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Effects of Agricultural Intensity and Landscape Complexity on Plant Species Richness

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Abstract

During the last decades, raised inputs, changed cultivation measures and changes in the farm layout have been implemented in order to raise crop yields. The result has been an intensification of farming with negative consequences for farmland biodiversity. In this study, the impact of different levels of agricultural intensity on plant species richness in winter wheat (*Triticum aestivum* L.) production has been examined.

The presence of vascular plant species in 160 fields was examined at 32 farms in Uppsala County in the plain districts of south central Sweden. The sampling was performed between the 19th of June and the 13th of July 2007, during the flowering period of the winter wheat.

The relationship between species richness and eight different variables measuring aspects of intensity was examined: yield, crop cover, nitrogen application, herbicide use, soil cultivation, proportion arable land, field size and perimeter-area ratio. Crop management intensity was quantified using farmers' questionnaires. Landscape data was collected by using the block database from Uppsala County Administrative Board and analysed with GIS. Further, the variation in species richness within the farms and between the farms was examined using additive partitioning.

Increased proportion crop cover decreased species richness of plants in arable fields significantly. This was found on both organic and conventional farming systems. Crop cover reflects intensive agricultural practices with high levels of inputs in combination with the appropriate timing of the cultivation measures, which results in a dense and competitive crop stand. Species richness was generally higher on organic than conventional farms. Variables measuring landscape structure seemed to be of minor importance for weed species diversity in arable fields.

Approximately 70 % of the total diversity within the region could be attributed to differences between farms. Local field diversity, between field diversity and between farm diversity all decreased with crop cover. Hence, agricultural intensification influenced the biodiversity negatively both at the local scale and on the between farms scale in the region.

Keywords: Additive partitioning, agricultural intensity, arable landscape, plant diversity, weeds

Sammanfattning

Jordbrukets intensitet har under de senaste decennierna ökat genom effektiviserad teknikanvändning och ökade insatser av pesticider och växtnäring. Detta har inte bara lett till ökade skördar utan även till negativa konsekvenser för den biologiska mångfalden i jordbrukslandskapet.

I denna studie inventerades förekomsten av kärlväxter i 160 höstvetefält (*Triticum aestivum* L.) på 32 gårdar i Uppsala-Enköpingsregionen under sommaren år 2007. Förhållandet mellan artrikedom och åtta olika intensitetsvariabler undersöktes genom linjär regression: skörd, grödans täckningsgrad, kvävetillförsel, herbicidanvändning, jordbearbetning, andel odlad mark, fältstorlek och omkrets-area-kvot. Vidare studerades variationen av artsammansättning inom och mellan gårdarna genom beräkning av betadiversitet.

Ökad täckningsgrad hos grödan medförde signifikant lägre artrikedom bland kärlväxter i fälten, både i ekologiska och konventionella odlingssystem. Hög täckningsgrad hos grödan är ett resultat av intensiv odling med höga insatser av kväve, jordbearbetning och herbicidanvändning, i kombination med rätt tidpunkt för åtgärderna, vilket resulterar i en tät och konkurrenskraftig gröda. Artrikedomen på ekologiska gårdar var generellt högre än på konventionella. Landskapets struktur visade inga tendenser till att påverka antalet arter.

Cirka 70 % av den totala artrikedomen inom i studieområdet kunde förklaras av skillnader mellan gårdar. Artrikedomen på enskilda fält, mellan fält och mellan gårdar minskade alla med ökande täckningsgrad hos grödan. Följaktligen påverkar jordbrukets intensifiering den biologiska mångfalden av kärlväxter negativt både på den lokala skalan och mellan-gårdskalan i regionen.

Nyckelord: Betadiversitet, biologisk mångfald, jordbrukets intensifiering, jordbrukslandskapet, ogräs

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1 Introduction

The fact that the human population is growing rapidly along with raised standards of living is a known challenge for the world's food and energy producers. Simultaneously, a large number of species that have adapted to agricultural ecosystems are threatened (Krebs *et al.* 1999; Chapin III *et al.* 2000; Tilman *et al.* 2002; Green *et al.* 2004). Today, agricultural land including rangeland covers nearly half of the worlds' terrestrial area (Chapin III *et al.* 2000). One organism group that is affected by land-use change in agricultural landscapes is vascular plants. Weeds compete with the crop in the fields and can reduce the yields remarkably. Therefore strategies of weed control are a priority for farmers. Along with changes in crop management and the development of weed control, the flora of arable land has changed markedly (Fogelfors 1979; Mahn 1984; Andreasen *et al.* 1996; Marshall *et al.* 2001; Marshall *et al.* 2003).

Sweden is one of the 190 countries that have signed the Convention on Biological Diversity and are committed to conserve and use biodiversity in a sustainable way (UNEP web 2007). The diversity of wild vascular plants in arable land is important to maintain for a number of reasons. Apart from cultural, intellectual, aesthetic and spiritual values (Chapin III *et al.* 2000), ecological services such as nutrient cycling and pest control are functions that weeds could directly or indirectly contribute to (Altieri 1999). Another reason to preserve the diversity of wild plants in arable land is that they form an important basal resource in food webs in arable land. For example, some insect species are dependent on weeds for food supply, shelter and nesting (Marshall *et al.* 2003). These insects provide food for birds and insect predators that also could regulate insects harmful to the crop (Hendrickx *et al.* 2007).

Increased intensity in crop production has been found to decrease the diversity of herbivorous insects (Hendrickx *et al.* 2007). Also, recent studies (Wretenberg *et al.* 2006) have found that agricultural intensification is the main cause of declining bird populations. A low abundance and diversity among arable weeds, both among seed producing plants and the seed bank has been suggested to play a major role (Newton 2004).

The majority of weed species are self pollinated, but some species are both dependent on and provide food for pollinators as wild bees, flies and butterflies. Plant-pollinator interactions have been found to change with agricultural intensification and might lead to an altered community structure of plants (Kremen *et al.* 2002; Gabriel & Tscharntke 2007).

Several studies have examined how differences between cropping systems affect farmland biodiversity. Many of them have found effects of farming system on plant diversity (Bengtsson *et al.* 2005; Roschewitz *et al.* 2005a; Gabriel *et al.* 2006; Clough *et al.* 2007; Rundlöf *et al.* submitted 2007) others have not (Weibull *et al.* 2003a). Clough *et al.* (2007) concluded that the intensity of the cultivation even in organic farming systems determines the impact on biodiversity. For example, a more intense mechanical soil cultivation in order to reduce the amount of weeds could reduce the diversity of plants on an organic farm to the levels of a low intensity conventional farm. All farming systems must aim for sustainability, where conservation of biodiversity is an important component to maintain both the ability to produce crops and ecosystem functioning (Tilman *et al.* 2002). Therefore, the question of how the level of intensification affects the biodiversity is of interest (Shriar 2000; Hendrickx *et al.* 2007).

Further, it is also of interest to examine how agricultural intensification affects the diversity at different scales, not only at the field scale, but also the within and between farms. Biodiversity at a local scale is affected of both local conditions and processes at the landscape scale (Leibold *et al.* 2004). Landscape homogenisation could result in a decline in total diversity even if the diversity at the local scale is high. This could be studied by applying the additive partitioning method (Gering *et al.* 2003). A comparison of farms with different intensity of agriculture could be of importance for designing programs or policies for the conservation of agricultural biodiversity, and the partitioning suggests which scale conservation measures should be applied on (Clough *et al.* 2007).

The main objective of the present study was to quantify the effect of agricultural intensification on weed species diversity. More specifically, the aim was to answer the following questions: 1) Which aspect of agricultural intensification is the best predictor of weed species diversity, landscape structure or the cultivation measures? 2) Which are the most likely underlying processes connected to intensity that determine weed species diversity? 3) At which scale does intensification affect weed species diversity most, at the local scale or the between-farm scale?

