	0	+	+	+	2	0	0	0	0	+
Tripleurospermum inodorum	+	3	0	3	4	1	1	0	6	+	+	4	3	0	0	+	2
Veronica spp.	+	0	1	0	0	0	+	1	+	5	+	+	0	+	0	0	+
Vicia spp.	+	2	2	3	2	0	4	0	0	2	+	1	4	7	0	+	2
Viola arvensis	4	7	+	11	11	17	10	7	11	26	1	3	7	8	4	12	8
Mean total, kg ha^{-1}	93	212	140	338	333	272	263	247	255	288	148	189	494	449	377	241	251
Median total, kg ha^{-1}	28	84	36	141	195	220	155	163	153	144	61	88	335	195	248	109	110

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N = 503) and in organic production 519 plants m^{-2} (SD = 244, median = 468, N = 72). The total weed densities were significantly lower ($p < 0.05$) in the regions with intensive cereal production (e.g. regions 1, 4, 9, 12) compared with regions (e.g. 6, 7, 13) where cattle farms and organic production predominated.

The five most abundant weed species in organic fields were *Chenopodium album* (on average 107 plants m^{-2}), *Elymus repens* (68), *Spergula arvensis* (50), *Viola arvensis* (31) and *Stellaria media* (26). Correspondingly, the five most abundant weed species in sprayed conventional fields were *Viola arvensis* (24), *Lapsana communis* (13), *Poa annua* (13), *Elymus repens* (12) and *Chenopodium album* (11).

Although not revealed in observations from sample quadrats, the substantially increased number of fields infested with *Avena fatua* was an evident discovery of the survey. Typically, some individuals of *A. fatua* grew in a few patches in infested fields. The information from farmers' interviews provided support to this conclusion as they classified almost 30% (168 fields) of fields as infested and we detected even more fields. In comparison, the proportion of surveyed fields infested with *A. fatua* was only around 10% (74 fields out of 690 fields) ten years ago.

Weed biomass

The average biomass production of weeds was 251 kg ha^{-1} (SD = 382, median = 110, N = 595) (Table 6). The difference between cropping practices was as clear as in the case of weed densities, in that for sprayed conventional fields the average weed biomass was 167 kg ha^{-1} (SD = 239, median = 83, N = 503) and for organic production it was more than four times higher, namely 775 kg ha^{-1} (SD = 590, median = 563, N = 72).

The five weed species producing the highest amounts of biomass in organic fields were *Elymus repens* (average air-dry weight 242 kg ha^{-1}), *Chenopodium album* (115), *Spergula arvensis* (70), *Sonchus arvensis* (52) and *Galeopsis* spp. (39). Correspondingly, the five most productive weed species in sprayed conventional fields were *Elymus repens* (46), *Galeopsis* spp. (13), *Chenopodium album* (13), *Viola arvensis* (9) and *Lapsana communis* (8).

Although the number of recorded weed species was relatively high, the number of species mainly contributing to the biomass production was relatively low. The ten most abundant weed species accounted for 72% of the weed biomass production in the fields of the southern survey zone, 87% in the western zone and 80% in the eastern zone.

Elymus repens was the most efficient biomass producer, accounting for 31% of the total weed biomass production pooled over all organic fields and for 28% in sprayed conventional fields (Fig. 2).

The proportion of weed biomass relative to total vegetative biomass (crop + weeds) was relatively low (mean = 2.9%, median=1.2%) in sprayed conventional fields, but considerably higher (mean = 21.3%, median=16.0%) in organic fields. For conventional cropping the proportion of weed biomass was less than 5% in 84% of the survey fields whereas the majority (89%) of organically cropped fields fell into classes above 5% infestation (Fig. 3). In most cases the high relative proportion of weeds was due to abundant infestation of *Elymus repens*.

Seed bank

Altogether, 27 species were encountered in seed bank samples (Table 7). Only seven species exceeded the frequency level of 10%, *Chenopodium album* and *Fallopia convolvulus* being the most common species. The average size of the seed bank in the 5 cm surface layer was 1684 seed m^{-2}. *C. album* was the most abundant species, comprising 66.2% of the total seed sample and having 1115 seeds per m^{-2}, followed by *Spergula arvensis* and *F. convolvulus*.

