

**TEMPORAL AND SPATIAL VARIATION IN WEED COMMUNITY
COMPOSITION OF SPRING CEREAL FIELDS**

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ACADEMIC DISSERTATION

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CONTENTS

ABSTRACT

LIST OF ORIGINAL ARTICLES

1. INTRODUCTION	1
2. MATERIAL AND METHODS	4
2.1. Study areas	4
2.2. Study design and sampling, measurements	4
2.3. Analyses of the data	5
2.3.1. Weed infestation	5
2.3.2. Species diversity	5
2.3.3. Species composition	6
3. RESULTS AND DISCUSSION	6
3.1. Weed infestation (I, II)	6
3.2. Species diversity (I, III, IV)	8
3.3. Spatial variation in weed communities (I, II, III, V)	9
4. CONCLUSIONS	10
ACKNOWLEDGEMENTS	11
REFERENCES	12

ABSTRACT

The thesis focuses on the impacts of recent changes in cropping practices on the abundance, species diversity and species composition of weed communities in Finnish spring cereal fields. The most important changes have been a decline in the application rates of herbicides, an increase in the application of sulphonylureas and expansion of the area of organic cropping. The main factors driving these changes were the pesticide reduction programme and adoption of the Common Agricultural Policy of the EU.

To explore the abundance, species composition and species diversity of the weed communities, a survey of weeds was conducted in 16 regions of southern and central Finland in 1997-1999. Data were collected from conventional and organic farms, all applying their normal cropping practices. A total of 690 fields were investigated. Data from 10 of the regions were applied in a detailed comparison with corresponding weed survey data collected in 1982-1984. The species composition and diversity of weed communities of conventional and alternative (organic or low-input) cropping were compared in a three-year field survey and in a six-year field experiment. Furthermore, the spatial variation in the species composition of a weed community was investigated in a field survey of a patch of farmland.

The current weed infestation level was found to be 329 kg ha⁻¹ and 243 individuals m⁻². The difference in weed abundance between organically and conventionally cropped fields was clear in terms of both dry weight (678 vs. 163 kg ha⁻¹) and number of individuals (469 vs. 136 individuals m⁻²). The change in weed abundance between the 1980s and 1990s was small (31.1 kg ha⁻¹ and 46.6 individuals m⁻²). The most important weed species were to a large extent the same as in the 1980s. The effect of the more common use of sulphonylureas had only a minor effect on species composition.

Altogether 160 or 188 weed species were recorded in the weed survey, depending on the size of the sample quadrat applied. No threatened weed species were found. Alternative cropping was found to support a higher total and mean number of weed species than conventional cropping. The mean species number was higher in alternative cropping both in the field survey of organic fields (variation in averages between regions 14-25.1 vs. 6.6-17.6 species) and in the experimental study of low-input cropping (average per field strip 20.2 vs. 13.1 species). The difference in the mean species number between cropping practices remained minimal (two species) when the number of species was adjusted to similar sample sizes in terms of the number of individuals. Application of herbicides in conventional cropping was regarded as the most important factor affecting the difference in species richness compared to organic cropping. The impact of nitrogen fertilisation and crop rotation was weak. Specialisation of production and the application of different management practices increased the spatial variation among farms. The spatial variation in the weed community was greater within the patch of farmland than between regions.

In terms of crop protection, the current weed infestation level of conventionally cropped spring cereal fields can be regarded as tolerable. In contrast, organic cropping will require direct weed control measures in the future. As to biodiversity, the slight increase in the abundance of some broad-leaved weed species in conventional fields and the high species diversity of organic cropping can be regarded as beneficial. Spring cereal fields, however, are not an important habitat for species conservation.

LIST OF ORIGINAL ARTICLES

The thesis is based on the following articles, which are referred to by their Roman numerals in the text.

- I Salonen, J., Hyvönen, T. and Jalli, H. 2001. Weeds in spring cereal fields in Finland – a third survey. *Agricultural and Food Science in Finland* 10: 347-364.
- II Hyvönen, T., Ketoja, E. and Salonen, J. 2003. Changes in the abundance of weeds in spring cereal fields in Finland. *Weed Research* 43: 348-356.
- III Hyvönen, T., Ketoja, E., Salonen, J., Jalli, H. and Tiainen, J. 2003. Weed species diversity and community composition in organic and conventional cropping of spring cereals. *Agriculture, Ecosystems & Environment* 97: 131-149.
- IV Hyvönen, T. and Salonen, J. 2002. Weed species diversity and community composition in cropping practices at two intensity levels – a six-year experiment. *Plant Ecology* 159: 73-81.
- V Hyvönen, T., Holopainen, J. and Tiainen, J. 2004. Detecting the spatial component of variation in the weed community with variation partitioning by CCA (submitted manuscript).

