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Weed flora and weed management of field peas in Finland

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The composition of the weed flora of dry pea (*Pisum sativum* L.) fields and cropping practices were investigated in southwestern Finland. Surveys were done in 2002–2003 in 119 conventionally cropped fields and 64 fields under organic cropping. Herbicides were applied to 92% of conventionally cropped fields where they provided relatively good control but were costly. Weeds were controlled mechanically only in five fields under organic production. A total of 76 weed species were recorded, of which 29 exceeded the 10% frequency level of occurrence. The average number of weed species per field was 10 under conventional cropping and 18 under organic cropping. The most frequent weed species in both cropping practices were *Chenopodium album*, *Stellaria media* and *Viola arvensis*. *Elymus repens* was the most frequent grass species. The difference in species composition under conventional and organic cropping was detected with Redundancy Analysis. Under conventional cropping, features of crop stand and weed control explained 38.7% and 37.6% of the variation respectively. Under organic cropping the age of crop stand and field location (y co-ordinate) respectively explained best the variation. Weeds could be efficiently managed with herbicides under conventional cropping, but they represented a significant problem for organic production. Mixed cultivation of pea with cereals is recommended, particularly for organic cropping, as it favours crop competition against weeds.

Key words: biodiversity, bentazone, herbicides, metribuzin, organic farming, *Pisum sativum*, Redundancy Analysis, variation partitioning, weeds, weed control

Introduction

Pea (*Pisum sativum* L.) is a minor field crop grown only on about 5 000 hectares corresponding roughly to 0.25% of the cultivated field area in Finland (Ministry of Agriculture and Forestry 2004). About 34% of that dry pea area was under certified organic production in 2002–2003. Combine-harvested field pea is grown for human consumption, animal feed or seed for sowing. Peas are often grown in a rotation with cereals and also mixed with cere-

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als, particularly with oats (*Avena sativa* L.) and typically on organic farms. Cereal-dominated crop rotation is typical of conventional farms in southwestern Finland, whereas organic crop production aims at more diverse crop sequences. Dry pea production would provide conventional farms in particular with an excellent alternative crop, but the uncertainty of harvest under rainy conditions in August and high production costs (seed, crop protection, drying) limit expansion of pea cultivation.

A research programme, "Pea as a source for domestic protein", was launched in 2002 in Finland to improve crop reliability and economics of pea production through better management. A subproject of the research programme, a survey of diseases, pests and weeds in pea fields, was carried out in 2002–2003. The objective was to establish the major targets for crop protection in order to define control recommendations, particularly in the case of possible marked expansion in pea production. In addition, the current crop management and crop protection practices for pea cultivation were investigated by interviewing farmers.

Published information on diseases, insect pests and weeds of pea fields in Finland is sparse. Recent weed research activities have been directed at herbicide testing in field pea (Ruuttunen 1999). On the other hand, there are detailed descriptions of the weed flora in spring cereals from the late 1990s (Salonen et al. 2001a, b). Earlier, an inventory of weeds in organically cultivated cereal fields was carried out on 40–48 farms visited annually in 1984–1986 (Mela 1988).

This paper focuses on the results of a weed survey with two specific aims. First, we aimed to study the general patterns of weed community species composition in relation to crop management in all fields examined. Secondly, we analysed weed communities in conventionally and organically cropped fields separately, aiming to explore the relative importance of different cropping measures as well as other factors explaining the variation in weed species composition. We expected that the application of herbicides with various active ingredients would be of central importance in conventionally cropped fields, while in organically cropped fields the variation would be explained with various cropping measures of more equal importance.

Material and methods

Study regions, farms and fields

The weed survey was carried out in southwestern Finland in 2002–2003 (Fig. 1). The survey regions and farms were randomly selected using national statistics on pea cultivation from previous years provided by the Information Centre of the Ministry of Agriculture and Forestry. Regions of intensive and less intensive pea cultivation were included. The majority of organic farms studied had converted from conventional to organic cropping in the mid-1990s and had carried out organic cropping on average for seven years.

The number of pea fields examined was 93 in 2002 and 90 in 2003. In both years 32 fields were under organic production. Pea was typically grown in pure stands, but 28% of fields were mixed stands, predominantly (87%) pea with oats. According to EU regulations, the proportion of cereals may not exceed 15% of the weight of sown seed in a mixture. Altogether 11 pea varieties were grown, of which a Swedish variety Karita (55%), a Danish variety Stok (19%) and a Finnish variety Tiina (14%), were the most common varieties, present in almost 90% of survey fields.

In most cases there were 1–3 pea fields per farm. The previous crop in pea fields was predominantly spring cereal (Table 1). Grassland had been included in crop rotation during the previous five years in 22% of conventional fields studied and in 82% of organic fields. Manure was applied to about 15% of the fields studied and manure was used both in conventional and organic cropping.

