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Plant diversity and land use under organic and conventional agriculture: a whole-farm approach

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Summary

1. Organic farming is thought to lead to increased biodiversity and greater sustainability than higher-yielding conventional farming systems. It is usually assumed that organic farms have both larger and higher quality areas of semi-natural habitats, although this assumption has not been unequivocally tested.

2. Here we test the hypothesis that in comparison to conventional farms, organic farms have larger areas of semi-natural and boundary vegetation, and organic farms support higher levels of plant abundance, richness and diversity within cropped and semi-natural areas.

3. Our study compared whole-farms: 10 organic farms were paired with 10 conventional farms in a complex landscape in the south-west of England. On average, organic farms were 7·3 years post conversion. Plant abundance, species richness and diversity were measured in all crop and non-crop landscape elements on each farm.

4. Organic farms had greater total areas of semi-natural habitat (woodland, field margins and hedgerows combined). Woodland area on it's own was also significantly greater. Organic farms had more continuous blocks of woodland (with simpler perimeters than similarly sized patches on conventional farms), whereas woodland on conventional farms often consisted of more linear patches.

5. Semi-natural habitats on organic farms did not have higher plant abundance, richness or diversity than their conventional counterparts. The only landscape element that showed a significant increase in plant abundance, richness or diversity was arable fields.

6. *Synthesis and applications*. Even within a complex agricultural landscape differences do exist between organic and conventional farms, these differences being larger areas of semi-natural habitats on organic farms. However, with the exception of arable fields, no habitats on organic farms were yet of a better quality than their conventional counterparts in terms of plant abundance and diversity. Conventional farmers may be able to achieve an increase in plant diversity within arable fields by adopting some organic management practices at the field scale (e.g. exclusion of synthetic herbicides), and whole-farm conversion to organic practice might not be required. However, further work is needed to determine any biodiversity benefits of larger areas of semi-natural habitat on conventional farmland.

Key-words: agroecology, arable weeds, GIS, habitat heterogeneity, plant diversity, production syndromes

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Introduction

The intensification of agriculture over the last 50 years has been associated with substantial losses of biodiversity (Robinson & Sutherland 2002). Maintaining current levels of food production in the future presents a challenge to conservationists already struggling to

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sustain marginalized and fragmented populations of plants and animals. Solutions to this dilemma fall into two categories: land sparing, which seeks to increase yield and so reduce demand for more farmland; and wildlife-friendly farming, which seeks to encourage populations of plants and animals on farms but may result in decreased yields (Green *et al*. 2005). Organic farming falls into the latter category and is thought to result in higher levels of biodiversity and to be more sustainable than higher-yielding conventional farming systems. Indeed, the organic sector in the United Kingdom is booming with high numbers of farm conversions underway and further financial support in the form of government environmental incentive schemes (Defra 2006). However, the organic farming industry has been criticised for the perceived lack of scientific methodology underpinning its farming methods (e.g. Kirchmann & Thorvaldsson 2000; Trewavas 2001; Barlow 2002). The organic community defends itself by claiming that direct comparisons of organic and conventional crops are inappropriate and that only the whole system can be compared (MacKerron *et al*. 1999).

In theory, organic farming, which forbids the use of synthetic chemicals (pesticides and fertilizers) and encourages the sympathetic management of all habitats within a farm, should promote landscape heterogeneity and thereby increase plant and subsequently animal diversity. However, recent reviews highlight apparently contradictory results between studies (Bengtsson *et al*. 2005; Hole *et al*. 2005) which resulted from differences in the taxa under investigation and methodological issues surrounding the comparisons of two inherently different farming systems. Bengtsson *et al*. (2005) found that positive effects of organic farming on abundance of organism groups were present at the plot and field scales, but not for whole farms in matched landscapes. Landscape heterogeneity may have a greater impact on arthropod diversity than regional or local management factors such as farming system. Some studies suggest that differences between organic and conventional farming systems are often only clear when the study sites are located within an intensively farmed landscape matrix (Weibull & Bengtsson 2000 for butterflies; Weibull *et al*. 2003 for plants and four arthropod taxa; Schmidt & Tscharntke 2005 for spiders). Weibull & Bengtsson (2000) attempted to disentangle the effects of farming system and landscape heterogeneity on the diversity of farmland butterflies in central Sweden. They found that habitat heterogeneity influenced the number of butterfly species present to a far greater extent than did farming system, and concluded that all farmers should be encouraged to increase small-scale heterogeneity on their farms to enhance diversity. This view is supported by Hole *et al*. (2005) who questioned whether a ‘holistic’ whole-farm approach (i.e. organic) enhances biodiversity more than focusing efforts on small areas of habitat within a conventional farming approach. If this is in fact the case, can the extra effort and money put into encouraging farmers to convert to organic be justified on the basis of biodiversity enhancement?

There are many organic farming practices that could potentially enhance biodiversity, including the avoidance of synthetic pesticides, herbicides and fertilizers. Studies of bird diversity and abundance (Chamberlain *et al*. 1999; Freemark & Kirk 2001; Fuller *et al*. 2001) have suggested that enhanced bird abundance on organic farms is at least in part a result of larger and better quality areas of semi-natural habitats and boundaries. Wickramasinghe *et al*. (2003) found bat activity was significantly higher on organic farms and this was attributed to taller hedgerows and better quality water habitats. Thus, it is often assumed that organic farms have larger and better quality areas of both semi-natural habitats and boundaries; however, this statement has not been rigorously tested to our knowledge. Here we test the hypotheses that organic farms have larger areas of semi-natural and boundary vegetation (i.e. hedges and field margins) and that they support higher levels of plant abundance, species richness and diversity within both cultivated and semi-natural areas of vegetation. We measured plant diversity because this is likely to drive changes in biodiversity at higher trophic levels (Altieri 1999; Clough *et al*. 2007) and has shown the most consistent response to farming system in other studies (Fuller *et al*. 2005).