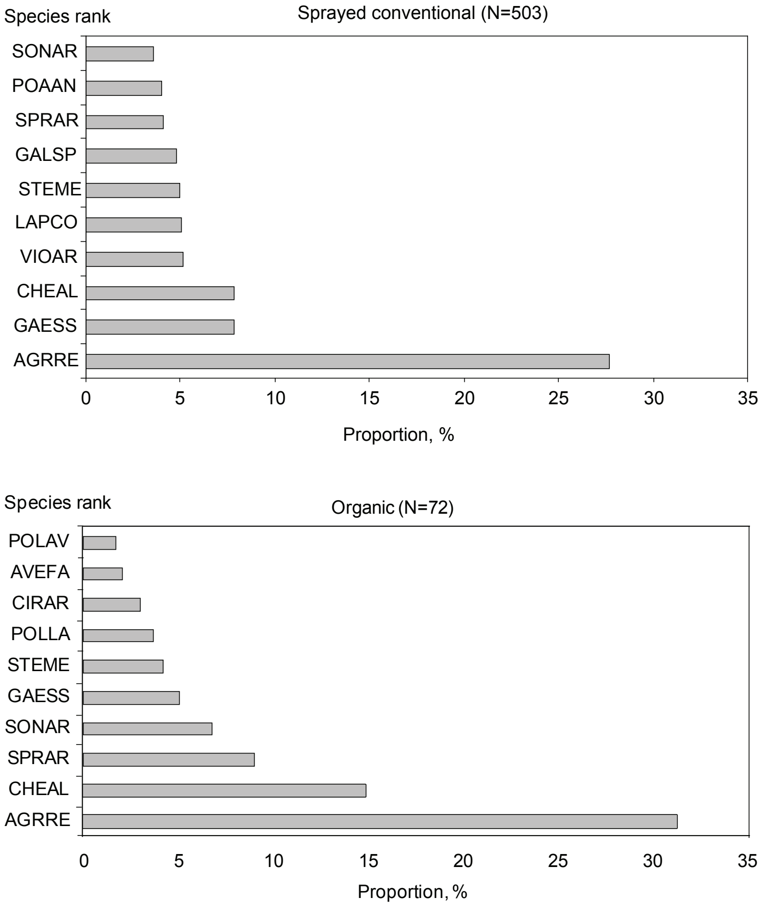

Fig. 2. Proportion of the total weed biomass production by the most abundant species in conventional and organic fields. Key of EPPO code abbreviations: AGRRE *Elymus repens*, AVEFA *Avena fatua*, CHEAL *Chenopodium album*, CIRAR *Cirsium arvense*, GAESS, *Galeopsis* spp., GALSP *Galium spurium*, LAPCO *Lapsana communis*, POAAN *Poa annua*, POLAV *Polygonum aviculare*, POLLA *Persicaria lapathifolia*, SONAR *Sonchus arvensis*, SPRAR *Spergula arvensis*, STEME *Stellaria media*, VIOAR *Viola arvensis*.