Weed samples

The occurrence of weeds was assessed from five 1.0 m^2 (1.0 m × 1.0 m) sample quadrats randomly

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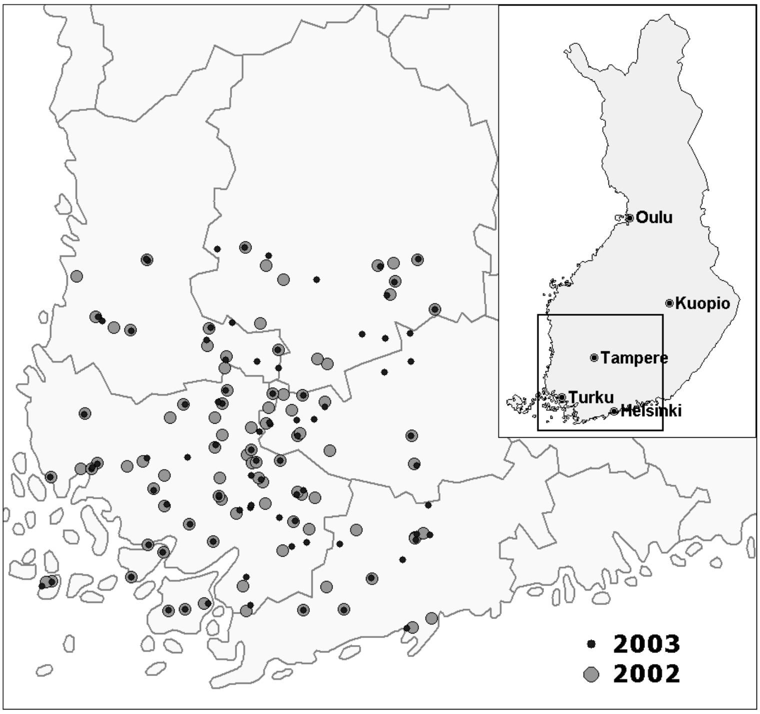

Fig. 1. Location of surveyed pea fields in southwestern Finland.

Table 1. Background information on the cropping practices of studied fields. Number of fields (nominal variables) or median, minimum and maximum (continuous variables) of explanatory variables used in Redundancy Analysis (RDA).

Variable (scale or unit)	Comment	All data (n = 171)	Conventional (n = 109)	Organic (n = 57)
Conventional/organic	Farm type	109/62	–	–
Crop/dairy	Cropping practice	117/54	–	–
Weed control (yes/no)	Chemical or mechanical weed control applied	107/64	–	–
SPATIAL				
Field size (ha)	Size of the field	3.8 (0.1–13)	5 (0.5–12)	3 (0.1–13.3)
X co-ordinate	X co-ordinate of the field midpoint	3287738 (3197235–3395928)	3285319 (3197235–3395928)	3309969 (3211991–3367192)
Y co-ordinate	Y co-ordinate of the field midpoint	6737983 (6665859–6830757)	6737983 (6665859–6830148)	6735754 (6683866–6830757)
CROP STAND				
Age of stand (days)	Difference between sowing date and sampling date	52 (21–86)	52 (23–75)	51 (21–86)
Cover of pea (%)	Cover of pea and other crop (data pooled over five sample quadrats)	260 (5–485)	302 (48–485)	180 (5–440)
Height of pea (cm)	Height of pea in sample quadrat	40 (4–90)	45 (5–90)	25 (4–60)
Mixed (yes/no)	Pea cropped in the mixture with other crop	48/123	11/98	34/23

Table 1. Continued

Variable (scale or unit)	Comment	All data (n = 171)	Conventional (n = 109)	Organic (n = 57)
WEED CONTROL				
Chemical weed control				
No weed control		–	9	–
Herb1: Bentazone or bentazone+MCPA	Weak effect against POLAV, VIOAR, POAAN and SENVU	–	34	–
Herb2: Aclonifen or Aclonifen+bentazone or Aclonifen+bentazone+MCPA	Weak effect against VIOAR, POAAN and SENVU	–	16	–
Herb3: Metributzin+bentazone or Metribuzin+bentazone+MCPA or Metribuzin + aclonifen	Effective against most broad-leaved species	–	8	–
Herb4: Metribuzin or Metribuzin+MCPA	Weak effect against GALSP	–	42	–
Non-chemical weed control (yes/no)	Mechanical weed control applied	–	–	5/52
Years in organic production (years)		–	–	7 (2–25)
CROP ROTATION				
Pre crop				
Spring cereal		101	71	28
Winter cereal		26	15	10
Grassland		11	1	9
Pea		12	7	4
Sugar beet		9	9	–
Other		12	6	6
Grass (yes/no)	Grassland in crop rotation	75/96	24/85	47/10
SOIL				
Soil type				
Coarse		14	5	8
Clay		151	102	45
Organic		6	2	4
TILLAGE				
Autumn ploughing		121	81	40
Spring ploughing		15	6	8
Minimum tillage		35	22	9
FERTILIZATION				
Manure (yes/no)	Manure applied as fertilizer	25/146	13/96	12/45
N (kg ha^{-1})	Amount of nitrogen in mineral fertilization and manure	32 (0–100)	44 (0–100)	0 (0–39)
P (kg ha^{-1})	Amount of phosphorus in mineral fertilization and manure	6 (0–42)	11 (0–28)	0 (0–32)