Materials and methods

STUDY REGION

The study was carried out in the south-west of England, a region that can be described as a complex agricultural landscape *sensu* Marino & Landis (1996). The average farm size (for conventional farms) in the region is 51 ha, which is below the national average of 73 ha (Defra 2005) and only 12% of farms are larger than 100 ha. Grassland dominates the region, with 41% of holdings being classed as dairy and 29% as cattle and sheep. Over the past 20 years there has been a decline in the area of cereals grown (especially spring-sown cereals) and an increase in oilseed rape, linseed and maize. The south-west currently contains 46% of all organic producers and growers in England (the highest proportion of any region). Total organic hectarage currently represents 2·3% of farmland in the region and uptake of this method of production is increasing (Defra 2005). The nature of the south-west’s pastoral area, with its mild climate and limited input of chemicals, gives conventional farmers in this region a relative advantage if they wish to convert to organic farming methods.

FARM SELECTION

Ten organic and 10 conventional farms were selected according to a paired design, surrounding the city of Bristol in the south-west of England (Fig. 1). These

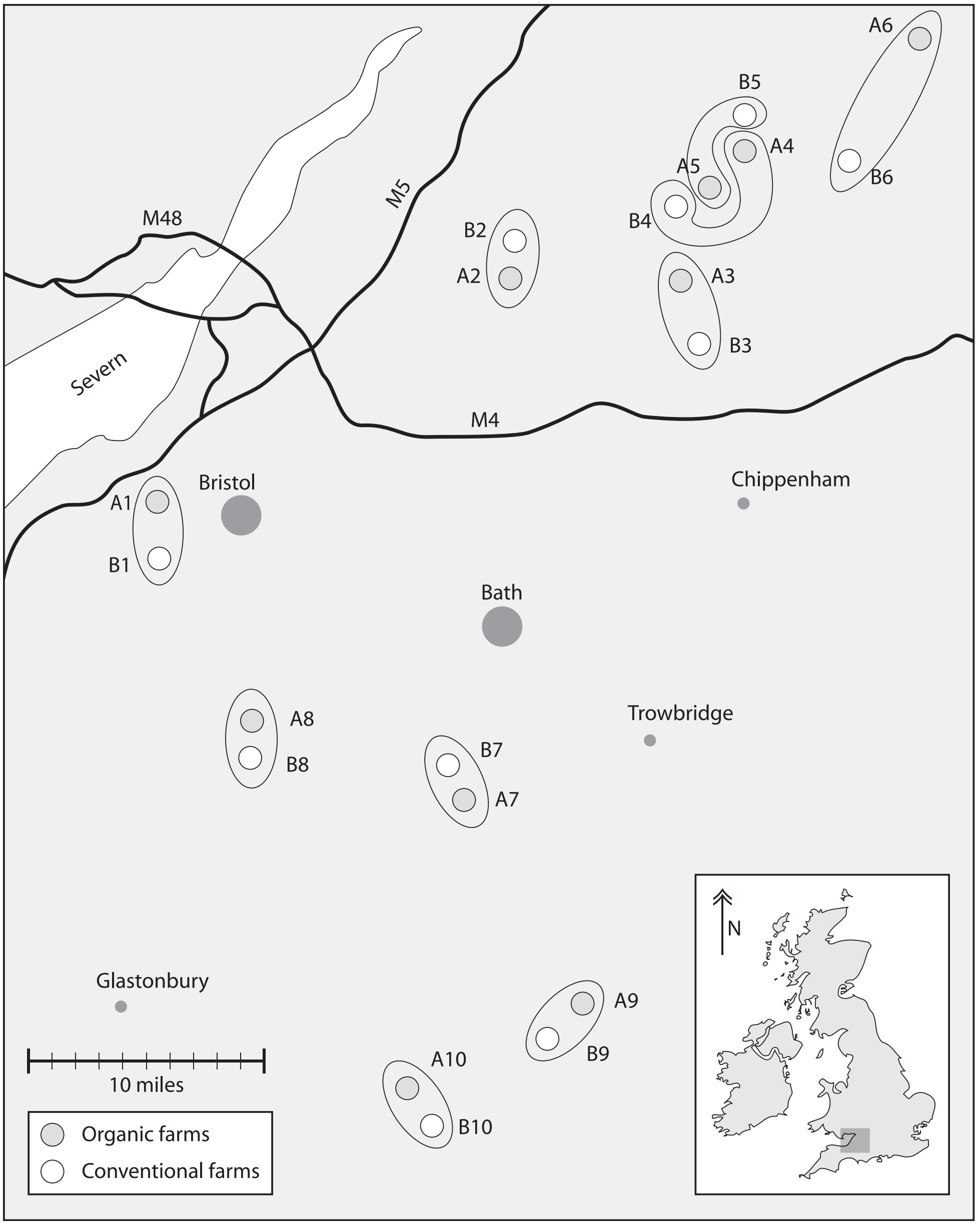

Fig. 1. Location of field sites in south-west England used for study. The 10 pairs of farms are shown in circles. The unusual pairing of farms north-east of Bristol is due to farms in this cluster sharing field boundaries.