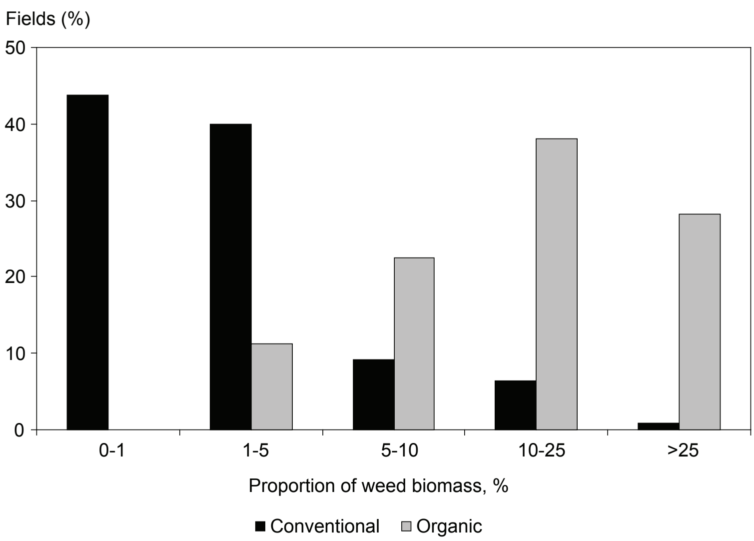

Fig. 3. Relative number of fields (%) in different weed biomass classes in two cropping systems. Weed biomass is proportioned to total vegetative biomass (crop + weeds).

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Table 7. Occurrence of weed seeds in the top-soil (0–5 cm) of the survey fields.

Weed species	Frequency of occurrence (%)	Proportion of total sample (%)	Seeds m^{-2}
Agrostis capillaris	0.5	0.1	1
Alopecurus geniculatus	6.1	1.6	26
Brassica rapa	0.5	0.1	1
Capsella bursa-pastoris	0.3	0.1	2
Chenopodium album	79.8	66.2	1115
Cirsium arvense	0.5	<0.1	1
Elymus repens	3.9	0.6	10
Fallopia convolvulus	41.5	8.0	136
Fumaria officinalis	1.5	0.1	2
Galeopsis spp.	23.4	3.8	64
Galium album	0.2	<0.1	<1
Galium spurium	17.0	2.6	44
Lapsana communis	1.2	0.1	2
Myosotis arvensis	6.2	1.2	20
Persicaria lapathifolia	13.8	1.8	30
Phleum pratense	2.0	0.2	4
Poa annua	0.3	0.1	1
Polygonum aviculare	12.1	1.9	32
Ranunculus repens	0.3	<0.1	1
Rumex longifolius	0.2	<0.1	<1
Sonchus asper	0.2	<0.1	<1
Spergula arvensis	10.1	10.6	179
Stellaria media	3.9	0.6	9
Taraxacum officinale	0.2	0	<1
Thlaspi arvense	1.0	0.1	1
Vicia cracca	1.0	0.1	1
Viola arvensis	1.3	0.3	4

Discussion

The weed survey in 2007–2009 can be regarded as a follow-up study for the previous survey carried out in 1997–1999 in the same 16 regions and mainly at the same farms and fields (Salonen et al. 2001a). Moreover, the monitoring protocol was exactly the same as in the 1990s. Spring cereals, covering about 50–55% of the arable land, still dominate crop production in Finland and the only major shift in cereal cropping during the last ten years has been the doubled area of spring wheat, reaching almost 200 000 ha, having been around 100 000 ha ten years ago (TIKE 2009). The areas of spring barley (52% of spring cereal area) and oats (30%) remain much higher than that of spring wheat. A marked shift towards winter cereal cropping, as in Denmark (Andreasen and Stryhn 2008), has not occurred in Finland.

The number of weed species, 148, found in small sample quadrats (0.1 m^2) was slightly lower than ten years ago when 160 species were recorded (Salonen et al. 2001a). In the larger (1.0 m^2) quadrats the number of observed species was now

175 versus 188 species ten years ago. An obvious reason for reduction in floral diversity is that the total number of surveyed fields was lower (595 vs. 690). Particularly the number of organically grown fields was less than half compared with the 1997–1999 survey. In comparison, the total number of weed species found in spring cereal fields in the Czech Republic was 101, with an average of 13 species per field (Tyšer & Kolárová 2010). Much lower total numbers of weeds, 64 species, were found in arable fields in Alaska, at a similar latitude as in Finland (Conn et al. 2011), whereas the species number recorded in Danish arable fields in 2001–2004 was as high as 225 (Andreasen and Stryhn 2008).