located in each field. The term frequency refers to the proportion of fields where the species was found in quadrats. In addition, visible patches of the common and troublesome perennial weeds *Cirsium arvense*, *Elymus repens* and *Sonchus arvensis* were recorded separately over the whole field. Weed cover was visually assessed and recorded using a scale of 0–3 (0 = not present, 1 = less than 5% cover, 2 = 5–25% cover and 3 = more than 25% cover) by species. The weed cover data

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from five sample quadrats were pooled and the sum was used as a measure of weed abundance in the data analyses. The plant species nomenclature follows that of Hämet-Ahti et al. (1998). The full scientific names with attribution are given in Table 2. Bayer codes for weed species (Bayer 1992) are used in the presentation of results.

Statistical analyses

Conventional and organic production are characterised by different crop management practices, including fertiliser application method and amount. Herbicide application in conventional cropping clearly creates a significant selection pressure in weed communities (Hald 1999, Hyvönen and Salonen 2002, Poggio et al. 2004) that is absent in organic cropping. Several factors associated with crop rotation, crop management and diverse environmental variables, should be taken into account (see e.g. Haas and Streibig 1982, Rydberg and Milberg 2000). Therefore, the application of multivariate methods was considered appropriate for analysing these complex data (see e.g. Salonen 1993, Hallgren et al. 1999, Lepŝ and Šmilauer 2003).

The complete data set derived from 183 fields that were used in frequency calculations (Table 2). In the ordination analyses some fields were excluded due to missing data of explanatory variables (see Table 1 for the number of fields in each analysis). Data on factors involved in each field were collected through observation, measurement or by interviewing the farmer. The statistical analyses were performed either using SAS procedures (version 8.2., SAS Institute Inc. 1999) or with CANOCO 4 software (ter Braak and Šmilauer 1998).

The preliminary analysis of the data was conducted using Detrended Correspondence Analysis (DCA) to measure the lengths of gradients. Since the lengths of gradients for the first and the second DCA axes were short (2.4 and 2.5, respectively), an analysis with the linear response model (i.e. Redundancy Analysis, RDA) was considered more appropriate than analysis with the unimodal response model (i.e. Canonical Correspondence Analysis, CCA) (see Lepŝ and Šmilauer 2003). The default options of CANOCO were applied. All the species for which there was a single observation (13 species in all data, 15 species in organically cropped fields and 18 in conventionally cropped fields) were given a zero weight in the analyses (i.e. they did not affect the analyses).

In the first series of analyses of complete data, all explanatory variables (see Table 3) were included in the forward selection procedure of CANOCO. The statistical significance of the terms was tested using the unrestricted Monte Carlo permutation test (999 permutations). Explanatory variables with a P-value > 0.05 were excluded from further analyses (Table 3). For the exploration of general patterns in species composition of the weed community, and the relationship between the species composition and explanatory variables, RDA was conducted on the species matrix constrained by statistically significant explanatory variables (Fig. 2). The significance of the first RDA axes and the overall significance of the RDA models were evaluated using Monte Carlo permutation tests with trace as a test statistic and 999 permutations.

In the second series of analyses, weed communities of conventionally and organically cropped fields were analysed separately (data on 109 and 57 fields, respectively). The relative importance of various factors was studied using variation partitioning (Borcard et al. 1992). For variation partitioning, the explanatory variables were classified into seven groups (Table 1). The variables included in the groups of weed control and fertilization differed between cropping practices (see Table 3). All groups of explanatory variables were submitted to the forward-selection procedure, and the following series of analyses were conducted with statistically significant explanatory variables: 1) RDA of the species matrix constrained by the matrix of each group of significant explanatory variables one at a time and 2) partial RDA of the species matrix constrained by the matrix of each group of significant explanatory variables one at a time and using one of the other matrices as a covariate. Variation partitioning was conducted by applying the variation explained by the explanatory variables, i.e., the sum of all canonical eigenvalues in RDA analysis where all significant explanatory variables and no covariables were included in the analysis, as a measure of the total variation (Økland and Eilertsen 1994, Økland 1999).

Results

Weed species composition and weed cover

A total of 76 weed species were recorded in sample quadrats. The 29 most frequent weed species were found in more than 10% of surveyed fields (Table 2). The average number of weed species per field was 10 (min 3, max 21) under conventional cropping and 18 (min 8, max 31) under organic cropping.