farms, and this study, were part of a larger study investigating plant–herbivore–parasitoid trophic networks at the whole-farm scale under the two farming systems. All farms were mixed, with either dairy or beef cattle herds plus at least two arable crops. Organic farms were selected first then paired with a conventional farm of similar size within 5 km that did not have fields adjoining those of the organic farm. Such pairing was designed to minimize differences in geology and elevation. Criteria such as the amount of semi-natural habitat or non-cropped areas were not matched within pairs. Larger areas of semi-natural habitat, including hedgerows, are recommended as part of the organic approach (as source areas for natural enemies of pest species; Lampkin *et al*. 2004), and therefore excluding such factors may result in underestimating differences between organic and conventional farms. If parts of a farm were non-contiguous only the main fragment surrounding the farmhouse was used for the study. Farm size was calculated, and if there was a difference in size between a pair of greater than 10%, land was removed from the larger farm by randomly choosing a single point on the edge of the farm and then removing fields or discrete areas such as woodlands surrounding this point. All landscape elements within the adjusted farm size were then mapped. The organic farms had all finished the conversion process (the introduction of altered pest management strategies, changes to crop rotations, and modifications to livestock-rearing systems, Lampkin *et al*. 2004). The earliest completion date was 1994, and the latest was 2003, with an average of 7·3 years and a minimum of 2 years since conversion.

Farm mapping

During winter 2004/2005 all the landscape elements listed below were mapped on each farm using a GPS unit (GeoXT™ Pocket PC handheld GPS unit with FastMAP CE™ software). Farmhouses and gardens were not included in the area calculations. Landscape elements were grouped into the following broad classes for mapping.

Grass fields included grass leys, improved pastures and permanent pastures. Levels of management varied widely within this habitat type.

Arable fields included all crop types sown or growing during the summer sampling period. These were *Triticum* sp. (wheat), *Avena* spp. (oats), *Hordeum vulgare* (barley), *X-Triticosecale*, *Zea mays*, *Secale cereale*, *Brassica napus* sp., *Lupinus* sp., *Vicia faba*, *Brassica juncea*, *Brassica oleracea (Acephala group)*, *Medicago sativa* and *Trifolium* spp. Single vegetable crops (e.g. *Solanum tuberosum*, potato) were also included (see below). Uncultivated field margins were not included in the calculations of arable field size.

Woodlands included established woodlands (with a closed canopy), new plantations of trees (without a closed canopy), and any area with three or more trees close enough that their canopies formed continuous cover when in leaf. Solitary trees within fields or along field boundaries were not included.

Hedgerows were defined as vegetation thick from the ground upwards and forming an obvious field boundary, or vegetation thick above waist height with trunks visible below, but forming a thick continuous field boundary of even height and width. This vegetation could consist of newly planted or mature hedgerow shrub species (e.g. *Crataegus monogyna*, *Corylus avellana* and *Sambucus nigra*) and other vegetation (e.g. *Rubus fruticosus*, brambles), which exhibited clear evidence of laying, trimming or other hedgerow management practices. In each field, on all 20 farms, the width of the hedgerow in two positions (randomly located) was measured during winter months. These measurements were used to calculate the average hedgerow width across the entire farm. The location and length of all hedgerows on a farm were mapped using the hand-held GPS. In the mapping program the hedgerows were represented as a single line. The total length of hedgerow was obtained from the FastMAP program and multiplied by the average hedgerow width to give an estimate of hedgerow area per farm. During the summer of 2005 measurements of hedgerow height and width were taken at six locations per farm. The height was multiplied by the width to give a comparison of cross-sectional area of hedgerows in each farming system.

Field margins were defined as any area of semi-natural habitat (uncultivated) greater than 1 metre in width that formed the perimeter of a field and was located between the crop and the fence-line or hedgerow. This is necessarily a broad definition because the width and composition of margins varied considerably across farms. Margins ranged from highly managed grass strips to unmanaged remnant strips of crops or weeds (Marshall & Moonen 2002). The width of the margin was measured at a single position (randomly located) on four sides of a field. In the mapping program a single line was added to the sides of the field with margins and their length was calculated. The length was multiplied by the width recorded for that side to calculate an estimated area for the whole farm. It was assumed that a margin maintained the same width across the entire side of the field.

Rough ground was any area of land that was not managed by the farmer with the aim of returning profit by producing crops or maintaining livestock. This included dumping areas for farm machinery and animal waste, and land that was unsuitable for cultivation. The vegetation usually consisted of grass, and other opportunistic species, but also patches of *Ulex europaeus* within fields. The definition also included areas in long-term set-aside (i.e. for more than 3 years).

Orchards were defined areas of land that contained planted fruit trees, regardless of the age, density or management of the trees.

Set-aside included areas of land not used for crop production or livestock maintenance for a short period of time (usually up to 3 years). Set-aside was only found on conventional farms due to the environmental incentives scheme active at the time of mapping.

Mixed vegetables were areas of land used for the production of multiple vegetable crops on a regular basis. When whole fields or significant sections of a field were sown to a single vegetable type (e.g. potato) they were incorporated into the arable fields calculations.

Game cover was an area (usually strips) of land planted with vegetation to maintain bird populations on the farm. Commonly *Zea mays*, *Panicum miliaceum*, *Fagopryum esculentum* and *Helianthus* sp. were planted.