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1. INTRODUCTION

Concern about the loss of biodiversity has grown since the adoption of the Convention on Biological Diversity at the United Nations Conference on Environment and Development in Rio de Janeiro in 1992. The biodiversity of agroecosystems includes both domesticated and wild species and covers a wide range of organisms (Swift & Anderson, 1993; Collins & Qualset, 1999). Concern about the loss of diversity of wild species has focused mainly on the most species-rich habitats, e.g. meadows; the diversity of the wild species occupying arable fields has received less attention.

The biodiversity of arable fields can be divided into 'planned' and 'associated' biodiversity (see Altieri, 1999; Vandermeer *et al.*, 2002). Planned biodiversity refers to the diversity directly manipulated by a farmer, for instance, the crops chosen for planting. Associated biodiversity consists of the organisms that have colonised the field and thrive there, depending on the way the planned biodiversity is managed. Weed species, i.e. all non-cropped plant species encountered in the field, constitute an important part of the associated biodiversity of arable fields. The weeds within these fields are important for the conservation of rare and endangered species (Wilson, 1991) and for the support of other farmland species by acting as a food source for beneficial insects and farmland birds (Sotherton, 1990; Wilson *et al.*, 1999; Marshall *et al.*, 2003).

The plant species of arable weed communities have adapted to cope with regular disturbances in the form of cropping measures. These disturbances form a disturbance regime characterised by the frequency, intensity and extent of the disturbances (Pickett & White, 1985). Changes in these three characters maintain the dynamics of the species composition of the community whilst changes in cropping measures alter the relative abundance and number of species in the weed community. Shifts in the relative abundance of species are of interest in terms of weed control, and shifts in the number of species in terms of biodiversity. This thesis focuses on the effects of recent changes in cropping practices on the weed communities of Finnish spring cereal fields. Both weed control and biodiversity are considered.

The weed communities of Finnish spring cereals were surveyed in 1961-1964 and 1982-1984 (Mukula *et al.*, 1969; Mukula, 1974; Erviö & Salonen, 1987). Between these surveys, there was a marked intensification in the cropping practices of Finnish agriculture (see Fig. 1), and a tremendous decline in weed abundance was observed. The decline was attributed to the higher rate of nitrogen fertiliser application, more effective fertilisation methods, the increased use of crop monocultures and the application of herbicides. Similar changes have been recorded in other European countries, too (Albrecht 1995; Andreasen *et al.*, 1996). At the end of the 1990s, it was considered necessary to undertake a third weed survey of spring cereals since several further changes in arable crop production had taken place. The changes were driven by concern about the environmental impacts of modern agriculture and by adjustments to the Finland's agricultural policy.