1.1 Measures of Agricultural Intensity

The concept of agricultural intensity (AI) is often used but usually vaguely defined (Shriar 2000). Accordingly, AI has been measured in different ways. In 1965 one of the first theses about intensification, “The conditions of agricultural growth” was written by Boserup. It primarily connected agricultural intensification to labour, capital and frequency of cultivation. Since then, many attempts to quantify agricultural intensification have been made. Brookfield (1993) stated that intensity is the substitution of inputs for land in order to make crop production more concentrated. Definitions usually refer to an increase in or rationalisation of food production by increasing the input of energy, labour time, capital, technique or frequency of cultivation (Turner II *et al.* 1978).

In order to measure AI, often both the landscape structure and the crop management intensity are included. It is of importance to keep these concepts apart, since they are not always linked together (Roschewitz *et al.* 2005a; Roschewitz *et al.* 2005b; Herzog *et al.* 2006). Separation of the effects of agricultural intensification and landscape homogenisation is important both to understand the underlying processes of diversity and to create a basis for appropriate and effective guidelines and environmental schemes concerning the biodiversity of agricultural landscapes (Tscharntke *et al.* 2005; Hendrickx *et al.* 2007). For weeds, landscape structure may be important for dispersal and recolonisation of fields (Roschewitz *et al.* 2005a). Since annual field is a habitat with frequent disturbance, seed rain from field margins could be an important addition to the seed bank. The management intensity of the field affects the possibilities of weeds to colonise, survive and set seeds. In this study the intensity is divided in two parts, aspects of landscape complexity and aspects of cultivation measures.

Several studies have summarised all intensity measures in one measure (Hendrickx *et al.* 2007). However, Herzog *et al.* (2006) suggests that overall intensity indexes should not be used for analyses of relationships between intensity and biodiversity since they often tend to simplify relationships that are complex in reality. Instead, individual indicators are more accurate to base the analyses upon. The selection of intensity measures can be based upon factors that are considered to have direct effect on biodiversity (Herzog *et al.* 2006).

1.2 At a Larger Scale: the Contribution of Landscape Heterogeneity

The difference in weed species composition at different scales in the landscape affects the total diversity in the landscape. Heterogeneity between fields increases the total species diversity at a farm, and heterogeneity between farms increases the total diversity within a landscape. Diversity at different scales can be partitioned by adding the mean diversity of individual samples to the difference in diversity between the samples (Allan 1975; Lande 1996). The sum is the total diversity of the samples and the method is called additive partitioning (Crist *et al.* 2003; Gering & Crist 2003). In the present context, the point of doing this is to see how farms at different levels of intensity contribute to the total species diversity in a region.

2 Background

2.1 Measures of Landscape Structure and Heterogeneity

Changing the farm layout has been a common way of rationalising and intensifying crop production since the 1950's (Robinson & Sutherland 2002). Landscape elements interfering with management like hedgerows, ditches and stonewalls have been removed to make better way for new and larger machines. Smaller fields have been merged into bigger units. Landscape structure has changed from being highly complex with several different biotope types and patches to more simple landscapes with arable land as the major biotope. Several studies have shown that the floral diversity of agricultural fields have declined with the reduction of structural elements and landscape complexity (Weibull *et al.* 2003a; Gabriel *et al.* 2005; Roschewitz *et al.* 2005a; Baessler & Klotz 2006).

Weeds can either disperse actively through seed rain, root shooting or runners, or passively by wind, water, fauna or humans through machines and inadequately cleaned seeds (Fogelfors 1979). Many of these processes can be related to the structure of the landscape. Both permanent field edges, such as stone walls and ditches, and other habitats such as forest patches and semi-natural habitats, function as propagule sources, dispersal corridors, alternative habitats and sources for recolonisation (Roschewitz *et al.* 2005a; Roschewitz *et al.* 2005b). Therefore, more species should be found in fields with a higher proportion edge (Gabriel *et al.* 2005).

In this study, three different aspects of landscape heterogeneity were measured: proportion arable land at each point, field size and the ratio of perimeter and area (P/A-ratio).

2.1.1 Field Size

The size of the field is affecting the proportion of edge in the landscape. A large field also implies a high intensity where obstacles to cropping have been removed and small fields have been merged into larger to facilitate rational management (Hovd & Skogen 2005). Additionally, farms with larger field sizes are associated with a specialisation in annual crop production. Thus field size could be used as an indirect measure of agricultural intensity (Roschewitz *et al.* 2005b). However, Herzog *et al.* (2006) found that field size was not an appropriate overall measure of crop production intensity.

2.1.2 Proportion Arable Land

The proportion arable land may not reveal much about the composition of the landscape and which biotopes the non-arable area consists of. However, the diversity of habitats has been found to decrease with a higher proportion of arable land per farm (Roschewitz *et al.* 2005b). The proportion of arable land is also a hint of the dominance of arable land in the vicinity of the fields under study. A low proportion of arable land might indicate a small-scale field and a low intensity. However, Roschewitz *et al.* (2005b) did not find any relationship between number of weed species and proportion arable land neither on farm scale nor landscape scale.

2.1.3 Perimeter-Area Ratio

The perimeter-area ratio (P/A-ratio) is a direct measure of the proportion of edge in each field. Recent studies of the relationship between P/A-ratio and species richness have shown different results. Weibull *et al.* (2003a) found a tendency to a positive relationship between plant species richness and the P/A ratio on conventional farms. Other studies have found strong positive relationships between weed species richness and perimeter-area ratio (Gabriel *et al.* 2005). The P/A-ratio was intended to be a measure of the amount of edge in the vicinity of the sample point. Disturbed habitats like road verges and ruderal land patches have been found to be important sources for species immigration to fields. Also, field edges have been found to be managed more extensively than field centers and thereby host a higher plant species richness than the field centers (Wagner & Edwards 2001).

2.2 Measures of cultivation intensity

There are two aspects of cultivation intensity, one is the output of the cultivation as in yield or crop cover, the other one is the amount of inputs, for example the applied amount of nitrogen, pesticides, soil cultivation, area under irrigation, crop rotation and number of harvests per year (Shriar 2000).

2.2.1 Yield

Since the main reason for intensifying the inputs in crop production is to raise the output, often the yield quantity, the yield per unit of area reflects the collected inputs (Turner II *et al.* 1978). In this respect, yield could be used as a measure of intensity. It could be measured by any measure tonnage, energy or protein content etc. per unit of area and time. This production intensity measure has, however, been criticised for being a too rough measure, excluding the effects of external factors, e.g. a fertile soil and local climate (Dayal 1978). One should also bear in mind that quantitative output measures do not include yield quality (Charles *et al.* 2006). A farmer could reach a high quantity yield with low quality with smaller amounts of inputs. The opposite is also likely; a high input agriculture could result in a low quantity yield with high quality. That means that the variable yield in tonnes not always reflects a high intensity.

2.2.2 Crop cover

The crop cover of the ground might be a more appropriate indicator of intensity than the yield. Crop cover reflects the timing of the cultivation measures, the quality of the inputs and most importantly, the effect of crop competition on the weeds. Studies of weed species diversity and crop stand competition in peas have shown that both weed growth and the number of species was reduced with a denser crop stand and increased competition from the crop (Topham & Lawson 1982). However, in a study in winter wheat by Gabriel *et al.* (2005) weed species richness was not related to crop cover. Hyvönen & Salonen (2002) found only a weak negative relationship between crop stand productivity and species diversity.

2.2.3 Soil cultivation

Soil cultivation includes all disturbances on the soil with different equipment, techniques and objectives, for example weed control, seedbed preparation and sowing. There are different strategies for soil cultivation. On one hand, there is reduced tillage which includes minimised soil disturbance with sowing in the stubble without ploughing. On the other hand, there is conventional tillage which includes both ploughing and secondary tillage equipment (Chauhan *et al.* 2006). The intensity of soil cultivation could be important for the amount of weeds in the field, but how it affects their diversity is not well known (Chauhan *et al.* 2006).

The effects on the weeds, how the seeds redistribute in the soil and the roots are divided, depends on when, in what way and how often the soil is disturbed. Also, weeds react in a species specific way to soil cultivation depending on their reproductive strategy and other characteristics and many studies have found different effects on the weeds from reduced soil cultivation. Broadleaved species are more abundant in more intense tillage systems, probably because of their ability to adapt to disturbance. Windspread species, annual grasses, species with light-stimulated germination and volunteer crops have in general an advantage in reduced tillage systems due to a less extent of seed burying (Chauhan *et al.* 2006). Whether perennial species are favoured by reduced tillage or not is under debate, but they could be favored by reduced tillage due to less disturbance to their root systems.