Plant diversity and abundance

In each of the landscape elements plant diversity and abundance were recorded along transects, between April and September 2005. A total transect area of 150×1 m was sampled per farm on six occasions at monthly intervals. The transects were divided up according to the area occupied by each landscape element per farm. Total sampling effort was equal between pairs at the whole-farm scale (150 m^2 per sampling occasion), but within each landscape element sampling effort was adjusted for the proportion of the total farm area occupied by that element. For example, on one farm on each visit we sampled 50 m^2 of grass field, 35 of another grass field, 18 of an arable field (barley), 21 of arable (wheat), 9 of arable (oats), 11 of woodland, 1 of rough ground, 4 of hedge and 1 of field margins. Thus, proportionately more effort went into sampling larger habitats, as a large area of a low diversity landscape element may contribute more species than a small area of a high diversity landscape element. The smallest transect was 1 m in length and the longest 50 m in length.

Transect location within the farm was determined by randomly choosing a starting point for each visit then selecting the landscape elements, starting with the grass field, as close as possible to this point. This was done for the practical reason that it reduced the time spent walking between the different sampling sites. The location of the starting point varied between each visit ensuring coverage of the entire farm. Hedge transect location was selected independently by randomly choosing a field number and picking a length of hedge within this field. Sampling the same area or field twice was avoided. In reality, some landscape elements (game cover plots, mixed vegetable plots, and rough ground) made up a very small proportion of area on a farm and did not have multiple patches within a farm. In these situations the same patch was sampled more than once, but within the patch the transect location was moved so the same area was not sampled twice. In grass and arable fields transects began a minimum of 10 m into the centre of the field in order to avoid edge effects. For all other landscape elements transects began as close to the centre of the plot as possible. Within each transect all plants present were identified to species and given an abundance measure of 1–4. Category 1 plants were rare, only present once to a few times in the whole transect (0–1 plants m^{-2}). Category 2 plants were present in high enough numbers to be seen easily but occupied < 10% of the transect area (2–5 plants m^{-2}). Category 3 plants could be seen throughout the whole transect but occupied < 50% of the transect area (6–20 plants m^{-2}). Category 4 plants were the most abundant occupying > 50% of the transect area (> 20 plants m^{-2}). Plant abundance per transect was calculated by summing the abundance measure of each plant species.

STATISTICAL ANALYSIS

The majority of the data were analysed in SPSS using a paired multivariate analysis of variance (MANOVA). This is more commonly known as a repeated measures MANOVA, but we are using the term ‘paired’ for clarity. The organic farm was selected first and then paired with a suitable conventional farm in the area so they cannot be considered independent for statistical purposes. We had multiple dependent variables that we wished to analyse, and if we had used multiple one-way ANOVAS to try to do this, we would have raised the probability of a Type I error. MANOVA controls the experiment-wide error rate. Multiple dependent variables that were related (e.g. total farm area and field size, etc.) were analysed in one test, with the farming system (organic or conventional) being treated as the two levels of the treatment factor. Five groups of related dependent variables were analysed.

Comparison of farm size and structure

The calculations on farm size and structure (e.g. total farm area, arable field size, etc.) were grouped together and analysed using a paired MANOVA.

Proportion of each landscape element across a farm

The proportion of each landscape element per farm was calculated from the GIS data collected during winter. All proportional data were arc sine transformed prior to analysis. For this analysis all non-crop landscape elements were combined (as well as being analysed separately). This included woodland, hedgerows, field margins and rough ground and represented the total natural and semi-natural area of vegetation on a farm. The landscape elements were grouped together and analysed in SPSS using a paired MANOVA. The hedgerow cross-sectional area, measured during summer, was analysed separately using a paired *t*-test. Hedgerow shape, size and the accuracy of measurement changes dramatically from well-trimmed defoliated winter shrubs (when the GIS data was taken) to bushy summer shrubs (when the hedge height and width data were taken) and so these two data sets could not be combined and analysed together.

Woodland analysis

The abundance and spatial distribution of woodland patches on each farm was analysed further using ArcView GIS 3·2™ and the Patch Analyst 3·1 extension (Rempel & Carr 2003). The following metrics were calculated for all woodland patches on each farm: total patch area, number of patches, mean patch size, patch size standard deviation, edge density and mean patch edge. Edge density is the amount of edge relative to the total patch area, and mean patch edge is the amount of edge per patch averaged across all patches on the farm. Two measures of patch shape complexity were calculated: area weighted mean shape index (AW mean shape index), is the sum of each patch perimeter divided by the square root of patch area for all patches and adjusted by the number of patches. AW mean shape index = 1 when all patches are circular and is weighted for the area of each patch. Area weighted mean patch fractal dimension (AWM patch fractal dimension) approaches 1 for patches with simple perimeters and approaches 2 when patches are more complex. Individual patch area weighting is applied to each patch because larger patches tend to be more complex than smaller patches; this has the effect of determining patch complexity independent of size. These matrices were grouped together and analysed in SPSS using a paired MANOVA.