Only 38 weed species or taxa exceeded the overall frequency level of 5%. Among the most common weed species, *Galium spurium*, (+16% units increase since the 1990s), *Fumaria officinalis* (+9), *Lapsana communis* (+5) and *Fallopia convolvulus* (+5) have become more frequent, whereas *Elymus repens* (-9) has become less frequent since 1997–1999. The newcomers in the list of 40 most frequent species were *Alopecurus geniculatus*, *Artemisia vulgaris*, *Phleum pratense*, *Poa pratensis* and *Sonchus asper*. Appearance of new grass species in the list is evidently a consequence of increased proportion of survey fields with reduced tillage, which favours grasses, as demonstrated in other studies (e.g. Gruber et al. 2000, Jalli et al. 2006, Tørresen et al. 2006, Thomas et al. 2011). Moreover, it has been demonstrated that reduced tillage has a major, although complex, role in promoting weed species diversity (Murphy et al. 2006) and in determining the weed community composition (Légère et al. 2005). In our survey fields, the proportion of non-inversion tillage (i.e. only tine-cultivated or direct-drilled) had increased from 14% in 1997–1999 to 44 % (27% tine-cultivated and 17% direct-drilled) in 2007–2009.

Overall, the frequencies of occurrence for the most common weed species were significantly higher in organic cropping than in conventional cropping. Evidently this is partly due to the success of chemical weed control, but is also a consequence of more intensive crop management resulting in more competitive crop stands in conventional cropping. The impact of intensity is an obvious reason also for the tremendous decline in the number of seeds in the soil between the present survey (1168 seeds per m^{-2}) and the 1960s survey (43850 seeds per m^{-2}) (Paatela and Erviö 1971). Such a difference is partly due to the difference in the soil sample, which was taken from a 5 cm top layer in our study and from a 20 cm layer in the 1960s. However, *Chenopodium album* was the most common and abundant species in both decades.

The proportion of organically cropped survey fields was relatively high in certain regions such as Kitee, Kihniö/Parkano and Imatra/Ruokolahti and this is reflected to some extent in the results, for instance as a higher frequency of *Spergula arvensis* in those regions. On the other hand, some common species were relatively rare in certain zones, like *Lapsana communis* in western Finland, as discovered already in the 1960s (Mukula et al. 1969). The regional specialization is a complex of many factors, including prevailing crop rotations, soil types, tillage practices, proportion of organic farming etc., still existing and affecting the specific weed occurrence in different regions.

Galium spurium (probably including some populations of *Galium aparine*) is a typical example of this ‘regionalization’ as it has become very frequent (66% in southern vs. 35–37% in eastern and western zones) in the southern survey zone, which is characterized by clay soils, monoculture of cereals and reduced tillage. For instance, reduced tillage practices seem to favour *Galium* species (Tørresen & Skuterud 2002, Thomas et al. 2011). In addition, a long-lasting use of first generation sulphonylurea herbicides with weak efficacy against *Galium* species has been an evident promoting factor, although Hyvönen et al. (2003b) found only weak statistical support for the selection pressure on weed communities due to the application of sulphonylureas. This aspect is worth re-analyzing by further dissecting the survey data series and making comparisons between the decades now that sulphonylureas have largely replaced phenoxy acid herbicides.

Elymus repens is the most harmful weed species for spring cereals in Finland, producing about 30% of weed biomass in both cropping systems. In conventional cropping, farmers seemingly re-

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spond to the situation as the sales of glyphosate have more than doubled in ten years (Londesborough et al. 2000, Evira 2010). Approximately 60% of the direct-drilled survey fields had been treated with glyphosate in the spring before sowing and the annual application of glyphosate before sowing time was a common practice in these fields. Likewise, the decline of *E. repens* has been observed in Denmark and associated with increased use of glyphosate (Andreasen and Stryhn 2008).