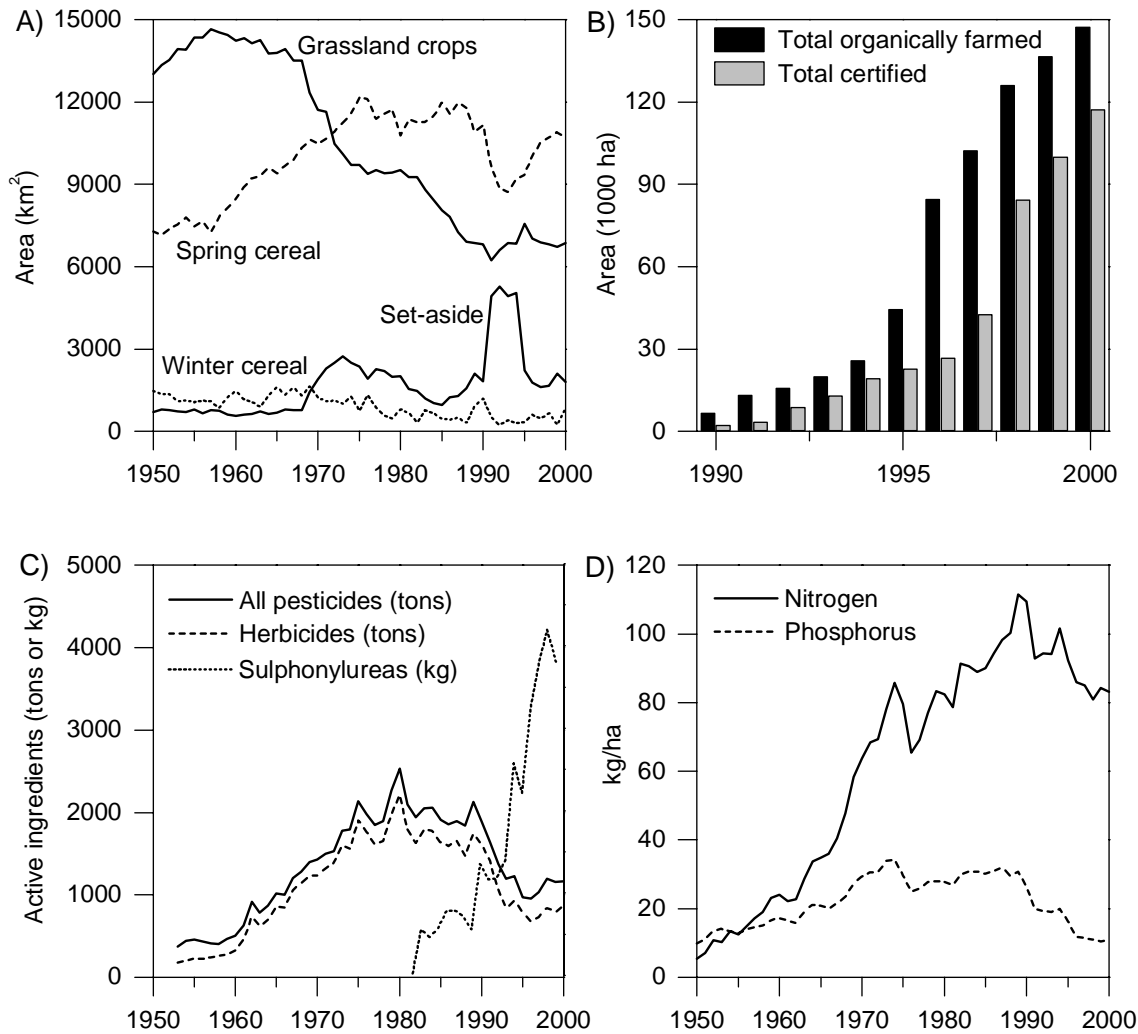


Fig. 1. A) Field use in Finland 1950-2000 (Data source: National Agricultural Statistics). B) Area of organic farming in Finland (Data source: KTTK). C) Pesticide sales in Finland 1953-2000 (Data source: KTTK). D) Use of mineral fertilisers in Finland 1950-2000 (Data source: Kemira Ltd.)

In the early 1990s, concern about environmental issues led to the introduction of a pesticide reduction programme (Ministry of the Environment, 1992). The goal of the programme was to halve the use of pesticides between 1992 and 1995 from the baseline value (average use in 1987-1991). Around the same time, the implementation of an extensive set-aside scheme made for a vast increase in the area of set-asides (Fig. 1A). In 1995, Finland joined the European Union and adopted the Common Agricultural Policy (CAP) of the EU. This entailed various changes to Finland's agricultural policy, one of which was the launch of the Agri-Environmental Support Scheme (Ministry of Agriculture and Forestry, 1994). The prime aim of the scheme was to reduce the nutrient load on water systems from agriculture and the side effects of pesticides on the environment. The main measures were a reduction in the use of fertilisers and pesticides, and the creation of wider field boundary strips as buffer zones. The reduced application of pesticides could be expected to have a direct effect on weed communities; however, the goal of the reduction was not specified. Another measure of the scheme with an impact on weed communities was the support given to organic farming. As a result, the area of organic farming expanded greatly in the 1990s (Fig. 1B). The Agri-Environmental Support Scheme proved to be successful since over 90% of farmers were involved in the basic scheme. In general, the adoption of CAP lowered the prices of products,

which in turn reduced economic rates of application, e.g. of herbicides. Furthermore, the application of low-dose herbicides had become more common after the weed survey of the 1980s (Fig. 1C).

The above changes in cropping measures can be expected to affect weed communities in several ways. First, a decline in application rates or abstention from the application of herbicides can be expected to increase the abundance and species richness of weed communities. Second, the application of herbicides with a certain mode of action, e.g. sulphonylureas, can be expected to affect the species composition of weed communities. Third, organic cropping can be expected to increase the abundance and species richness of weed communities and to change their species composition owing to the abstention from herbicide application, lower level of nitrogen fertilisation and greater diversity of crop rotations. These hypotheses are briefly reviewed in the following.

The results of previous studies on the effects of herbicide application on weed species richness are contradictory. Several experiments on the long-term application of herbicides have failed to report eradication of a weed species as a consequence of the application of herbicides (Fryer & Chancellor, 1970; McCurdy & Molberg, 1974; Chancellor, 1979; Mahn & Helmecke, 1979; Haas & Streibig, 1982). However, for rare and endangered species, the omission of herbicides has been found to be beneficial (e.g. Svensson & Wigren, 1986; Sotherton, 1990). The number of species per area has been found to be lower after post-emergence herbicide application (Derksen *et al.*, 1995; Hald, 1999a; Boström & Fogelfors, 1999; Boström & Fogelfors, 2002), which can be regarded as a short-term effect of herbicide application on species richness. Comparisons of weed species richness between cropping practices have shown that organic cropping supports higher species richness (e.g. Moreby *et al.*, 1994; Hald, 1999a) than conventional cropping with regular herbicide application, and also populations of rare and endangered species (Albrecht & Mattheis, 1998; Rydberg & Milberg, 2000).