Whole-farm landscape element diversity

The diversity of landscape elements on each farm was analysed using BioDiversity Professional™ version 7·0 software. Three diversity indices (Shannon J, Simpson D, and Berger-Parker dominance) were calculated for each farm using the area occupied by each landscape element. All diversity indices were arc sine transformed prior to analysis. A paired MANOVA was then used to determine if there was a difference between farming

Table 1. Proportion of different landscape elements on organic and conventional farms. The mean percentage area indicates the proportion of the entire farm occupied by this landscape element. All proportions were arc sine transformed for analysis, but the mean percentage area and the standard error were calculated from un-transformed raw data

Landscape element	Farm type	Mean percentage area	SE	$F_{1,9}$	P
All non-crop elements†	Organic	13·62	1·292	12·924	0·007*
	Conventional	7·80	1·350		
Woodland	Organic	8·90	1·421	12·191	0·007*
	Conventional	3·68	0·846		
Hedgerows	Organic	2·46	0·363	0·575	0·468
	Conventional	2·23	0·330		
Rough ground	Organic	0·74	0·173	0·083	0·780
	Conventional	0·88	0·427		
Field margins	Organic	1·52	0·456	N/A	
	Conventional	1·01	0·697		
Arable fields	Organic	22·84	2·756	11·785	0·007*
	Conventional	41·05	5·659		
Grass fields	Organic	57·87	3·570	5·62	0·042*
	Conventional	44·23	5·775		
Game cover	Organic	0·22	0·141	N/A	
	Conventional	0·11	0·084		

N/A = not assessed statistically due to zeros in data set.
*$P < 0·05$.
†All non-crop elements incorporate woodland, hedges, margins and rough ground.

systems for each diversity index, the number of landscape elements per farm and number of crop types per farm.

Plant species richness, abundance and diversity

The plant community composition was analysed at the whole-farm scale. All plant species collected within a landscape element were totalled across all sampling occasions. The total transect length sampled in each landscape element across the whole season was used to calculate number of species per metre. Plant diversity for each landscape element was analysed using the Bio-Diversity Professional™ program at the whole-farm scale. Shannon J, Simpson D, and Berger-Parker dominance diversity indices were calculated for each farm using total plant abundance in each landscape element. A paired MANOVA was used to determine if a difference existed between farming systems with respect to each plant diversity index (all arc sine transformed for analysis), or plant richness (Log_{10} transformed) at the whole-farm scale.

Results

COMPARISON OF FARM SIZE AND STRUCTURE

Conventional farms chosen for this study ranged in size from 55 to 830 ha (mean 216·2 ha) and organic farms ranged from 80 to 598 ha (mean 226·8 ha). There was no significant difference between the size of organic and conventional farms using the original farm sizes ($F_{1,9} = 0·055$, $P = 0·819$). Following adjustment, conventional farms ranged in size from 63 to 234 ha (mean 138·8 ha) and organic farms ranged from 55 to 252 ha (mean 141·1 ha). There was still no significant difference in farm size ($F_{1,9} = 0·706$, $P = 0·422$) indicating that our method of adjustment was not biased towards a particular farming system. There was also no difference between organic and conventional farms in number of fields per farm (26 on organic and 25 on conventional, $F_{1,9} = 0·221$, $P = 0·649$), or average field size (4·44 ha on organic and 4·97 ha on conventional, $F_{1,9} = 0·902$, $P = 0·367$).

PROPORTION OF EACH LANDSCAPE ELEMENT ACROSS A FARM

There was a clearly significant difference in the proportions of different landscape elements on organic and conventional farms (Table 1). Organic farms had significantly larger areas of their combined non-crop elements, and also had greater total area of the grass field and woodland landscape elements. In contrast, they were found to have a significantly smaller area of arable fields (Table 1). There was no difference in the amount of rough ground or the area of hedges on each farm type. However, when hedge height was taken into consideration there was a significantly greater cross-sectional volume of hedges on organic farms during the summer (Organic: mean = 7·07 m^2, SE 0·874. Conventional: mean = 2·50 m^2, SE 0·452, $T = 2·675$, $P = 0·025$, d.f. = 9). The proportion of some landscape elements could not be statistically analysed due to their absence on four or more farms. Field margins were present on six of the conventional farms, in comparison to all 10 organic farms, and on average there was greater margin area on organic farms. Game cover plots were planted on five organic farms and two conventional farms, and on average took up twice as much area on organic farms. Orchards were present on two conventional farms and

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Table 2. Comparison of woodland patches on organic and conventional farms. See Materials and methods for full description of spatial measures calculated. Total woodland area and mean patch size are shown in metres squared. Data were analysed using a paired MANOVA

Woodland measure	Farm type	Mean	SE	$F_{1,9}$	P
Total woodland area	Organic	122971·68	22945·597	11·786	0·007*
	Conventional	46186·05	9089·773		
Number of woodland patches	Organic	38·40	9·713	0·016	0·901
	Conventional	37·20	6·248		
Mean patch size	Organic	4334·05	1483·539	3·292	0·103
	Conventional	1405·56	311·781		
Edge density	Organic	0·11	0·015	11·793	0·007*
	Conventional	0·21	0·030		
Mean patch edge	Organic	389·73	91·196	2·256	0·167
	Conventional	230·09	31·498		
AW mean shape index	Organic	2·56	0·230	0·037	0·853
	Conventional	2·51	0·127		
AWM patch fractal dimension	Organic	1·45	0·019	13·991	0·005*
	Conventional	1·54	0·023		

AW = area weighted; AWM = area weighted mean.
*$P < 0·05$.

Table 3. Comparison of landscape element diversity on organic and conventional farms. Data were analysed using a paired MANOVA. All diversity indices were arc sine transformed for analysis, but the mean and standard error were calculated from the un-transformed raw data. The number of arable crops includes only those sown between April and September 2005

Farm feature	Farm type	Mean	SE	$F_{1,9}$	P
Number of landscape elements	Organic	9·70	0·597	0·016	0·901
	Conventional	9·80	0·646		
Number of arable crops	Organic	3·10	0·567	0·444	0·522
	Conventional	3·50	0·373		
Shannon J	Organic	0·59	0·031	3·178	0·108
	Conventional	0·68	0·035		
Simpson D	Organic	0·42	0·037	2·807	0·128
	Conventional	0·33	0·040		
Berger–Parker dominance	Organic	0·60	0·035	4·061	0·075
	Conventional	0·48	0·055		

three organic farms, and mixed vegetables grown on one conventional farm and two organic farms. Set-aside was found only on five conventional farms and so was not included in the analysis although it was left in the diversity calculations.