If deep ploughing is practiced, the seeds could be transported deeper down in the profile. In some cases this could make the seedbed broader, but sometimes it puts the seeds in a depth too deep for emergence to be possible. More shallow tillage concentrates weed seeds closer to the surface (Streit *et al.* 2003).

Streit *et al.* (2003) found that the preceeding crop and the timing of herbicide application affected weed populations more than the the tillage system. Also, in many cases of reduced tillage herbicides replaces cultivation in affecting weeds.

2.2.4 Herbicide Application

Herbicide applications in cereal fields have been suggested to be an important indirect cause of farmland bird population declines since weeds host phytophagous insects which are important food items for birds (Moreby & Southway 1999).

How herbicide applications affect weed species diversity depends on which active substances the herbicides contain, which amount is applied, weather during and after the application, application technique, in which development stage the target plants are in (time of application) and frequency. Broad spectrum herbicides could reduce more than 90% of the biomass of about 30 weed species by one application with full dose (e g. Ariane S^{TM}). The use of herbicides has become more frequent, resulting in lower species richness and biomass of weeds. Additionally, the composition of weed species has changed towards fewer herbaceous species and more grass species (Fogelfors 1979). Weed species diversity decreases with high doses, broad spectrum herbicides and the area being treated (Hyvönen & Salonen 2002).

A number of different ways can be used to measure the intensity of herbicide usage. The amount of pesticides is an inappropriate measure since it does not contain any information about how many and which active substances are being used, doses and the proportion of area being treated. However, there are a number of different indices used which incorporate the different factors into one number, for example, the Standardised Treatment Index (STI). STI provides information not only about how much of the recommended dose that actually was used, but also the proportion treated area of the field and how many active substances the application contained (Roßberg *et al.* 2002). One advantage with STI is that it contains information of the farmers aim at reducing the pesticide use, both by reduced doses and smaller proportion treated area (Sattler *et al.* 2007).

2.2.5 Nitrogen application

A high supply of nitrogen has been shown to reduce the number of weed species in agricultural fields (Givnish 1994; Pyšek & Lepš 1991). Nitrogen application is essential for crop growth and crop stand cover which limits the light reaching the weeds. In contrast, Hyvönen & Salonen (2002) found weed diversity responded weakly to nitrogen fertilisation. The form of the nitrogen, organic or mineral, has been found to be of little importance for weed species richness (McCloskey 1996). Manure from grazing animals could however spread seeds from the pasture to the field.

3 Material and methods

3.1 The Study Area

I studied 32 farms with winter wheat (*Triticum aestivum* L.) production in South-Central Sweden. Ten organic and 22 conventional farms were selected based on a gradient of winter wheat yield (average over three years) and location. One of the conventional farms had one organic managed field, and one organic farm had one conventional managed field. These were classified according to the dominating management type of the farm, conventional or organic. The distribution of the farms was evenly spread over the yield gradient and in the different areas of the region to cover a wide range of both agricultural intensity and landscape structure and to avoid a correlation between AI and landscape structure (Pearson Correlation: proportion arable land vs. yield: $r=0.16$ $p>0.1$ n.s.). The selection of farms was conducted by Camilla Winqvist (personal communication) as part of the pan-European AGRIPOPES project before this study started.

The studied farms are located in the Uppsala-Enköping region, which covers an area of 1500 km^2 within the county of Uppland, figure 1. Uppland is situated on the eastern coast of Sweden just north of the capital Stockholm. The studied region is located in the flat cultivated district, principally below 35 m a.s.l., with intensive crop production (NE Web 2007).

The type of farming in the county is mainly crop production and the most cultivated crop is ley, followed by cereals. The average winter wheat yield in the county was 5400 kg/ha in 2006 (Statistics Sweden 2007).

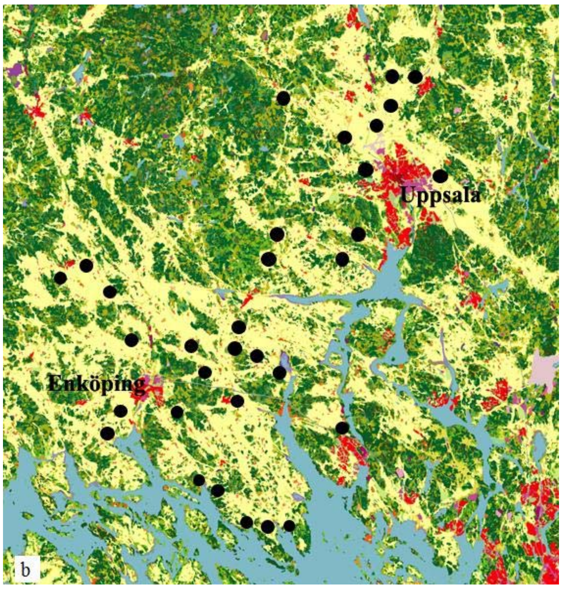

Figure 1. a) The study area (Wikipedia 2007-12-26) and b) the farms. The 32 farms are marked as dots. (Lantmäteriet 2007-09-09).

The fields studied within a farm were not further apart than 1 km. The total area of the study area on each farm always covered less than 1 km^2. All fields were at least one hectare and not irrigated. The distance between two farms was always more than 1 km to prevent strong spatial autocorrelation.

3.2 Plant Survey

The plant sampling was performed during the estimated flowering time of the wheat, growth stage 65 (Zadoks *et al.* 1974; Tottman 1987). In order to avoid systematic errors due to phenological differences, the plant sampling was evenly distributed during the area and the period. Respect was also taken to the average yield of the farm, so that farms with high yields not were examined in the beginning of the period and farms with low yields in the end of the season and vice versa.

A nested sampling design (farm, sample field, plot) was used to examine the effect of spatial scale on the weed species diversity. Five sampling points per farm were examined to obtain a representative measure of each farm's biodiversity. Depending on availability of winter wheat fields, the five sample points were placed on one to five fields. The distance between the sample points was at least 50 meters. The sample points were placed parallel to the field edge, 10 meters from the border of the field. The field edges were always perennial, dominated by grasses without shrubs or trees, and the sample points were never shadowed. Sample points were placed centred on the longest un-shaded side with grass-dominated vegetation field edge as far as possible. Although some sample points were not positioned on the longest field side because they needed to be easily available for other samplings. Though, if more than one sampling point was in the same field, the second sample point was localized on the second longest field side. If only one field with four sides was available on a farm, the fifth sampling point was located on the longest field side, at least 50 meters away from the first sampling point.

In every sample point plants were sampled in three 2 x 2 m plots with 5 m distance between plots. All plants with at least two normal leaves within the plot were determined to species. The plants were identified according to Fogelfors (1989) and nomenclature follows Flora Europaea (web 2007). Plant species richness was measured as the number of species found. Plants that could not be identified to species but were clearly different taxa were considered as a single additional species in the analysis.

3.3 Intensity Variables

In the present study, we used eight variables to quantify the intensity for each field on the measured farms. Three variables were related to the landscape: field size (ha), perimeter-to-area ratio (P/A ratio) (m ha^{-1}) and proportion arable land in the area of a circle with 500 m radius around each sample point (%). Another five variables were connected to the cultivation measures on individual fields: the use of nitrogen (kg N ha^{-1}), soil cultivations (number of cultivations per year), pesticide use (the number of applications, dose rate and the number of active substances of herbicides applied per year), crop yield (kg ha^{-1}) and percentage crop cover (%). The input and output variables relating to intensity, except for the crop cover, were recorded by farmers questionnaires about the management practices of the measured winter wheat fields during the growing seasons 2006 and 2007.