The application of selective herbicides has a pronounced effect on the relative abundance of species in a weed community. Herbicides differ in terms of active ingredients, and weed species in terms of susceptibility against the active ingredients. The regular application of a herbicide with a certain active ingredient reduces the density of susceptible species and favours tolerant species (e.g. Chancellor, 1979; Mahn & Helmecke, 1979; Hume, 1987; Salonen, 1993a). Since herbicides are most often applied against broad-leaved dicots, the abundance of tolerant grasses has been found to increase (Haas & Streibig, 1982). The change in species composition is further enhanced by the shift in competition relations: herbicide-tolerant species encounter less competition when the abundance of herbicide-susceptible species has declined (Hume, 1987).

Fertilisation plays an important role in the dynamics of weed communities. Nitrogen can be regarded as the most important fertiliser although other nutrients, e.g. phosphorus, are also of some importance (Banks *et al.*, 1976; Hoveland *et al.*, 1976; Goldberg & Miller, 1990). Increased nitrogen fertilisation promotes the biomass production of crop and weeds (e.g. Mahn, 1988; Jørnsgård *et al.*, 1996), which leads to greater competition for light between weeds and crops (Haas & Streibig, 1982; Pyšek & Lepš, 1991; van Delden *et al.*, 2002; see also Wilson & Tilman, 1991). The greater competition for light has been found to favour species with a tall and erect growth form (Pyšek & Lepš, 1991) or physiological shade tolerance (Haas & Streibig, 1982). As a direct consequence of high nitrogen availability, the abundance or frequency of occurrence of nitrophilous species (e.g. *Chenopodium album* and

Elymus repens) increases (Haas & Streibig, 1982; Mahn, 1988). Organic cropping has been found to support populations of non-nitrophilous species (Rydberg & Milberg, 2000). Direct and indirect consequences of high nitrogen fertilisation have been cited as one reason for the decline in some rare weed species (Svensson & Wigren, 1986; Wilson, 1991; Wilson, 1999).

In organic cropping, diverse crop rotation – typical of animal husbandry farms – is applied as a means of fertility management (e.g. green manuring crops in rotation) and weed control. Diversity of crop rotation is expected to have only a minor effect on weed species composition (Bàrberi *et al.*, 1997) and species diversity (Doucet *et al.*, 1999) unless the rotation includes cereals sown in different seasons (Hald, 1999b) or grasslands (Paatela & Erviö, 1971; Stevenson *et al.*, 1997; Sjørnsen, 2001). Practising conventional dairy or organic cropping can be assumed to increase the diversity at landscape scale. The difference in crop rotation between animal and crop husbandry can be expected to have an effect on regional differences in the species composition and diversity of weed communities, too, since crop husbandry is concentrated in south and southern-western Finland whereas animal husbandry is practised mainly in eastern and central Finland.

This thesis examines the weed communities of Finnish spring cereal fields in the light of the hypotheses outlined above. The thesis had the following aims:

- 1) *to explore the current weed infestation level and the most important weed species of spring cereals (I)*
- 2) *to study the response of the weed communities of spring cereals to recent changes in herbicide application practices (II)*
- 3) *to compare the species diversity and species composition of weed communities between the conventional and alternative (low-input or organic) cropping of spring cereals (III and IV)*
- 4) *to explore the spatial variation in species composition and environmental variables explaining the species composition in the weed community of arable fields (V)*

2. MATERIAL AND METHODS

2.1. Study areas

The data for the national weed survey were collected in 16 regions in southern and central Finland (see Fig. 1 in I). Two of the southern regions – called Lammi and Jokioinen according to their base municipalities – provided the data for the comparison of organic and conventional cropping (see Fig. 1 in III). The experiment to compare low-input and conventional cropping (IV) was conducted at Jokioinen (60°49'N, 23°28'E), and the data for detecting spatial variation (V) were collected from a patch of farmland situated near Lammi Biological Station (61°03'N, 25°03'E).

2.2. Study design and sampling, measurements

Four of the papers (I; II; III; V) were based on data collected from ordinary farms; one (IV) was based on the data of a field experiment.

The weed survey (I; II) included the farms of the previous weed surveys as well as new ones. Organic and conventional cropping were compared (III) with the aid of patches of farmland comprising the neighbouring fields of an organic, a conventional arable and a conventional

mixed (dairy production) farm. The sampling in the weed survey (I; II) and the comparison of organic and conventional cropping (III) were conducted by placing 10 sample quadrats in each field randomly. Two of them were placed at a distance of 1-3 m from the sown field edge and the other eight more than 5 m from the edge. Weed density was determined by counting the number of shoots by species from a rectangular frame measuring 0.1 m² (25 cm × 40 cm). In four out of ten sample quadrats, weeds and cereals were cut at the soil surface and their biomasses were weighed by species after drying the samples in an air-flow dryer at 40 °C for some days. The information on cropping measures was recorded by interviewing the farmers. Both studies were conducted in 1997-1999. The weed survey data were gathered from a total of 305 farms and 690 fields.