WOODLAND ANALYSIS

Landscape element analysis showed that there was significantly greater area of woodland on organic farms; consequently, a series of spatial indices were calculated to further characterize the woodland patches. There was no difference in the number of woodland patches found on the two farm types (an average of 38·40 patches on organic and 37·20 patches on conventional, Table 2). The high number of patches per farm reflects our broad definition of woodland, including even small patches of remnant vegetation with three or more trees with continuous canopies. The mean size of woodland patches was greater on organic farms (0·43 ha) than conventional farms (0·14 ha); however, this was highly variable between the pairs and not significantly different (Table 2). Edge density and AWM patch fractal dimension were both significantly lower on organic farms than conventional farms ($P = 0·007$ and $P = 0·005$, respectively) indicating that woodland patches on organic farms had simpler perimeters and consequently less edge than similarly sized patches on conventional farms. The other measure of shape complexity, AW mean shape index, showed no difference between farm types.

WHOLE-FARM LANDSCAPE ELEMENT DIVERSITY

There were no major differences between landscape element diversity on organic and conventional farms (Table 3). Both farming systems had similar numbers of landscape elements and planted the same diversity of arable crops. Of the four diversity indices tested, only the Berger–Parker dominance index showed any suggestion of a difference between the farming systems, probably due to the greater area taken up by grass fields on organic farms.

PLANT SPECIES RICHNESS, ABUNDANCE AND DIVERSITY

In total, 325 plant species were identified across all 20 farms. Most plants recorded were common on agricultural land in the area; however, one rare plant subject to a Biodiversity Action Plan, *Scandix pecten-veneris* (Shepherd's needle), was recorded in an arable field on a conventional farm. At the whole farm scale, organic farms had significantly higher plant species richness than conventional farms (means of 107·90 and 93·40 plant species, respectively, Fig. 2a and Table 4). One of the three diversity indices (Shannon J) showed a significant treatment effect. Organic grass fields contained significantly greater numbers of species (Fig. 2c) and greater plant abundance. However, this trend was not carried over in the numbers of plant species per metre (Table 4), nor any of the diversity indices. This indicates that the greater number of species is probably a result of the greater area of grass fields on organic farms and was not due to a true increase in plant diversity within this landscape element. Organic arable fields on average contained significantly greater numbers of plant species than their conventional counterparts and higher plant abundance (Fig. 2b). This translates into a greater number of species per metre in organic arable fields despite the lower proportion of arable land on organic farms (Table 4). Furthermore, all three diversity indices showed a response to the increase in plant diversity on organic farms (Table 4).

There were no significant differences in plant species richness between organic and conventional farms for any of the semi-natural habitats analysed. The number of species found in woodlands on organic farms was slightly, but not significantly higher, than on conventional farms (Fig. 2d, Table 4). However, when area of woodland sampled is included, conventional farms actually have significantly greater plant richness per metre than organic farms (mean of 0·53 species per metre on organic, 1·24 species per metre on conventional, Table 4). Hedgerows on average showed slightly greater plant species richness on organic farms (Fig. 2e) but these differences were not significant (Table 4). Plant species richness on rough ground did not differ between organic or conventional farms (Fig. 2f, Table 4). Field margins on conventional and organic farms showed similar levels of plant richness and diversity.

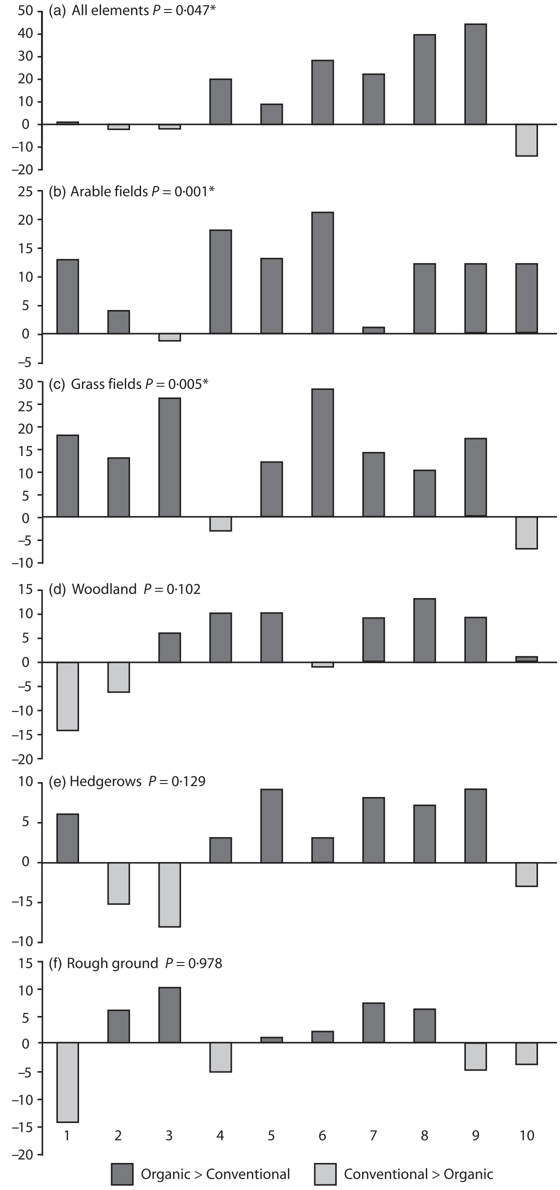

Fig. 2. Whole-farm plant richness on organic and conventional farms for each landscape element. Each bar represents the difference in the total number of plant species collected on each pair of farms (1–10). Positive values show a greater number of species on the organic farm and negative values show a greater number on the conventional farm. Data were analysed using a paired MANOVA.