3.3.1 Field Size

The definition of an arable field could have both spatial and temporal components. Arable weed diversity depends on farming measures in the studied year, on the surrounding landscape and on limitation of weed dispersal, but also on the crop rotation at the given place and the fields size variation in time. In this study, the definition of a field is one or more parcels, measured in hectares, which were situated next to each other without a permanent edge between and were treated as a unit in the same way and at the same time. The field size data was collected from the Swedish Board of Agriculture. In this study, mean field size did not differ significantly between farming system nor did it relate to the number of fields measured on each farm (Field size: ANOVA p=0.265 n.s; no. fields, r =-0.202, n.s.).

3.3.2 Proportion of Arable Land

We calculated the proportion arable land in a circle of 500 m radius around each sample point using ArcMAP version 9.1 (ESRI 2003) and a terrain map (Lantmäteriet 2007).

3.3.3 P/A-Ratio

Agricultural regulations defines that no permanent edges are included within blocks. Fields in a block normally border to each other without permanent edges between and are therefore less appropriate to base the P/A-ratio upon. Blocks could border to a road, forest, arable land, ditches, lakes and streams. Therefore, the area in this case was based on the block size, not the field size.

The P/A-ratio was measured in units of meters per hectare using data from the Swedish Board of Agriculture. The mean P/A-ratio was calculated for each measured point at all farms in the study.

3.3.4 Yield

The yields were calculated means (kg/ha) for the winter wheat fields in which the sampling points were placed. In some cases the yield was estimated by the farmer if the exact yield was not known since the harvest was not sold at the time.

3.3.5 Crop cover

The percentage cover of the crop (%) was estimated visually in the three sample plots of every sample point and the mean crop cover per sample point was calculated.

3.3.6 Soil cultivation

In this study, the number of soil cultivations were summarised for each field. Ploughing, harrowing and sowing was considered as equal in this respect.

3.3.7 Herbicide use

Data on herbicide use with product name, doses, time of application and proportion treated area was collected. the Standard Treatment Index (STI) was calculated for each field (Roßberg *et al.* 2002):

$$STI = \Sigma\ AS\ (n) \cdot AR\ (\%) \cdot TA\ (\%)$$

where AS is the number (n) of active substances per application, AR the actual application dose in relation to the recommended one (%) and TA the treated area (%).

The herbicide applications included several different products with different active substances, which might not be comparable. However, all herbicides in this study were broad-action herbicides with at least twenty target species. On eight of the farms, herbicides against both mono- and dicotyledonous were used, nine of the farms did not use herbicides at all and the remaining fifteen farms used herbicides against dicotyledonous species only. However, in the studied fields the number of grass species found was too low to analyse.

3.3.8 Nitrogen application

The amount of nitrogen was recorded in kg total N/ha. No separation of organic or mineral nitrogen was done; hence the total nitrogen included mineral fertilisers, animal manure and green manure. The nitrogen content of the green manure depends on the community composition of the green manure ley, which in turn depends on cultivation measures and local conditions (Bischoof & Mahn 2000). The farmer estimated the nitrogen content of the animal manure and the green manure if no laboratory analysis was done.

3.4 Additive Partitioning of Weed Species Diversity

In this study, plant species richness of the whole region was partitioned in order to find out how the richness at different scales contributed to the total richness of the region. The percentage contribution of each level of diversity in relation to the gamma diversity was calculated. Additionally, how the diversity within each farm and between the fields on each farm varied with intensity was examined.

The alpha field (α_{field}) diversity is the mean number of species per field, alpha farm (α_{farm}) the mean number of species per farm and gamma (γ) diversity the total number of species found in all of the farms. The beta diversity within farms (β_{field}) is the difference between the total number of species found on a farm and the mean number of species per field. The beta diversity between farms (β_{farm}) is the difference between the gamma diversity and the mean number of species per farm. Beta diversity can be considered as a measure of the mean number of absent species per field or farm (Crist *et al.* 2003).

$$\gamma = \alpha_{\text{field}} + \beta_{\text{field}} + \beta_{\text{farm}}$$

In the beta diversity analysis, which is describing the heterogeneity of the diversity, the number of sampling points is of great importance. Hence, on farms with more than one sampling point per field, one randomly chosen point per field was analysed and the remaining points in that field excluded. Only three fields per farm were included and in the farms with more than three fields, two of them were randomly excluded. Farms with less than three winter wheat fields were excluded from the analysis. Thus, only 23 farms were analysed of which 6 were organic and 17 were conventional. On farms with fields managed with both farming systems, only fields that represented the main farming system of the farm were included in the analysis.

3.5 Statistical Analysis

The total number of weed species per sample point, per farm and on all of the farms was calculated. Also, the mean number of species per field and farm was calculated. Mean values per field and farm were calculated for each of the explanatory variables. Sample points positioned in the same field were considered dependent of each other. Hence, on farms with more sample points than one per field, the mean for each field was calculated before the mean for the whole farm was calculated.

Simple correlation analyses with Pearsons correlation coefficients (SAS proc Corr) were performed to examine correlations between all of the variables, including species diversity.

An analysis of co-variance (ANCOVA) was performed using plant species richness as the response variable, organic/conventional farming system as factor and the eight intensity measures as explanatory variables in order to examine the influence of farming systems on each variable’s effect on plant species richness. For variables without significant interactions with farming system, the variable had a similar effect on species richness in both farming systems. In such cases, differences between the farming systems were examined to see if there were significant effects of the farming system. General linear models were used to examine the relationships (SAS proc GLM).

After the ANCOVAs simple linear regressions between the independent variables and species richness were made and the two farming systems, organic and conventional, were compared (slopes and intercepts).

In the beta diversity analysis, mean values for the variables were calculated from the points included in the analysis. Pearson correlation coefficients were calculated using SAS (proc Corr) and simple regressions was made in Minitab 15.1.1.0 (Minitab Inc.).

The statistical analyses were conducted in SAS System 9.1.3 for Linux (SAS Institute Inc., Cary, NC, USA) unless otherwise is stated.

4 Results

4.1 Species Richness and Agricultural Intensity

In total, 108 plant species were found, of which 95 were dicotyledons and 13 monocotyledons. Among the grasses, *Elymus repens* (L.) Gould and *Poa annua* L. were the most frequent species, and among the herbs *Polygonum aviculare* (L.), *Stellaria media* (L.) Vill, *Galium aparine* L. and *Myosotis arvensis* (L.) Hill were the most common species.

All variables measuring inputs to and outputs from the field were significantly correlated with species richness (table 1). However, there was no correlation between species richness and any of the landscape variables.

The farm with the lowest number of species had 6.5 weed species per field, while the mean number of species among all farms was 13.2 weed species per field, and the maximum 21.2 spp (table 2). The maximal mean crop cover per field and farm was 94%, the minimum 51% and the mean crop cover among the farms was 82%.

Table 1. Correlation matrix (Pearson correlation coefficients) between all measured values of intensity and species richness. n=105. r-values > 0.195 are significant at p≤0.05. Significant values are in bold.

	Output		Landscape			Input		
	Crop cover	Yield	% arable land	P/A ratio	Field size	Soil cultivation	Herbicide use	Nitrogen application
Yield	**0,617**							
% arable land	0,072	0,163						
P/A ratio	-0,081	-0,028	**-0,334**					
Field size	-0,004	**0,196**	**0,195**	**-0,523**				
Soil cultivation	**-0,427**	**-0,477**	0,084	-0,080	-0,016			
Herbicide use	**0,481**	**0,714**	0,094	0,095	0,051	**-0,406**		
Nitrogen application	**0,608**	**0,790**	0,098	-0,011	0,189	**-0,490**	**0,729**	
# spp. per farm	**-0,569**	**-0,554**		0,087	-0,126	**0,454**	**-0,509**	**-0,630**
# spp. per block			0,087					

Table 2. Mean values, standard deviation, min- and max-values per farm (n=32) for the eight variables. All of the min- and max-values are mean values per field and farm, except from the perimeter-area ratio, which are mean values per block and farm.