For the detection of spatial variation (V), a 60 m × 60 m grid was placed in the study area running in a north-south direction. The study area, which was made up of small fields (average area 4.1 ha), comprised 450 ha of farmland surrounded by forests. Weed shoots were counted by species from each sample quadrat (50 cm × 50 cm) established at the centre of each grid cell. Data were collected from 68 fields belonging to nine farms (662 sampling quadrats) in July-August 1998. The information on cropping measures and soil was recorded by interviewing the farmers.

The study design to compare low-input and conventional cropping (IV) comprised two approaches differing in respect of the application of herbicides and fertilisation. In the conventional cropping, mineral fertilisers and herbicides were applied whereas in low-input cropping, manure was used as fertiliser and no herbicides were applied. Both cropping practices had the same five-year crop rotation and other management practices. Since there were ten field strips in the experiment, each crop occupied one field strip each year. The field strips were about 40 m × 140 m in size. Years were regarded as replicates. Weed samples were collected from the cereal field strips in August in 1992-1997. Twelve samples (area = 0.5 m²) were taken from each field strip per year. All weed individuals and the crop plants were cut at the soil surface and taken to the laboratory for sorting and counting.

The nomenclature of plant species follows that of Hämet-Ahti *et al.* (1998) in all papers.

2.3. Analyses of the data

2.3.1. Weed infestation

The analysis of weed survey data (I) was conducted with descriptive methods. Analyses of the changes in weed abundance between the 1980s and the 1990s (II) were based on random effects models.

2.3.2. Species diversity

Three different levels of species diversity can be distinguished: point diversity (alpha diversity), the rate of change in point diversity between two samples and the turnover of species (beta diversity) and the number of species in the whole region (gamma diversity) (Whittaker, 1970). Here, species diversity was studied at all three levels. Gamma diversity was measured with the aid of the number of species (I, III, IV). Beta diversity was measured with the aid of Jaccard's similarity coefficient (I; III), the similarity ratio (IV) and the proportion of joint species in the species pool (I; III) (see van Tongeren, 1995). The number of species (I; III; IV) along with diversity indices (Shannon diversity index (IV) and Hill's evenness index (I) (see Magurran, 2004)) was applied as a measure of alpha diversity.

Since the number of species and the number of individuals have a positive relationship (e.g. Magurran, 2004), species numbers were adjusted to the same number of individuals for the comparison by rarefaction (I; III; see Heck *et al.*, 1975) and general linear mixed models (III). In one of the studies (IV), the statistical significance of the differences in number of species, the values of Shannon diversity indices and the biomasses of crops were tested between low-input and conventional cropping using the Wilcoxon Signed Rank test (accidentally, Wilcoxon two-sample test was applied in the original article, see ‘errata for the article IV’ for explanation).

2.3.3. Species composition

The variation partitioning method (Borcard *et al.*, 1992) by Canonical Correspondence Analysis (CCA) was applied to study the interaction and importance of farm, soil, physical, crop and spatial variables to explain the variation in weed species composition (V). The CCA analyses were performed with CANOCO 4 software (ter Braak & Šmilauer, 1998).

Ellenberg nitrogen (III; IV) and light (III) figures were used to compare species in relation to nitrogen and light between conventional and alternative cropping practices (Ellenberg *et al.*, 1991).

3. RESULTS AND DISCUSSION

3.1. Weed infestation (I, II)

The current weed infestation level of Finnish spring cereals – measured by the dry weight and number of individuals – was found to be 329 kg ha⁻¹ and 243 individuals m⁻² (I). The figures correspond with those found in unsprayed fields in the early 1980s (Erviö & Salonen, 1987). Since the latest weed survey included sprayed and unsprayed conventional as well as organically cropped fields, the current weed infestation level can be regarded as higher than that in the 1980s. The importance of chemical weed control for weed abundance was evident: the difference in the total biomass of weeds between sprayed conventional (163 kg ha⁻¹) and organic (678 kg ha⁻¹) and unsprayed conventional (605 kg ha⁻¹) fields was clear (I). Comparison of the weed abundance of 80 conventionally treated fields revealed only a minor increase in the dry weight (31.1 kg ha⁻¹) and number of individuals (46.6 individuals m⁻²) between decades (II). Thus, the most important change affecting the weed infestation level of Finnish spring cereals was the adoption of organic cropping (I); changes in conventionally cropped fields treated with regular herbicide applications were minor (II).