The most frequent weed species in both cropping systems were *Chenopodium album, Stellaria media* and *Viola arvensis* (Table 2). Of the total 76 recorded weed species 59 species occurred in conventionally cropped fields and 68 species in organically cropped fields. There were 17 weed species that were found only in organically cropped fields (e.g. *Achillea millefolium* L., *Barbarea vulgaris* R.Br., *Rumex longifolius* DC. and *Sonchus asper* (L.) Hill). On the other hand, 8 weed species (e.g. *Atriplex patula* L., *Avena fatua* L., *Solanum nigrum* L.) were found occasionally in some conventionally cropped fields. In some fields volunteer crop plants including *Avena sativa* L., *Hordeum vulgare* L., *Linum usitatissimum* L. and *Phleum pratense* L. occurred as weeds.

To supplement information on the most common perennial weed species in our random sample quadrats, comprehensive observation of weed patches increased the number of fields infested with *Cirsium arvense* (frequency 33% vs. 43%). This suggested that growth of *C. arvense* was more patchy, or the patches were higher and more visible than those of *Elymus repens* and *Sonchus arvensis* in early July. In all, these three perennial species were more frequently found in organic fields than in conventional fields (Table 2).

The observed weed cover of individual species was usually less than 5%, corresponding to the rank value 1 on the scale for visual observation. The crop cover, pea alone or pea with cereal, was on average 60% under conventional cropping and 40% under organic cropping in early July. On some organic farms pea stands completely failed following poor crop emergence and/or vigorous weed growth.

In the analysis of the comprehensive data (all 171 fields) using RDA, only eight variables proved to be statistically significant in the forward selection procedure (Table 3). The first RDA axis captured 13.5% of the variation in the species composition and 67.1% of the variation in the species-environment relation; the second RDA axes captured only a minor portion of the variation (2.2 and 11.1%, respectively). A Monte Carlo permutation test showed both the first and all RDA axes together to be statistically significant ($P < 0.01$).

The main gradient in the variation in species composition along the first ordination axis was the difference between conventionally and organically cropped fields (Fig. 2). In addition to cropping practices, the first axis was related to weed control and grassland-dominated crop rotations. The most dominant species included herbicide-susceptible *Spergula arvensis* and *Erysimum cheiranthoides* as well as species typical of grassland-dominated crop rotations, e.g. *Elymus repens*, *Ranunculus repens* and *Plantago major*. The second axis was related to properties of the crop stand (cover and age) as well as soil type and tillage. The most dominant species included herbicide tolerant *Galium spurium* and *Fumaria officinalis*.

Cropping practices

Chemical weed control was practised on 92% of conventionally cropped fields. Bentazone and metribuzin were the most frequently applied active ingredients. Other compounds applied were aclonifen or MCPA mixed with bentazone. In addition

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Table 2. Frequencies of occurrence (%) of 32 most frequent weed species in pea fields.

Species/Taxon	Bayer code	Production type				Total
		Conventional			Organic	
		Unsprayed	Sprayed	All		
Achillea millefolium L.	ACHMI	0	0	0	8*	3
Brassica rapa L. ssp. *oleifera* (DC.) METZG.	BRSRO	22	10	11	25*	16
Capsella bursa-pastoris (L.) MEDIK.	CAPBP	22	17	18	47*	28
Chenopodium album L.	CHEAL	89	68	70	97*	79
Cirsium arvense (L.) SCOP.	CIRAR	22	21	21	56*	33
Elymus repens (L.) GOULD	AGRRE	67	56	57	75*	63
Equisetum arvense L.	EQUAR	22	12	13	22	16
Erysimum cheiranthoides L.	ERYCH	78	38	41	81*	55
Fallopia convolvulus (L.) À.LÖVE	POLCO	44	55	55	75*	62
Fumaria officinalis L.	FUMOF	67	55	56	72	62
Galeopsis L. spp.	GAESS	78	55	57	97*	71
Galium spurium L. [a]	GALSP	33	65	63	59	62
Gnaphalium uliginosum L.	GNAUL	11	2	3	13*	6
Lamium L. spp.	LAMSS	11	43	40	56*	46
Lapsana communis L.	LAPCO	56	40	41	70*	51
Matricaria matricarioides (LESS.) PORT.	MATMT	11	10	10	30*	17
Myosotis arvensis (L.) HILL	MYOAR	56	16	19	47*	32
Persicaria lapathifolia (L.) GRAY	POLLA	33	12	13	59*	30
Plantago major L.	PLAMA	11	7	8	20*	12
Poa annua L.	POAAN	22	12	13	17	14
Polygonum aviculare L.	POLAV	44	44	44	47	45
Ranunculus repens L.	RANRE	11	4	4	22*	10
Sonchus arvensis L.	SONAR	67	44	45	80*	57
Spergula arvensis L.	SPRAR	56	15	18	70*	36
Stellaria media (L.) VILL.	STEME	67	68	68	92*	77
Taraxacum officinale WEBER in WIGGERS	TAROF	0	11	10	17	13
Thlaspi arvense L.	THLAR	22	12	13	47*	25
Trifolium L. spp.	TRFSS	67	21	24	63*	38
Tripleurospermum inodorum (L.) SCH.BIP.	MATIN	33	40	39	73*	51
Tussilago farfara L.	TUSFA	0	3	3	16*	7
Vicia cracca L.	VICCR	11	7	8	27*	14
Viola arvensis MURRAY [b]	VIOAR	100	79	81	81	81
Number of fields		9	110	119	64	183