Variable	Unit	Mean	SD	Min	Max
Species	#	13.2	3.9	6.5	21.2
Yield	kg/ha	5765	1397	3450	8000
Crop cover	%	82	11	51	94
Field size	ha	12.3	11.7	2.96	63.80
Proportion arable land	%	69.0	12.8	42.18	88.76
Perimeter-area ratio	m/ha	191.2	70.5	52.30	322.23
Soil cultivation	#	4.2	1.5	1.0	7.3
Herbicide application, STI		1.3	1.0	0.0	3.0
Total nitrogen application	kg N/ha	126	48	0	180

Plant species richness decreased with increasing crop cover in both farming systems (figure 2). There was no significant difference between the slopes for the two systems (ANCOVA: Species richness vs. crop cover and organic/conventional farming system: model: df=1,102, F=41.48, P<0.0001; crop cover: F=8.97, P=0.0034; farming system: F=23, P<0.0001; crop cover*farming system: F=0.05 n.s.,).

Crop cover was the only variable with significant effects within both farming systems. Other variables did not give significant effects on the plant species richness in both farming systems.

There was a negative relationship between yield and species richness (r=0.55). However, this could be explained by the fact that organic farms had both lower yields and higher richness than conventional farms (figure 3). Organically managed farms had on average six more species per field and 2500 kg/ha lower yield than conventional farms. The effect of yield on plant species richness was not significant when the farming system was taken into account (ANCOVA: Species richness vs. yield and organic/conventional farming system, model: df =1, 102, F=34.53, P<0.0001; yield: F=0.62 n.s.; farming system: F=16.55 P<0.0001; yield*farming system: F=0.34, n.s.). There was no significant effect of yield on plant species richness within each farming system (figure 3).

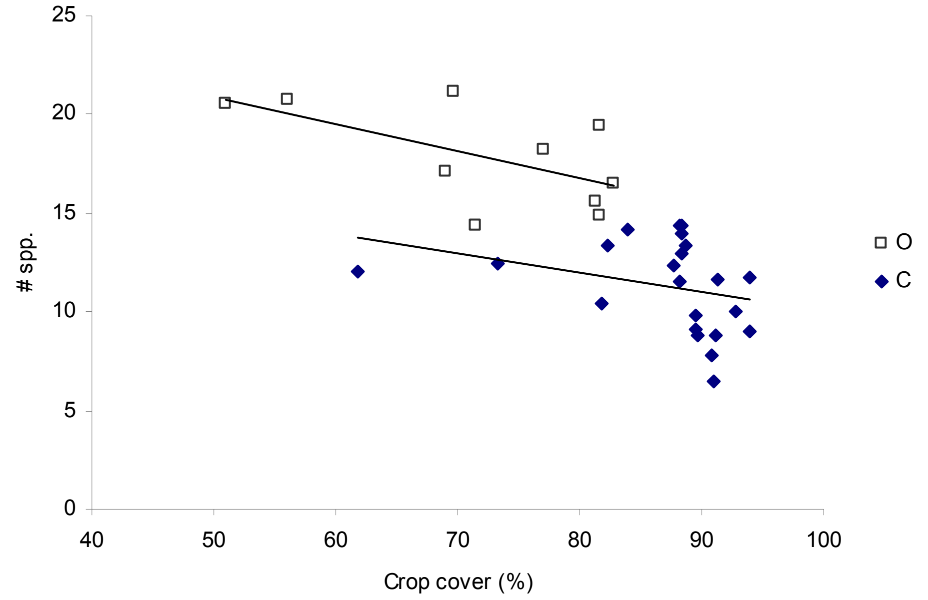

Figure 2. Relationships between mean plant species richness per field and farm and mean crop cover (%) per field and farm for organic farms (O) (slope=-0.1225) and conventional farms (C) (slope=-0.1210).

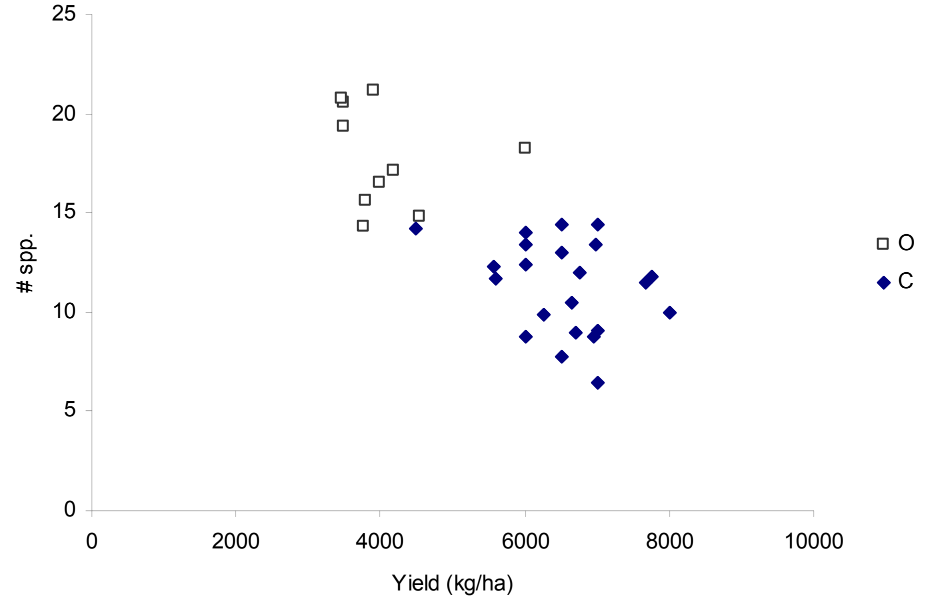

Figure 3. Relationships between mean plant species richness per field and farm and mean yield (kg/ha) per field and farm for organic farms (O) mean no. of species: 17,85, SE ± 2.56 and conventional farms (C) mean no. of species: 11.31, SE ± 2.31.

No significant relationships were found between the proportion arable land or field size and plant species richness when all farms were analysed together or when only conventional farms were included in the analysis (figure 4). However, on organic farms a higher amount of edge resulted in a small but significant increase in plant species richness (species richness vs. perimeter-area ratio: slope=0.024, r^2=0.22, P=0.0132).