The pesticide reduction programme launched at the beginning of the 1990s had the ambitious goal to halve the use of pesticides by the amount applied (but not by the area treated) (Ministry of the Environment, 1992). There was no follow-up on the consequences of the reduction programme but the statistics on pesticide sales in Finland showed a marked decline in trends in terms of active ingredients (Fig. 1C). At the same time, Salonen (1993b) studied the performance of herbicide application in Finnish spring cereals, and suggested that the application rates of herbicides could be reduced by 30% annually without a decline in the efficacy of weed control. In the field survey comparing weed abundance between the 1980s and the 1990s (II), the decline in the average application rates of MCPA was about 25%. Furthermore, half of the farmers had applied doses lower than recommended on the herbicide label or the minimum dose in the 1990s (II). The minor change in weed abundance found in the comparison can be regarded as support for the suggestion of Salonen (1993b).

Evidence of the effect of application of sulphonylureas on species composition remained weak (II). The most abundant weed species were mostly the same in both decades (II). Six out

of the twelve most abundant species had a higher number of individuals in the 1990s than in the 1980s but the changes in the number of individuals were minor (II). Changes in the frequencies of occurrence, however, were clear; the most conspicuous increase was in the frequencies of *Chenopodium album* and *Galium spurium*. The most marked percentage increase, however, was in the frequency of occurrence of *Cirsium arvense*. Earlier studies have documented a shift in the species composition of weed community as a consequence of the application of a herbicide with a certain active ingredient (Mahn & Helmecke, 1979; Hume, 1987). However, documentation of the effect of herbicide application derived from small-scale field experiments (Hume, 1987) whereas the present comparison was conducted as a large-scale on-farm survey. The application of low-dose herbicides was probably not long-lasting enough to cause a shift in weed species composition. Furthermore, different products of low-dose herbicides differed in their active ingredients. Therefore, the effect of low-dose herbicides as a group on different weed species was not consistent. The application of low-dose herbicides as a mixture with phenoxy herbicides was also common (I). Our results suggests that the application of sulphonylureas, which started in the early 1980s, has not affected the structure of weed communities of Finnish spring cereals.

The difference in the weed infestation level between organically and conventionally grown fields was clear (I). In organic cropping, weed biomass accounted for 17.1% of total biomass production, whereas in conventional cropping the proportion remained at around 3% (I). Although the biomass production of herbicide-susceptible weeds differed enormously between cropping practices (e.g. *Chenopodium album*), the most abundant species tended to be the same in both cropping practices (e.g. *Elymus repens*, *C. album*, *Stellaria media* and *Galeopsis* species) (I). Broad-leaved species accounted for 43% of the total biomass in sprayed conventional and for 72% in organic fields (I), which can be regarded as a consequence of chemical weed control directed against broad-leaved annuals (Hume, 1987). Since the proportion of broad-leaved species was lower in conventional than in organic cropping, the contribution of grasses to weed infestation has become pronounced in conventional cropping. The most abundant grass weed was *E. repens*, which comprised 26% of the total biomass of weeds in organic and 50% in conventional fields (I). The weed infestation level and changes in the relative abundance of weeds of conventional fields receiving regular chemical weed control is tolerable (I; II). However, the high proportion of *E. repens* (I) and the huge increase in the frequency of occurrence of *Cirsium arvense* (II) give cause for concern because both of these are perennial species that reduce yield and are difficult to control.

The current weed infestation level of organic fields was found to be the same as in the 1980s (Mela, 1988), when the number of individuals was 505 m⁻², biomass production 575 kg ha⁻¹ and abundance as a proportion of total biomass 10-13%. Most of the fields studied in the 1990s had only a short history of organic cropping, i.e. they had been converted from conventional to organic cropping earlier in the same decade. High weed infestation may occur after conversion from conventional to organic cropping (Davies *et al.*, 1997). The increase in the seed numbers in the seed bank after conversion from conventional to organic cropping has been found to be dependent on the proportion of cereals in crop rotation (Albrecht & Sommer, 1998; Sjursen 2001). Despite high weed infestation levels, direct weed control measures are rarely applied in organic cropping in Finland (III). In the future, however, such measures (see Rasmussen & Ascard, 1995) will have to be applied in organic cropping.

3.2. Species diversity (I, III, IV)

The structure of the weed community of Finnish spring cereals was typical of any community of organisms: a few of the species were common and abundant but the majority were rare and less abundant. In the weed survey data, 21% of the species exceeded the frequency of occurrence of 10%, and only the three most abundant species produced half of the total biomass (I). The total number of species, i.e. gamma diversity of Finnish spring cereal fields, was observed to be 160 or 188 depending the sample area applied (I). Mukula *et al.* (1969) found 304 species in their study of 2710 fields. Since the number of fields sampled differs between weed surveys, the total numbers of weed species detected in weed surveys in the 1960s and in the 1990s are not comparable. However, it is clear that the weed flora of Finnish spring cereals includes numerous species in addition to those which are of interest in terms of weed control.