[a] = incl. *G. aparine*, [b] = incl. *V. tricolor*
* Significant difference in frequencies between "Conventional All" and "Organic" (Fisher's Exact Test, P < 0.05)

to the relatively effective control of broad-leaved weeds, grass weeds, *Elymus repens* in particular, were controlled separately with selective graminicides, including fluazifop-P-butyl, propaquizafop and quizalofop-P-ethyl. However, selective grass weed control was not a common practice and was carried out only on seven of 119 conventionally cropped fields. In organically cropped fields, mechanical weed control, namely harrowing, was carried out only in five fields (i.e. 9%). More than 80% of survey fields were ploughed, mainly in autumn, but in some cases in the spring.

In conventionally cropped fields, the RDA analysis showed that the characteristics of crop stand – the height of pea, the age of crop stand and the mixed crop stand – were the most important

Table 3. Explanatory variables included in the forward selection procedure of Redundancy Analysis (RDA), their conditional variances and statistical significance. Statistical significance of variables was determined by forward selection in RDA with the unrestricted Monte Carlo (n = 999) permutation test.

Variable	Code	All data		Conventional		Organic	
		Conditional variance[1]	P-value	Conditional variance[1]	P-value	Conditional variance[1]	P-value
Conventional/organic	ORGANIC	0.12	0.001*	–	–	–	–
Crop/dairy	CROP	0.01	0.101	–	–	–	–
Weed control	WCTRL	0.02	0.001*	–	–	–	–
SPATIAL							
Field size	AREA	0	0.424	0.01	0.539	0.02	0.154
X co-ordinate	X	0.01	0.086	0.01	0.122	0.03	0.185
Y co-ordinate	Y	0.01	0.048*	0.02	0.040*	0.03	0.020*
CROP STAND							
Age of stand	AGE	0.01	0.001*	0.03	0.002*	0.03	0.036*
Cover of pea	COVER	0.01	0.003*	0.01	0.241	0.02	0.140
Height of pea	HEIGHT	0.01	0.205	0.03	0.001*	0.02	0.516
Mixed/Non-mixed	MIXED	0	0.329	0.02	0.022*	0.02	0.442
WEED CONTROL							
Chemical							
None	NHERB	–	–	0.02	0.003*	–	–
Herb1	HERB1	–	–	0.04	0.001*	–	–
Herb2	HERB2	–	–	0.02	0.135	–	–
Herb3	HERB3	–	–	0.02	–	–	–
Herb4	HERB4	–	–	0.03	0.008*	–	–
Non-chemical	NONCHE	–	–	–	–	0.01	0.794
Years in organic production	OYEARS	–	–	–	–	0.02	0.625
CROP ROTATION							
Pre crop							
Spring cereal	SPRINGC	0	0.736	0.01	0.417	0.02	0.114
Winter cereal	WINTERC	0	0.271	<0.01	0.732	0.01	0.955
Grassland	GRASS	0.01	0.760	0.02	0.085	0.01	0.613
Pea	PEA	†	†	0.01	0.286	0.01	†
Sugar beet	SUGAR	0	0.111	<0.01	†	†	†
Other	OCROP	0.01	0.347	0.01	0.400	0.03	0.258
Grass/No grass	GROT	0.01	0.014*	0.02	0.009*	0.01	0.723
SOIL							
Soil type							
Coarse	COARSE	0.01	0.073	0.01	0.192	0.02	0.201
Clay	CLAY	0.02	0.001*	0.01	0.391	0.03	0.055
Organic	ORG	†	†	0.01	†	0.03	0.072
TILLAGE							
Autumn ploughing	APLOUGH	0.01	0.116	0.01	0.344	0.02	0.354
Spring ploughing	SPLOUGH	0.01	†	0.01	†	0.02	0.161
Minimum tillage	MTILLAGE	0.01	0.028*	0.01	0.076	0.02	†
FERTILIZATION							
Manure	MANURE	0	0.818	<0.01	0.936	0.02	0.651
N	N	0.01	0.905	0.01	0.538	–	–
P	P	0.01	0.430	0.01	0.509	–	–

[1] The share of variance explained by each variable at the time it was included in the model.
*Included in the further analyses.
†No value received in the RDA analysis.