Discussion

The organic farms in this region do have significantly larger areas of semi-natural vegetation than their conventional counterparts, as well as differences in the proportions of grass fields and arable fields (Table 1). However, our study revealed no difference in farm size and structure (in terms of field sizes) or any aspect of landscape element diversity between organic and conventional farms in the south-west of England. Organic farms supported higher levels of plant abundance, species richness and diversity in arable fields but not in semi-natural areas of vegetation where there were no differences between organic and conventional farms.

Organic farms had significantly greater total area of semi-natural (woodlands) and boundary vegetation (field margins and hedges) and this may have an impact on biodiversity at higher trophic levels. There was no difference in hedgerow ground area between organic and conventional farms but analysis of summer measurements of hedge cross-sectional area showed a significant difference when height was taken into account. Hedgerows on organic farms were higher (also found by Fuller *et al.* 2005) suggesting they are trimmed less often, or that hedgerows on conventional farms are cut to shorter

Table 4. Comparison of whole-farm plant richness and diversity for each landscape element. The total number of species was calculated by summing the plant abundance for all transects across the entire sampling season. Data were analysed using a paired MANOVA. All diversity indices were arc sine transformed and number of species was $\log_{10}$ transformed

Landscape element	Measure	$F_{1,9}$	*P*
All elements	Total number of species	5·267	0·047*
	Shannon J	9·525	0·013*
	Simpson D	0·032	0·861
	Berger–Parker dominance	0·245	0·632
Grass fields	Total number of species	14·114	0·005*
	Number of species per metre	0·429	0·529
	Shannon J	4·823	0·056
	Simpson D	2·779	0·130
	Berger–Parker dominance	2·307	0·163
Arable fields	Total number of species	20·515	0·001*
	Number of species per metre	31·566	0·000*
	Shannon J	6·213	0·034*
	Simpson D	7·899	0·020*
	Berger–Parker dominance	7·313	0·024*
Woodland	Total number of species	3·310	0·102
	Number of species per metre	15·818	0·003*
	Shannon J	0·035	0·855
	Simpson D	1·989	0·192
	Berger–Parker dominance	0·079	0·785
Hedgerows	Total number of species	2·788	0·129
	Number of species per metre	0·000	0·987
	Shannon J	0·003	0·961
	Simpson D	4·301	0·068
	Berger–Parker dominance	2·205	0·172
Rough ground	Total number of species	0·001	0·978
	Number of species per metre	0·055	0·820
	Shannon J	0·032	0·862
	Simpson D	0·075	0·790
	Berger–Parker dominance	0·778	0·401

$^*P < 0·05$.

heights than those on organic farms. Higher hedgerows, with larger surface area, have been correlated with increased bat foraging activity (Wickramasinghe *et al.* 2003) and higher butterfly diversity (Ouin & Burel 2002). Bird species richness has been found to increase with the amount of hedgerow on farms, but only up to a certain landscape density, beyond which greater amounts do not result in greater species richness (Fuller *et al.* 2001).

Our results show that organic farmers leave a greater area of non-cropped margin around the edges of fields. However, none of these margins contained high plant species richness or diversity or were sown with any speciality wildlife-friendly plant mix. They were mostly remnant grass strips and may be of little use for biodiversity conservation at higher trophic levels (e.g. butterflies and bumble bees) compared to other margin management options (Meek *et al.* 2002). However, uncommon arable weeds do appear in naturally regenerated margin plots and Meek *et al.* (2002) noted that this might provide an important conservation opportunity.

The increase in woodland area on our organic farms can be explained by the higher occurrence of tree-planting efforts on organic farms (and not by chance occurrence of larger woodlands on these farms). Spatial analysis of woodland patches indicated that organic farms generally had patches with simpler perimeters (AWM patch fractal dimension closer to one) and consequently less edge than similarly sized patches on conventional farms. The organic farms had more continuous blocks of woodland whereas the woodland on conventional farms often consisted of more linear remnant patches, and this may have implications for biodiversity conservation (Kunin 1997). Usher & Keiller (1998) found that small woods on farms did not support characteristic woodland moth communities. Species richness of the moth family Geometridae was positively related to woodland area, as well as woodland shape, with compact shapes better then elongated shapes. The proportion of woodland habitat on or near farms has been related to the pollination services provided by native bees (Kremen *et al.* 2002; Kremen *et al.* 2004) and increases in bird richness (Fuller *et al.* 2001).

Organic farms supported higher levels of plant abundance, species richness and diversity in arable fields but not in semi-natural areas of vegetation. The differences found in the arable fields were significant despite all of our study farms being embedded in a complex landscape, which might be expected to counteract any effects of farming system on biodiversity

(Weibull *et al*. 2003; Bengtsson *et al*. 2005; Tscharntke *et al*. 2005). Furthermore, organic farms contained on average 10 more plant species in arable fields at the whole-farm scale despite having proportionally less area of arable fields. This result is unexpected given that, according to species-area relationships, we would expect fewer plant species in arable fields on organic farms. Clearly, arable field management (both past and present) on organic farms is more important for increasing plant richness. There also appeared to be greater plant abundance and species richness in grass fields on organic farms. However, this is likely to be a product of greater areas of grass fields on organic farms and not necessarily a true increase in plant diversity (Table 4). This suggests that if conventional farmers were to increase their area of grass fields to match those on organic farms they may see a similar increase in plant richness.