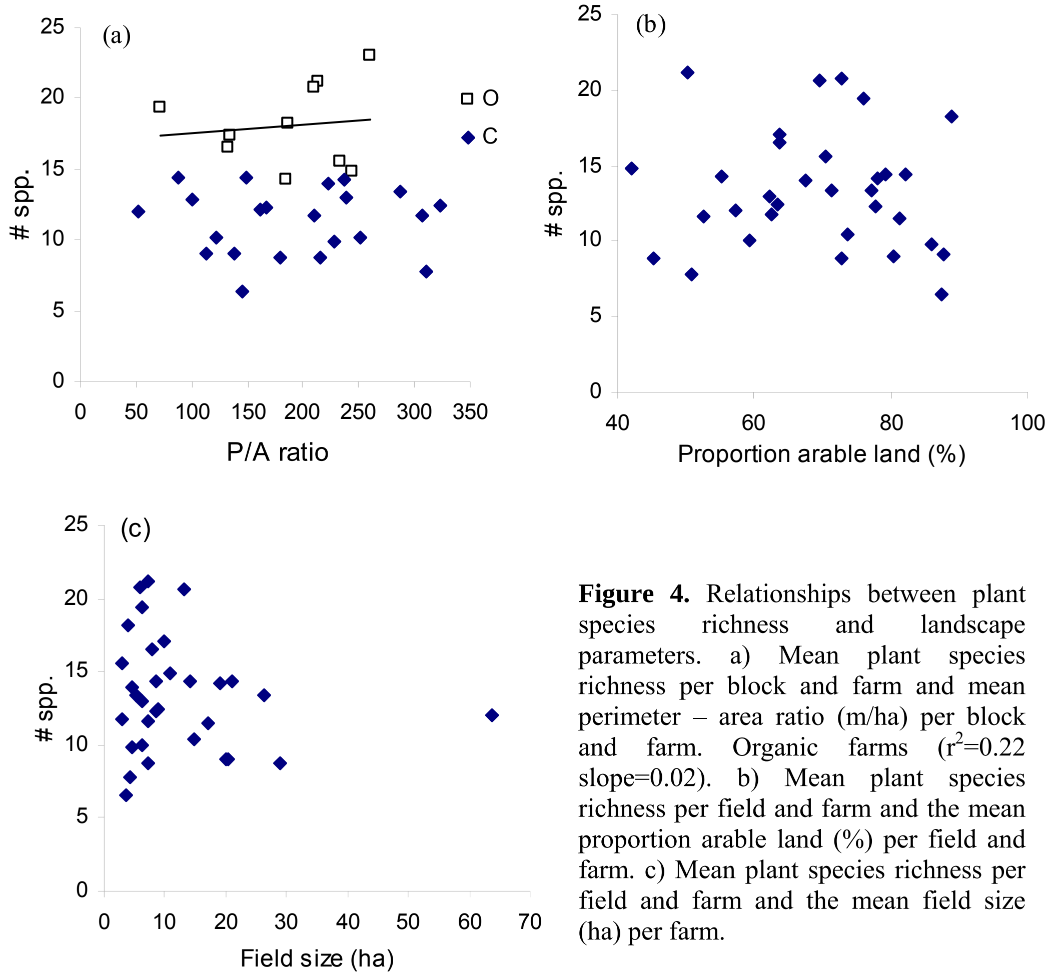

Figure 4. Relationships between plant species richness and landscape parameters. a) Mean plant species richness per block and farm and mean perimeter – area ratio (m/ha) per block and farm. Organic farms (r^2=0.22 slope=0.02). b) Mean plant species richness per field and farm and the mean proportion arable land (%) per field and farm. c) Mean plant species richness per field and farm and the mean field size (ha) per farm.

Plant species richness was not affected by the amount of herbicide use among the conventional farms (figure 5).

The effect of soil cultivations on plant species richness depended of the farming system (ANCOVA: Species richness vs. soil cultivation and organic/conventional farming system, model: df=1, 101, F=30.16, P<0.0001; soil cultivation, n.s., farming system: P<0.0001; soil cultivation*farming system: P<0.002). On organic farms, where the number of soil cultivations was higher than on conventional farms, the number of soil cultivations was not significantly related to species richness (figure 6) (Species richness vs. soil cultivation on organic farms: r^2=0.01, n.s.). In contrast, species richness on conventional farms increased significantly with more soil cultivations (r^2=0.11, P=0.0027).

There was a tendency of an effect of the total amount of applied nitrogen on plant species richness irrespective of farming system (figure 7) (ANCOVA: Species richness vs. nitrogen application and organic/conventional farming system, model: df=1,102, F=37.08, P<0.0001, nitrogen: F=3.69, P=0.0576, farming system: F=4.15, P=0.044, nitrogen*farming system, P=0.302). On conventional farms plant species richness showed a small significant decrease with increased nitrogen application (r^2=0.06, slope=-0.06, P=0.028).

Organically managed farms used less nitrogen than conventional farm, but no significant relationship between plant species richness and nitrogen application was found on these farms.

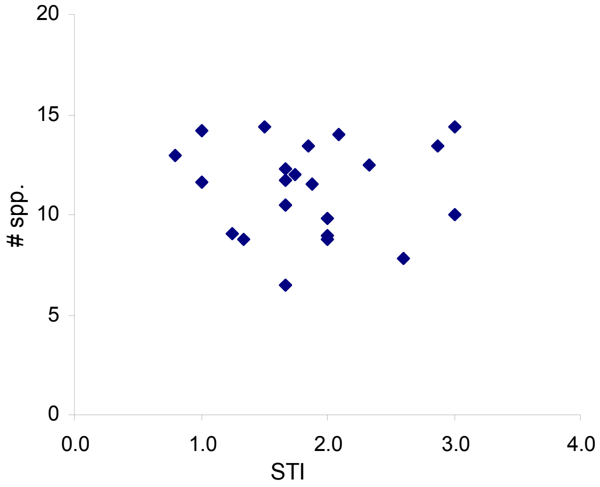

Figure 5. Relationship of herbicide application as in the mean standard treatment index (STI), and the mean species richness (# spp.) per field and farm. Only conventional farms shown.

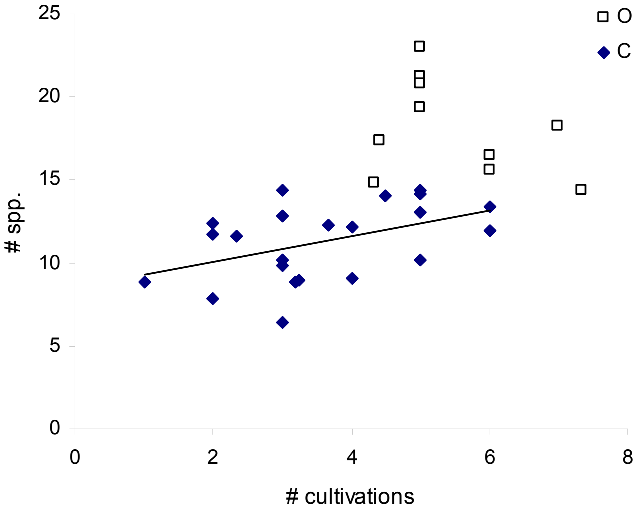

Figure 6. Relationships between the number of soil cultivations and mean number of species per field and farm for organic (O) and conventional farms (C) (r^2=0.11, slope=0.81).

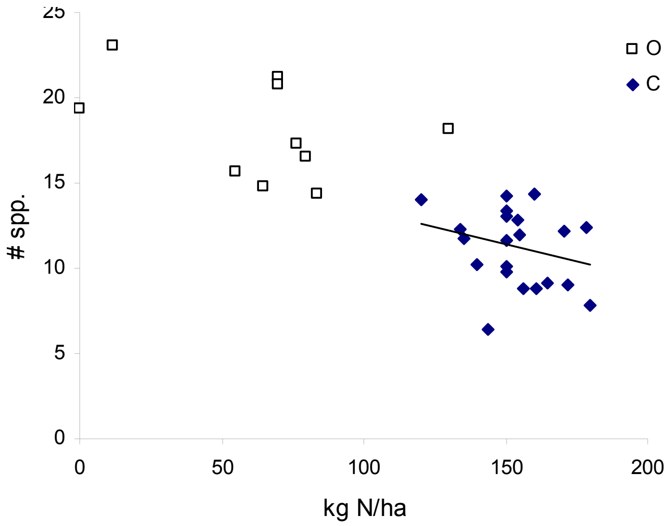

Figure 7. Relationships of mean species richness per field and farm and the mean amount of applied N (kg/ha) per field and farm for organic farms (O) and conventional farms (C) (r^2=0.06, slope=-0.06).

4.2 Beta Diversity

The diversity among farms (β_{farm}) was the greatest contributor to the total diversity with 73 % of the total diversity. The among (β_{field}) and within field (α_{field}) diversity contributed to 12 % and 15 % of the total diversity respectively (figure 8).

The within field-scale diversity (α_{field}) and the within farm-diversity (α_{farm}) were both correlated to the output and the input measures, but not with the landscape variables. The among-field within-farm diversity (β_{farm}) was only correlated to crop cover (table 3).

Species richness on the field scale (α_{field}) significantly decreased with increasing intensity (crop cover) (figure 9). The total diversity at the farm level (α_{farm}), the within field level (α_{field}) and the diversity among fields (β_{farm}) also significantly decreased with increased intensity. None of the different levels of diversity were significantly more affected by increased intensification than the others.

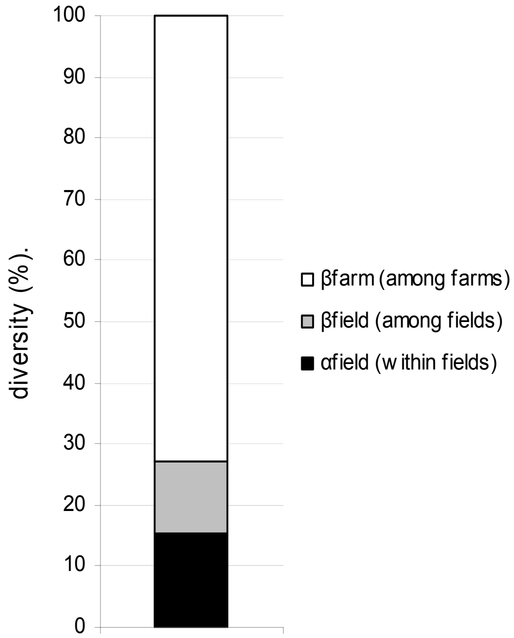

Figure 8. The percentage contributions to the total weed species diversity of field- and farm-scale diversity determined by additive partitioning. The total number in of species found was 85.