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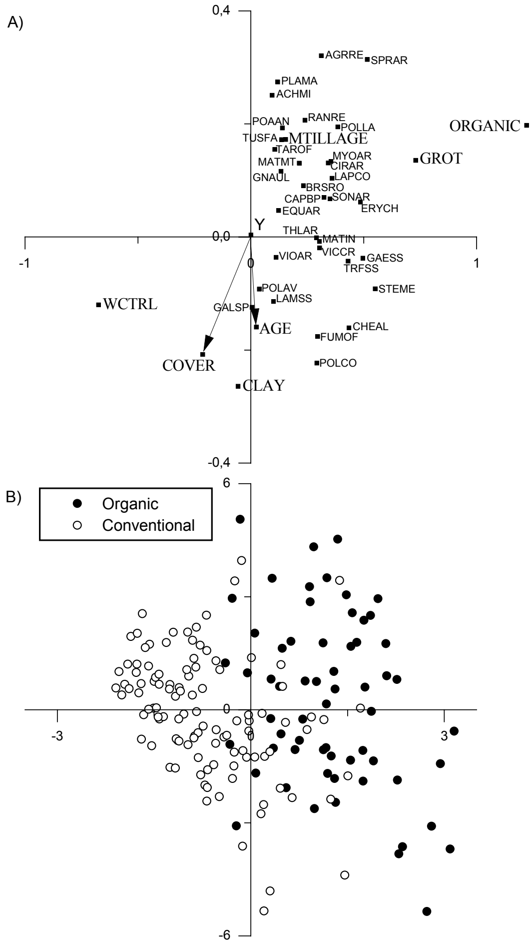

Fig. 2. Redundancy Analysis (RDA) of weed species and all statistically significant explanatory variables. Plot of species (only 32 most frequent species are shown) and explanatory variables (A) and of fields (B). Eigenvalues for axes 1 and 2 are 0.135 and 0.022, respectively. See Table 3 for abbreviations of explanatory variables and Table 2 for abbreviations of species' names.

factors (with 38.7% share) explaining variation in the species composition (Table 4). In general, conventional pea stands were higher and denser than those of organic pea (Table 1). Application of herbicides was the second most important group of factors explaining variation (with 37.6% share) in species composition. Within the weed control group, the application of bentazone alone or bentazone with MCPA, and application of pure metribuzin or metribuzin with MCPA, were the most important explanatory variables.

In the RDA analysis of organic fields, the two significant variables – y co-ordinate and age of crop stand – explained almost equal shares of the variation, 51.7% and 48.3%, respectively. The variables for weed management were not statisti-

Table 4. Partitioning of variation among the groups of variables for conventionally cropped fields.

		Variation explained (%) by			
Variable X	Covariable Y	Variable X	Joint of X and Y	Covariable Y	Other
Weed control	All variables	37.6	7.6	54.8	0
	Crop stand	41.4	3.8	40.3	14.5
	Crop rotation	43.0	2.2	9.7	45.1
	Spatial	42.5	2.7	6.5	48.3
Crop stand	All variables	38.7	5.4	55.9	0
	Crop rotation	41.9	2.1	9.7	46.3
	Spatial	44.6	–0.5	9.7	46.2
Crop rotation	All variables	8.1	3.7	88.2	0
	Spatial	10.8	1.1	8.1	80
Spatial	All variables	5.9	3.2	90.9	0

cally significant in the forward selection procedure (Table 3).

Discussion

The total number of weed species (76) recorded in pea fields illustrates the species richness of arable fields. It was, however, lower than the number of species (188) recorded in a survey of spring cereals (Salonen et al. 2001a). An obvious reason for this is that a smaller number of fields were surveyed in a more restricted geographical area. Consequently, our data set consisted mainly of samples from clay soils, which are predominant in southwestern Finland. In comparison with earlier studies in organically cultivated cereals fields, in the mid-1980s Mela (1988) found 103 weed species or taxa (221 fields studied) and Salonen et al. (2001b) in the late 1990s found 126 species or taxa (165 fields studied). In all surveys the most frequently occurring species were the same, but they ranked slightly differently. Similarities in weed flora of pea fields were recorded at the European level (Uludag et al. 2003).

The composition of weed flora is a result of long-term cropping histories, management practices and environmental conditions (see e.g. Håkansson 2003). As a consequence of such selection pressure within weed flora *Chenopodium album*, *Galeopsis* spp. and *Stellaria media* are characteristic of cereal-dominated rotations in Finland and have been among the most common species in all weed surveys of spring cereals (Mukula et al. 1969, Erviö and Salonen 1987, Mela 1988, Salonen et al. 2001a) as well as e.g. in organic spring cereals in Sweden (Rydberg and Milberg 2000). Clearly, the same weed species emerging from an established seed bank dominated our survey fields where pea was a component of cereal-based crop sequences. Moreover, the three mentioned species seem to be particularly typical of organic pea production as they exceeded the frequency level of 90%.