We would expect organic farming to have beneficial effects on plant diversity in semi-natural areas due to the absence of herbicide drift and artificial fertilisers, especially in landscape elements directly adjacent to arable fields (field margins and hedgerows). This has been shown for hedgerow bottom vegetation in Denmark (Aude *et al*. 2004) but was not the case in our study (despite the relatively larger areas of these landscape elements on organic farms). Woodlands on conventional farms contained a greater number of plant species per metre than their organic counterparts (Table 4), despite woodlands occupying a greater proportion of land on organic farms. The increased area is largely due to tree planting efforts and in these areas plant species richness is low, at least initially. The majority of other studies comparing these two farming systems have limited themselves to biodiversity assessments in arable fields, where management effects are most evident, and indeed, this is where differences in plant species richness, diversity and abundance were found in our study. Similarly, Roschewitz *et al*. (2005) found that weed species diversity in the vegetation, seed rain and seed bank of arable wheat fields was higher on organic farms; however, this was influenced by landscape complexity. Fuller *et al*. (2005) found greater plant diversity and abundance in arable fields, field boundaries (hedgerows) and field margins on organic farms but, unlike our study, they did not assess other areas of semi-natural vegetation on farms such as grass fields, woodland and rough ground. These habitats can constitute a large proportion of farm area and their biodiversity value needs to be considered in order to gain an accurate comparison of the differences between these two farming systems. The lumping of many habitat types into single landscape elements (e.g. established woodlands and new plantations) may have reduced our ability to clearly identify the reasons for differences within landscape elements between the farming systems. However, this study does suggest the landscape elements that require further research to determine which organic management practices affect plant diversity and abundance.

Implications for the future study of agricultural systems

The farms used in our study were carefully paired so that we could directly compare mixed organic farms with mixed conventional farms, with a range of sizes among pairs, within a complex agricultural matrix. Under these circumstances you would expect differences between the two farm types to be minimal, and indeed we found no difference in landscape heterogeneity (i.e. diversity of landscape elements across farms, Table 3), however, we did find a significant difference in the proportions of some landscape elements between the two systems. It could be argued that the conventional farms chosen for this study were not as intensively managed as some other crop-based conventional farms within England. However, these farms are typical for the region, and more importantly, in view of regional figures, are probably the type of conventional farm most likely to consider converting to organic. We suggest that the effects of differences in the areas of landscape elements, and non-crop elements in particular, should therefore be considered alongside the well-known differences in management practices, such as exclusion of synthetic pesticides, when interpreting results of similar studies.

From our results we can predict that if a conventional farmer in this region were to convert to organic production the proportion of semi-natural habitat on their farm would be likely to increase through the planting of new woodland areas, less frequent or more sympathetic hedgerow cutting resulting in greater hedge volume, and larger areas of margins left uncultivated around field edges. These are all farm management decisions that could potentially be replicated on conventional farms without conversion. However these management practices were not widely implemented on conventional farms when we sampled in 2005. This suggests that there is a benefit in organic conversion for biodiversity conservation that goes beyond the immediate effects of reduction in the use of synthetic pesticides (Hole *et al*. 2005).

We have demonstrated that differences do exist between organic and conventional farms, even within a complex agricultural landscape. However, despite their greater area, on semi-natural habitats, organic farms do not appear to be of a better quality than their conventional counterparts in terms of plant abundance and diversity. Burel and colleagues (cited in Ouin & Burel 2002) stated that the quantity of each landscape element on a farm depends on the farming system, and that the quality of each element is determined by management techniques. Their views are well supported by this study. For semi-natural vegetation on organic farms we would add that time (since conversion) may play a role in determining quality as measured by plant species richness and diversity. Furthermore, 'quality', as measured by species abundance or diversity within a habitat, may overlook the effect of different spatial arrangements of patches on important processes such as dispersal (e.g. Aviron *et al*. 2005; Burel & Baudry 2005). Furthermore, some animal taxa may only require an increase in area of their preferred habitat, not necessarily a dramatic increase in quality.

The newly introduced environmental stewardship schemes provide financial incentives for conventional farmers to increase margin width and reduce the frequency of hedge cutting (Birch 2005; Radley *et al*. 2005). It will be interesting to see how many farmers adopt these management options and if adoption results in changes to plant diversity (Whittingham 2007). The only landscape element that clearly showed a significant increase in quality on organic farms was arable fields and this is most probably a consequence of the exclusion of synthetic herbicides. Other management techniques common on organic arable fields, such as reduced soil tillage, under-sowing forage crops, crop rotations and organic fertilizer use, may also contribute to the increase in plant diversity. Given that many of the rare plant species in the UK are arable weeds (Rich & Woodruff 1996), discouraging conventional farmers from using large amounts of synthetic herbicides on their crops is one obvious tactic for encouraging the conservation of rare plants. This could be achieved by compensating farmers for production loss due to weed competition and could be easily implemented through the new environmental stewardship schemes. Some authors have suggested that environmental stewardship schemes, which represent ecological engineering on a grand scale, will result in a dramatic change to the UK countryside within a few years (Birch 2005). However, our results suggest that organic farms that have been converted for an average of 7·3 years in the South-west of England, and so are already carrying out some of these management options, have not yet seen a dramatic increase in the quality of their semi-natural habitats.

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