Table 3. Correlation matrix (Pearson correlation coefficients) between all measured values of intensity and alpha farm, alpha field and beta field diversity. n=85. r-values > 0.195 are significant at p≤0.05. Significant values are in bold.

		Output		Landscape			Input		
		Crop cover	Yield	% arable land	P/A ratio	Field size	Soil cultivation	Herbicide use	Nitrogen application
Output	Yield	**0.781**							
Landscape	% arable land	0.109	0.217						
	P/A ratio	0.053	0.187	**-0.504**					
	Field size	0.123	0.237	0.321	**-0.552**				
Input	Soil cultivation	**-0.517**	**-0.582**	0.125	-0.322	-0.079			
	Herbicide use	**0.599**	**0.794**	0.133	0.406	0.008	**-0.527**		
	Nitrogen application	**0.652**	**0.811**	0.194	0.161	0.250	**-0.619**	**0.808**	
Response	afarm	**-0.697**	**-0.546**	0.026	-0.141	0.009	**0.556**	**-0.454**	**-0.606**
	afield	**-0.705**	**-0.684**	-0.006	-0.223	-0.042	**0.552**	**-0.646**	**-0.760**
	bfield	**-0.440**	-0.196	0.052	0.001	0.063	0.363	-0.078	-0.218

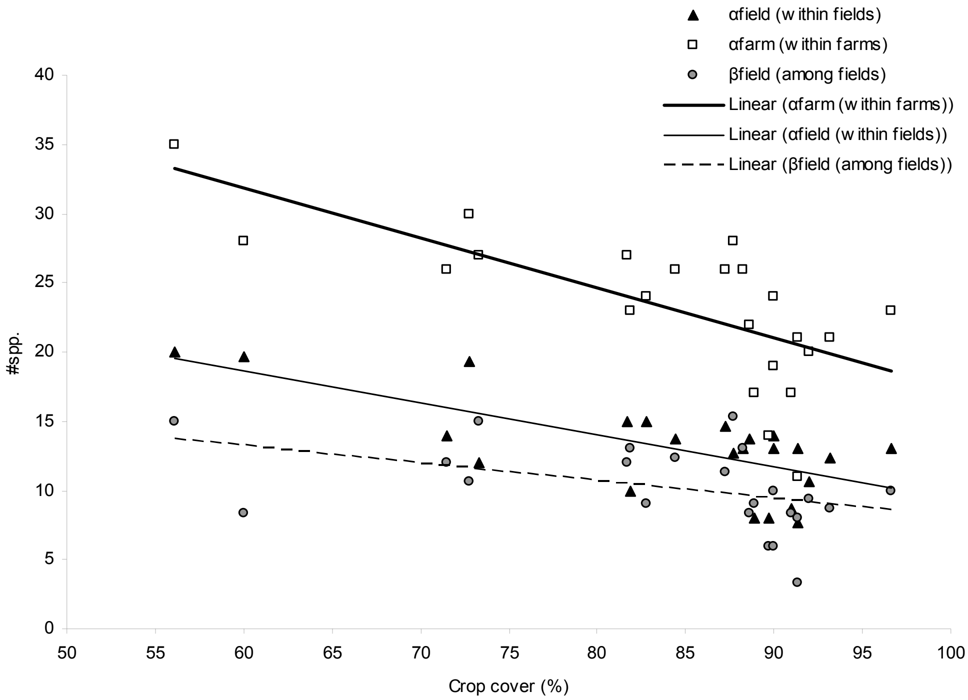

Figure 9. The relationships between α- and β-diversity and agricultural intensity as in crop cover (%). The total diversity at the farm level (α_{farm}) (r^2=0.486, slope=-0.358 ±0.080), the within field level (α_{field}) (r^2=0.497, slope=-0.230 SE ±0.050) and the diversity among fields (β_{field}) (r^2=0.194, slope=-0.127±0.057) significantly decreased with increased intensity.

5 Discussion

5.1 Increased Agricultural Intensification Decreases Weed Species Diversity

In this study, crop cover seemed to be the aspect of agricultural intensification that best predicted weed species diversity. Plant species richness significantly decreased with increased crop cover, but no clear direct effects of nitrogen application, soil cultivation or herbicide use were found when no consideration of farming system was taken in the analyses. Furthermore, no tendency for the landscape structure to influence the number of species was found. Instead, plant species richness in agricultural fields seems to be mostly affected by farm management.

In general, organically managed farms had on average six more species per field than conventional farms. Similar higher levels of species richness in organic farming have been found in several other studies (Roschewitz *et al.* 2005a, Bengtsson *et. al.* 2005, Gabriel *et al.* 2006).

Even if there is a well known positive relationship between yield and crop density (Hay and Porter 2006), the yield did not affect the plant species richness neither for all of the farms together nor within each farming system in this study. There are a couple of possible explanations for this. If any resource is limited, for exampel nutrients or water, the optimal crop stand density for a high yield is lower because fewer plants share the resource. A crop stand with a high number of plants sharing a resource at low levels, for example, water, could give a lower yield but the same crop cover as a crop stand with a low number of plants with adequate amounts of water. Still, if light is the limiting resource for the number of weed species in the field, both crop stands gives the same light conditions for the weeds even if the yields are dramatically different. That may be one reason to why the crop cover is a better predictor of plant pecies richness than the yield. Another reason is that different cultivars could yield the same but have different leaf angles and configuration and therefore different crop cover with different amounts of light reaching beneath the leaves.

The reason that none of the landscape variables significantly explained species richness could be that the landscape in the studied region is quite homogeneous, which means that the landscape gradient may not have been strong enough to have a large effect. Several other studies have found positive relationships between plant species diversity and increasing landscape complexity (Weibull *et al.* 2003a), especially on conventional farms (Roschewitz *et al.* 2005a). I found a small significant increase in plant species richness with increasing perimeter-area ratio on organic farms but no relationship on conventional farms. Gabriel *et al.* (2005) found that plant species richness in winter wheat fields increased with the density of edges (perimeter-area ratio) and decreased percentage arable land in the landscape. The contrasting results could depend on which aspects of the landscape are measured, the study design and where it is conducted. The proportion arable land among farms in this study covered a range from 42-88% (mean=69.0, SD±12.8) in landscape sectors of 1 km diameter that could be compared to 45-98% (mean=73.9, SD±16.9) in landscape sectors of 1 km diameter in the Gabriel *et al.* (2005) study. Hence, the difference of the amount of arable land around the measured fields between the studies does not seem to be crucial for the results. However, the study of Gabriel *et al.* (2005) was based on 18 fields with similar management intensity on a gradient of landscape complexity, while this study was designed to separate the effects of management intensity and landscape on 32 farms. Other studies have found that the effects of landscape complexity on plant species richness were weaker than the effects of farming system (Gabriel *et al.* 2006).

5.2 Competition, Dispersal and Weed Traits in the Crop Stand

No single input factor showed a clear relation to plant species richness. However, the combined effect of the level and timing of inputs, as measured by crop cover, seems to be important for weed species diversity. Crop cover was the variable that best explained plant species richness in this study. It was correlated to all three input measures in this study: nitrogen application, herbicide application and soil cultivation. The correlations make it hard to separate the direct and the indirect effect of the different cultivation measures on plant species richness.

Crop cover affected plant species richness in the same way on both organic and conventional farms. However, the strategies for reducing the competition from weeds and favour the crop differs beween the farming systems. Organically managed farms regulate the weed abundance with adjusted crop rotations and soil cultivations to a greater extent than conventional farms do, and organic farms do not use herbicides as conventional farms do. The strategies are however aiming at the same goal, to favour the crop over the weeds. At northern latitudes, competition of light and a usually good supply of water make high plant densities favourable. Plants on an agricultural field, both crop plants and weeds, compete for space, light, water and nutrients.