As expected, most variation in the species composition was established between organic and conventional cropping practices. The difference between cropping measures was related to weed control and the inclusion of grassland in the crop rotation. Both of these factors were also important in the separate analysis of conventionally cropped fields. The importance of weed control was not surprising since application of herbicides was shown to be an important factor previously (Hald 1999, Hyvönen and Salonen 2002, Hyvönen et al. 2003). In contrast, the effect of crop rotation has often been shown to be weak (Bàrberi et al. 1997, Andersson and Milberg 1998, Doucet et al. 1999), unless grasslands are included in the rotation (Paatela and Erviö 1971, Sjursen 2001). Evidently, organically cropped fields had more diverse crop rotation histories than conventionally cropped fields. The inclusion of grassland in a crop rotation increased the abundance of some perennial species (e.g. *Ranunculus repens* and *Achillea millefolium*) that are adapted to grasslands (Raatikainen and Raatikainen 1975).

In both cropping practices, the characteristics of crop stand explained a large share of the variation in the species composition. Age of crop stand, i.e. the difference between sowing and sampling dates, was an important variable among the crop stand characteristics. Apparently, competitive ability of crop stand is an important factor for reducing weed problems, especially under organic cropping where application of herbicides is avoided (Bond and Lennartson 1999). Pea breeding programmes in Finland have been successful in increasing the protein content of peas and developing high-yielding semileafless afila-type varieties (Hovinen 1988). However, such varieties are poor competitors against weeds. Competitive ability of pea stands should be taken into account when breeding new cultivars. Meanwhile, effective direct weed control is a prerequisite for a high pea yield.

Lawson (1983) showed that even though high-density pea stands suppress weeds very effectively, densely sown pea is no less vulnerable to yield loss than those at lower density are. In Finland the recommended crop density for semileafless pea is 110–120 plants m^{-2} (Laine and Kontturi 2002). The plant density was not recorded in our survey fields but the cover assessments indicate that in many

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cases the crop stand was not dense enough to compete against the weeds effectively. Intercropping of pea with cereals would evidently improve weed growth suppression (Hauggaard-Nielsen et al. 2001, Poggio 2005).

Weed management did not explain the variation in the species composition in organically cropped fields. Organic crop production aims at maintenance of weeds at a manageable level by cultural means (Bond and Lennartsson 1999). Weed management strategies should include diverse applications of crop rotation, cultivations, crop density, cultivar selection and mechanical control (Stopes and Millington 1991). Unfortunately, only a few of the survey farms carried out mechanical weed control even though it might have provided at least moderate control at an acceptable risk of crop damage (Larsen and Andreasen 2004). Organic farming appears to be beneficial for biodiversity since the number of weed species is often higher than in conventional farming (e.g. Hald 1999, Salonen et al. 2001a). This is in agreement with our results from pea fields.

The efficacy of chemical control was relatively good in most of the survey fields. For conventional cropping, the selection of herbicides available seems to be satisfactory for adequate weed control, but control costs are high. Mixtures of different active ingredients were commonly applied to broaden the control spectrum since e.g. *Galium spurium* was clearly a problem weed that remained in fields treated with metribuzin alone. Likewise, *Fallopia convolvulus*, *Polygonum aviculare* or *Viola arvensis* were not properly controlled with some other herbicides applied alone. However, even sensitive species like *Chenopodium album* and *Stellaria media* having a long period of emergence (Erviö 1981) were frequent in conventional fields, although much less abundant than in organic fields.

The cost of herbicides applied at the recommended rates varied between € 29–95 ha^{-1} in Finland in 2004. In Finnish field experiments the yield increase achieved with chemical weed control has reached 500 kg ha^{-1} (Pessala and Erviö 1979, Ruuttunen 1999). However, as mentioned by Knott (1994), it is questionable to recommend chemical weed control as being always economic at the current price level of food peas, € 200–250 per 1 000 kg (Ministry of Agriculture and Forestry 2004). Nevertheless, herbicide use is advisable as it represents a long-term strategy to keep the weed pressure at a low level.

In conclusion, the weed flora of pea fields was similar to that recorded in earlier surveys of spring cereal fields. Weeds can be efficiently managed with herbicides under conventional cropping but represent a great problem under organic cropping in which implementation of mechanical weed control methods is advisable in order to reduce yield losses. Mixed cultivation of pea with cereals is recommended, particularly under organic cropping, as it favours crop competition against weeds.

Weeds can not be regarded as a particular disincentive to planned expansion in pea production although they are expensive to control under conventional cropping and challenging to manage under organic cropping.