All comparisons of species richness between conventional and alternative cropping practices (I, III, IV) showed consistently that species richness was higher in alternative cropping with lower inputs than in conventional cropping. In accordance with the terminology of Whittaker (1970), organic cropping affected species diversity at all levels. In the weed survey data (I), gamma diversity was found to be higher in organic than in conventional cropping in nine out of 15 regions. Exploration of seasonal dynamics revealed that the difference in gamma diversity between organic and conventional cropping was more pronounced after the herbicide treatment of conventional fields (III). The proportion of co-occurring species, which was used as a measure of beta diversity, between cropping practices exceeded 50% in every region of the weed survey (I). The fields of conventional dairy farms were found to have more species co-occurring (63.5%) with organic fields than with conventional cereal fields (61.6%) (III). Alternative cropping was found to support higher alpha diversity both in the experimental (average per field strip 20.2 vs. 13.1 species) (IV) and in the on-farm study (variation in averages between regions 14-25.1 vs. 6.6-17.6 species) (I). However, the difference in the mean number of species between cropping practices remained minor (two species) when the number of species was adjusted to the number of individuals (III).

The application of herbicides in conventional cropping was regarded as the most important factor affecting the difference in species richness between cropping practices (I; III; IV). The importance of herbicide application for species richness was apparent, especially in the comparison of weed communities between cropping practices before and after the application of herbicides to conventional fields (III). These findings support the view that omission of herbicides is beneficial for the species number of the species pool (Svensson & Wigren, 1986; Sotherton, 1990) rather than that herbicide application would not reduce gamma diversity, i.e. the species pool (Fryer & Chancellor, 1970; McCurdy & Molberg, 1974; Chancellor, 1979; Mahn & Helmecke, 1979; Haas & Streibig, 1982). The contradiction between these two views lies more likely in the extent of the species pool they have focused on than in the impact of the herbicides. In the latter case, the species pool included only the most abundant weed species, i.e., those with a huge seed bank to buffer the deleterious effects of herbicide application. In the present studies (I; III; IV), the focus was on a whole species pool, which thus also included rare and less abundant species. Furthermore, in the latter studies the same experimental plots were investigated over several years whereas, here, a sample of fields was studied. Another result in contrast to previous findings was the magnitude of the difference in alpha diversity between organic and conventional cropping (III). Previous comparisons did not take the positive relationship between the number of species and the number of individuals into account (e.g. Moreby *et al.*, 1994; Hald 1999a). Therefore, the differences in the mean number of species between cropping practices, and thus the benefits of organic

cropping for the species number, were clearly overestimated, being partially a sampling artefact.

The contribution of nitrogen fertilisation to species composition proved to be of minor importance. The differences in the abundance of shade tolerant species (III) and in the occurrence of nitrophilous species between cropping practices were small (III; IV). This was in accordance with previous findings, since Rydberg & Milberg (2000) also found only weak support for the preference of non-nitrophilous species for organic cropping. Two reasons were suggested for the minor differences in species composition between cropping practices. First, the nitrogen concentration in conventional fields was not high enough to create dense crop stands and thus limit the amount of light (IV) or the occurrence of weed species directly (III; IV). Second, species with a low nitrogen preference had not returned to the species pool (see Bischoff & Mahn, 2000), insufficient time having elapsed since the shift from conventional to organic cropping (III). The first explanation is likely because the application rates of nitrogen fertilisation in Finnish conventional cropping are relatively low. In countries with intensive crop production, the application rates are clearly higher. Earlier, it was difficult to differentiate between the direct and indirect effects of nitrogen on the weed community (Pyšek & Lepš, 1991). Furthermore, the effects of nitrogen fertilisation on weed species composition and species number were previously found to be outweighed by other factors such as study site and crop species (Andersson & Milberg, 1998). In both of these studies (III; IV), the most important factor affecting weed community was herbicide application. However, the contribution of crop (IV) and crop rotation (III) to species composition was also established, which was probably due to different management attributed to the different crops in the rotation (Doucet *et al.*, 1999). The diverse crop rotation of organic cropping, which aims at maintenance of soil fertility and weed management, affects the species pool of the weed community.

In other countries, organic cropping (Albrecht & Mattheis 1998; van Elsen, 2000; Rydberg & Milberg, 2000) and the omission of herbicide application (Sotherton, 1990) has been found to support populations of rare and endangered weed species. In the present studies (I; III), none of the weed species classified as threatened in Finland (see Rassi *et al.*, 1992) was encountered. The only rare species noted was *Centaurea cyanus* (I; III; IV), which occurs mainly in autumn cereal fields in Finland. *C. cyanus* – like many other Finnish threatened weed species (Suominen, 1986) – has suffered more from the decline in the area of autumn cereals than from the intensification of spring cereal cropping practices. In terms of conservation biology, then, the importance of the weed communities of Finnish spring cereal fields remains low. In contrast, the increase in the abundance of common species may be beneficial for the functioning of the ecosystem. For example, the higher proportion of some broad-leaved weed species (e.g. *Chenopodium album*) found in organic cropping (I) is beneficial because weed pollen, nectar, shoots and seeds constitute an important food source for beneficial insects, such as pollinators and natural enemies of pest insects, and for farmland birds (Wilson *et al.*, 1999; Marshall *et al.*, 2001; Marshall *et al.*, 2003). Weeds also produce organic material for the decomposers and hence serve the cycling of material and nutrients. The increase in the area of organic cropping together with a slight increase in the abundance of weeds in conventional fields is therefore advantageous for the ecosystem of arable fields.