The abundance of weeds in organic cropping is slowly approaching the infestation level of 1 000 kg ha^{-1} recorded in unsprayed conventionally cropped fields in the 1960s (Mukula 1974). Therefore, measures promoting crop competition, as well as reliance on physical weed control should be emphasized in organic cropping (Kolb et al. 2010). For instance, the abundance of *E. repens* in organic cropping is a cause for some concern and calls for improved control strategies. Contradictory findings on the success of *E. repens* in organic cropping over time have been reported by Becker and Hurle (1998), who demonstrated decreased frequency of *E. repens*, whereas Riesinger and Hyvönen (2006b) found increased abundances as a function of the duration of organic farming. In general, *E. repens* is probably going to benefit from climate change, which could extend its period of autumn growth (Tørresen et al. 2010).

The area of organic farming in Finland has levelled out at around 6–7% of arable land (TIKE 2009) and subsidized by agri-environment policy this has successfully promoted diverse and abundant weed flora to the benefit of biological diversity. However, the success of *E. repens* in organic cropping should not be regarded as a positive trend because it is a very competitive species that greatly reduces crop yield and has only little benefit for biodiversity, and actually mainly benefits harmful phytophagous insects (Hyvönen and Huusela-Veistola 2008). As regards biological diversity, other frequently observed perennial weed species such as *Cirsium arvense* and *Sonchus arvensis* are more favourable (Hyvönen and Huusela-Veistola 2008)

In conventional cropping, the relatively high efficacy of weed control and good competitive ability of spring cereals leads to a conclusion that enhancement of biodiversity with rich and advantageous flora should be primarily realized by establishing specific flower-strips (e.g. van Elsen and Hotze 2008), “ecological compensation areas” (Aviron et al. 2009) or by introducing completely new incentives in which farmers commit themselves to conservation of weed species by reducing the chemical inputs, primarily fertilizers and herbicides (Ulber et al. 2010).

New grass weed species were introduced on to the list of most frequent species, possibly reflecting the changes in tillage practices towards non-inversion soil cultivation. The frequent occurrence of *Avena fatua* is alarming and requires prompt action to manage the problem. As suggested by Conn et al. (2011), research and implementation of prevention programmes should be emphasized as the costs of controlling an outbreak are much higher than for preventing one. Likewise, the success of *Poa annua* is worth taking note of as its frequency (31%) had significantly increased in ten years, having been 12% in 1997–1999 (Salonen et al. 2001a). The success of *P. annua* is in line with observations in the Nordic countries (Tørresen et al. 2006, Andreasen and Stryhn 2008). Among the broad-leaved weed species, the success of *Galium spurium* in conventional cropping, as well as *Fumaria officinalis*, *Myosotis arvensis* and *Persicaria lapathifolia* in organic cropping, should be regarded as a weed shift.

In conclusion, although the weed flora in Finnish spring cereal fields consists of numerous weed species, only a fraction of them severely threaten crop production at national level in terms of frequency and abundance. A wider range of grass weed species may interfere with the production of cereals in the future, particularly if there will be a shift towards winter cereal cropping with reduced tillage. Thus, new grass weed management strategies, both preventive and curative, should be emphasized. In general, the range of herbicides with different modes of action (mainly sulphonylureas, phenoxy acids and glyphosate) is limited on the Finnish market, and the risks of weeds evolving herbicide resistance should be taken into account.

At present, weeds in conventional cropping can be effectively managed with the current, relatively intensive cropping measures and with available herbicides whereas weed management in organic cropping calls for urgent measures such as direct mechanical weed control in crop stands, which was not practiced at all in survey fields. This would likely benefit also species richness by diminishing the dominance of competitive perennial weeds.

Acknowledgements. The weed survey was part of the follow-up study on the impacts of agri-environment policy measures (MYTVAS) and part-financed by the Ministry of Agriculture and Forestry. We thank all farmers who allowed us to visit their fields and provided us with information about their farming practices. Our permanent technical staff, Eira-Maija Tanni, Anne Muotila and Marjo Segerstedt and a team of field assistants Miko Häsä, Osmo Jalli, Marjaana Järveläinen, Saara Kinnunen, Sini Stenbacka and Tuija Vihervirta are acknowledged for their enthusiastic toil. Timo Hurme advised us in statistics. This paper is dedicated to Professor Leila-Riitta Erviö who passed away in May 2011.

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