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SELOSTUS

Hernepeltojen rikkakasvit ja niiden torjunta Suomessa

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MTT:n tutkimushankkeeseen "Kotimaista valkuaista herneestä" sisältyi vuosina 2002–2003 hernepeltojen rikkakasvikartoitus Varsinais-Suomessa, Hämeessä, Satakunnassa ja Uudellamaalla. Tutkimustilat valittiin satunnaisesti käyttäen apuna tilastotietoa (MMM/TIKE) herneen viljelyn laajuudesta vuosina 1997–2001. Otantaan sisältyi ruokaherne-, rehuherne- ja seoskasvustoja alueilta, joilla herneen viljelyn yleisyys vaihtelee. Rikkakasvit kartoitettiin, jotta voitaisiin todeta, mitkä rikkakasvilajit ovat yleisimpiä ja runsaimpia herneviljelyksillä, mitkä tekijät vaikuttavat rikkakasvien esiintymiseen ja miten hyvin rikkakasvien torjunta onnistuu kemiallisesti.

Vuonna 2002 kartoitettiin 93 peltoa ja vuonna 2003 90 peltoa. Kartoitukseen sisältyi 64 luonnonmukaisesti ja 119 tavanomaisesti viljeltyä peltoa, joiden rikkakasvit määritettiin heinäkuun alussa. Rikkakasvien esiintyminen havainnoitiin viideltä 1 m^2 näytealalta käyttäen luokittelevaa peittävyysasteikkoa (0–3). Lajiston koostumuksen vaihtelua ja sitä selittäviä tekijöitä tutkittiin redundanssianalyysin (RDA) avulla.

Hernepelloilta tavattiin yhteensä 76 rikkakasvilajia. Yleisimpiä rikkakasveja olivat jauhosavikka, pillikkeet, pihatähtimö ja pelto-orvokki. Yleisin kestorikkakasvi oli juolavehnä, jota tavattiin 57 %:lla tavanomaisesti viljellyistä ja 75 %:lla luonnonmukaisesti viljellyistä pelloista. Leveälehtisistä kestorikkakasveista peltovalvatti oli yleisempi kuin pelto-ohdake. Hernepeltojen rikkakasvilajisto oli paljolti samanlaista kuin aiemmissa kartoituksissa havaittu kevätviljapeltojen lajisto.

Tuotantomuoto vaikutti rikkakasvilajistoon. Tavanomaisesti viljellyillä pelloilla kasvoi keskimäärin 10 lajia ja luomupelloilla 18 lajia. Luomupeltojen rikkakasvillisuus koostui pitkälti samoista lajeista, sillä peräti 12 lajia tavattiin yli 70 %:lla tutkituista luomupelloista. Tavanomaisesti viljellyillä hernepelloilla lajisto sen sijaan vaihteli lähinnä sen mukaan, mitä torjunta-ainetta oli käytetty.

Rikkakasvien torjunta-aineista kolme selvästi eniten käytettyä olivat Senkor (metributsiini), Basagran SG (bentatsoni) ja Basagran MCPA (bentatsoni + MCPA). Valmisteiden teho oli yleensä hyvä, mutta herneen rikkakasvien kemiallinen torjunta on kallista esim. viljanviljelyyn verrattuna. Valikoivia juolavehnän torjunta-aineita ruiskutettiin vain seitsemällä pellolla. Mekaanisesti rikkakasveja torjuttiin viidellä luomupellolla.

Suurin vaihtelu lajiston koostumuksessa oli luonnonmukaisesti ja tavanomaisesti viljeltyjen lohkojen välillä. Torjunta-aineiden käyttö ja nurmen esiintyminen viljelykierrossa selittivät myös vaihtelua. Tavanomaisesti viljellyillä pelloilla hernekasvuston ominaisuudet ja torjunta-aineiden käyttö selittivät 38,7 ja 37,6 % lajiston koostumuksen vaihtelusta. Luomupelloilla hernekasvuston ikä (kylvö- ja näytteenottopäivän välinen erotus) ja pellon sijainti (y-koordinaatti) selittivät 51,7 ja 48,3 % lajiston koostumuksen vaihtelusta.

Hernepeltojen rikkakasveja voidaan torjua tehokkaasti torjunta-aineilla, mutta luomuviljelyssä rikkakasvit ovat ongelma, jonka voisi osittain ratkaista lisäämällä rikkakasvien mekaanista torjuntaa. Seoskasvustojen, esim. herne/kaura, käyttöä suositellaan erityisesti luomuviljelyssä, koska se tehostaa viljelykasvin kilpailua rikkakasveja vastaan. Rikkakasvit eivät aseta merkittäviä esteitä herneen viljelyn laajentumiselle, olkoonkin että niiden torjunta on kallista tavanomaisessa viljelyssä ja haasteellista luomuviljelyssä.