3.3. Spatial variation in weed communities (I, II, III, V)

Specialisation of production in different parts of Finland did not create marked regional differences in the species diversity or species composition of weed communities (I), only a slight regional trend being detected in species composition and the average number of species

between different parts of Finland. However, no difference was observed in the total numbers of species between regions (I). These findings contradict those of Mukula *et al.* (1969), who suggested a floristic division based on the weed survey data collected in Finland in the 1960s. More recent studies, however, have shown that factors related to regional variation exceed management factors in explaining the species composition of weed communities (Dale *et al.*, 1992; Salonen, 1993a; Hallgren *et al.*, 1999; Leeson *et al.*, 2000). The differences between regions would probably have been more pronounced had the sample of farms in each region better represented the distribution of farms in the region. Neither did the change in weed abundance between decades differ between regions: although the difference in numbers of weed individuals varied between regions, no regional trend in the variation was detected (II). Most of the variation in the change in weed abundance between decades was attributed to the lower scale, i.e. to the variability between fields within the same farm (II). Regional specialisation of production has been thought to pose one of the main threats to the biodiversity of Finnish agricultural habitats (Pitkänen & Tiainen, 2001). The present results did not provide strong evidence for this view regarding the weed communities of spring cereal fields. The impact of management factors on communities of farmland species seems to differ between groups of organisms (see Kinnunen *et al.*, 2001).

At a lower scale, the spatial variation was more pronounced. The comparison between organic and conventional cropping revealed differences in the species pool within both region (I) and patch of farmland (III). Practising organic cropping can therefore be thought to enrich the species pool, i.e. gamma diversity, of a region or patch of farmland. The species pool of conventional dairy farms differed roughly as much from the species pool of conventional cereal farms as did the species pool of organically cropped farms (III). The difference can be attributed to the crop rotation of dairy farms, which includes grasslands (Paatela & Erviö, 1971; Stevenson *et al.*, 1997).

A clear spatial structure in the variation in the species composition of weed communities was also detected at the scale of patch of farmland when all farms engaged in conventional cereal cropping (V). The management variables – farm and crop – explained more of the variation in species composition than did variables describing soil or the physical properties of the environment. The specialisation of some farms in a certain crop was found to be the main reason for the between-farm variation. In this case, however, the difference in beta diversity between farms due to specialisation did not necessarily contribute to gamma diversity at the scale of patch of farmland, because in some crops (e.g. sugar beet) the alpha diversity was low. It was clear that, at the scale of patch of farmland, the different management practices of individual farms can enrich the local species pool. The enrichment, however, is dependent on the management practices.

4. CONCLUSIONS

Adoption of the pesticide reduction programme and the Common Agricultural Policy (CAP) of the EU affected the cropping practices of Finnish spring cereal fields in the 1990s. The reduction in the application of herbicides required by the pesticide reduction programme has led to only a slight increase in the weed infestation level or the abundance of individual weed species. Another change in the application of herbicides – the more widespread application of sulphonylureas – has had a minor effect on the species composition of weed communities. In terms of crop protection, the current weed infestation level of conventionally cropped spring cereal fields is tolerable. As to biodiversity, the increase in the abundance of some broad-leaved weed species can be regarded as beneficial.

The adoption of the CAP has resulted in an increase in the area of organic cropping, a change found to be beneficial for the species diversity of weed communities. The weed infestation level of organically cropped fields is, however, high, and direct weed control measures will eventually be needed. Omission of herbicide application was regarded as the most important factor affecting the differences in weed communities between cropping practices.

Specialisation of production and the application of different management factors increase spatial variation. The spatial variation of the weed community was stronger within a patch of farmland than between regions. The increase in the area of organic cropping has been beneficial for biodiversity. In terms of species conservation, spring cereal fields are not regarded an important habitat.

The data obtained from on-farm studies and from national weed surveys of spring cereal fields were useful in monitoring the impact of changes in cropping practices on weed communities. A connection was found between agricultural policy and changes in weed communities. In the future, this connection will be strengthened since the data of national weed surveys are one of the indicators applied in efforts to monitor implementation of the Ministry of Agriculture and Forestry's strategy for the sustainable use of natural resources (see Yli-Viikari *et al.*, 2002). The weed indicator has to be interpreted with care. Further, more research is needed on the role played by weed species in supporting farmland biodiversity to enable us to answer the pivotal question: how many weeds and what species are needed?

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