A dense crop stand with high crop cover is obtained not only by optimal amounts of inputs; it also requires that the measures to be executed at the right stage of the crops or development of the weeds. For example, a large input of nitrogen does not necessarily lead to a high plant uptake of nitrogen, and a stand that closes early, and thus able to compete with weeds at an early stage, if the ability of the crop to assimilate the nitrogen is limited at the particular development stage. The same principle is valid for several cultivation measures: time of sowing affects the crop's ability to compete with early germinating weeds, the time of soil cultivation affects the damage to the crop. The effect on the weeds from herbicide application is also closely connected to the timing of the application. Hence, crop cover reflects not only the amount of inputs, but also the time of action of the cultivation measures.

Weed abundance and species frequency was not analysed in this study, but several studies have shown that weed biomass decreases with increasing crop cover (Weiner *et al.* 2001, Håkansson 2003, p. 90; Zimdahl 2004). It would be interesting to study the data further to find out if more intensive farms contains more shade-tolerant species than low intensive farms.

More specifically, plant species richness was not related to the extent of herbicide application on conventional farms. However, the application rates were in general quite low and no farm treated the fields on more than one occasion. The herbicide use among conventional farms is most likely a part of the explanation to the difference in species richness between organic and conventional farms.

All organic farms ploughed the soil, but repeated soil cultivations did not significantly affect the number of weed species on organic farms. On conventional farms plant species richness increased with the number of soil cultivations. Conventional farms with a smaller number of soil cultivations did not use more herbicides than farms with the same farming system and a higher number of soil cultivations, which would be logical since reduced tillage system often controls weeds with herbicides (Håkansson 2003, p. 193). All conventional farms did not plough the soils, but the farms that practiced ploughing had higher number soil cultivations. Studies on tillage systems have shown contrary results, that no-tillage systems promote the highest weed diversity (Murphy *et al.* 2006), or that it does not (Légère *et al.* 2005). The dataset needs to be studied in more detail to find out the processes behind the relationship.

The amount of nitrogen applied is strongly connected to the crop cover, as mentioned above, but the effect of nitrogen could also be direct. The impact on weeds is species-specific. There was a tendency of a negative relationship between the total amounts of applied nitrogen on plant species richness irrespective of farming system. When the two farming systems were analysed separately, the effect was found to be weak on conventional farms but non-existent on organic farms. Studies have shown that the impact of nitrogen application not only depends on the amount of nitrogen, but also if it is in organic or mineral form (Pyšek & Lepš 1991).

The crop rotation and the diversity and identity of crops within the rotation have been argued to be a vital factor for the weed community (Smith & Gross 2007). Others have only found weak effects from the crop rotation (Bàrberi *et al.* 1997; Murphy *et al.* 2006). Herzog *et al.* (2006) concluded that the intensity is not necessarily affected by the number of crops in the crop rotation, but the type of crops included. Organic farms have often longer crop rotations than conventional farms, and in general a higher proportion ley in the crop rotation, for silage or green manure production. That could result in a higher heterogeneity in both time and space on organic than conventional farms, which in turn increases the probability for more species to live and reproduce. However, the crop rotations were not analysed because of wanting information from the farms in our study.

The survey included both organic farms that recently has converted to conventional practice and vice versa. On these farms, the previous farming system may have affected the farms species pool and the number of species found. The farming history is important because it affects the seed bank and the species present in borders and adjacent habitats. Organic farms have been found to have a higher species richness than conventional farms (Bengtson *et al.* 2005; Rundlöf *et al.* 2007). A conversion from organic farming practises to conventional entails the introduction of herbicides and changed crop rotations, which are highly selective measures that reduces the number of species. The weed communities on conventional farms that convert the management to organic methods have to undergo a recolonisation if they should reach the level of species richness of long term organic farms. Recently converted organic farms have probably a lower species richness than farms with organic practise since decades, which makes the distinctiveness between the farming systems less sharp. Therefore, species richness on recently converted farms to either of the farming systems depends on the former farm management and not only on the current intensity of the production.

The measured landscape variables did not relate to the number of species. A Finnish study on plant species diversity of buffer zones in agricultural fields also showed that local species richness was not related to the habitat connectivity (Ma 2006). However, they also found that habitat connectivity affected the species diversity differently in different landscapes. Local resources explained species diversity best in lowly and intermediately connected landscapes, but in highly connected landscapes the connectivity between habitats was of higher importance. Our results could be explained by a similar reasoning. The mean perimeter-area ratio of our study areas was 191 m/ha (SD ±70,5 m/ha) and is most similar to the former landscape types, if we consider the amount of edge to be an important dispersal route. Then the lack of relationships between landscape measures and species richness could be explained by that the dispersal is too low to affect species richness.

5.3 At which scale does intensification affect weed species diversity

My results clearly show that increasing intensity in crop production results in a decrease of plant species richness at both the within-field and farm scales and at the between field scale. It means that the loss of species richness does not only occur on the field scale. Intensified crop production also results in a lower species turnover between fields. The result shows that a major part of weed diversity in agricultural landscapes is found between farms managed in different ways, and not at the scale of single fields. This indicates that management of biodiversity in agricultural areas needs to be conducted at the landscape level.

In this study, we found that the diversity among farms (β_{farm}) was most important for plant richness. The difference in species composition between the farms contributed with 73 % of the total plant species richness in the study. This indicates that there are considerable differences in the species pool between the different farms. Similar results have been found in several other studies (Roschewitz *et al.* 2005a; Gabriel *et al.* 2006, Clough *et al.* 2007). The explanation could be that plants are sessile organisms and the dispersal rates between farms are limited. Plants cannot choose habitat actively as many other organisms and are dependent on immediately adjacent habitats. High dispersal could homogenise the species composition, and consequently increase local diversity but decrease species turnover between sites. Another possible explanation is that surrounding habitats that influences species richness in arable fields differs between sites and brings heterogeneity to the landscape (Gabriel *et al.* 2005).

The beta diversity at each spatial scale is the result of environmental heterogeneity in space, time, and/or resources and niche differences among species. There are apparently large differences between the fields within the farms in the study, which indicates that there are considerable differences in species pool even on different sites on the farms.

Beta diversity of plant communities may be lowered by dispersal between spatial units that acts as a homogenising force. Dispersal processes operate at different spatial scales, at the microscale by seed rain and dispersal by cultivation and at the mesoscale by machinery, animals and wind (Gabriel *et al.* 2007). However, in this study dispersal was not high enough to have a homogenising effect. Dispersal among fields may have played a minor role relative to environmental factors, as farms were widely distributed and plant communities were not spatially autocorrelated.

Not only plants are affected by increased agricultural intensity and all organism groups do not react similarly to landscape and crop management factors (Dormann *et al.* 2007). Landscape complexity has been found to be of great importance for other organisms and has been suggested to be related to the mobility of different organism groups. Landscape complexity has been found to affect variation in species composition differently for organisms with different mobility. In a Swedish study of 16 farms in east central Sweden, the proportion of the total variation in species composition of butterflies with high mobility was explained by landscape complexity to a larger extent than for carabids with lower mobility (J. Bengtsson unpublished; based on Weibull & Östman 2003b). The variation of species composition of plants, which are sessile, was not affected at all by the landscape.

6 Conclusions and final remarks

Agricultural intensification with higher amounts of inputs, in combination with the timing of the cultivation measures, resulted in decreased local species richness of plants in arable fields both in organic and conventional farming systems. Increased agricultural intensity also decreased the heterogeneity in species composition between fields on a farm. Further studies on which and how specific species are affected by intensification are needed. For example, are species with certain traits and ecological functions more affected than others? How is the relationship between weed species richness and weed abundance and biomass production related to increased agricultural intensity? These are important questions for the development of adjusted cultivation measures and conservation actions in agricultural areas.

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Appendix 1. List of species

Appendix 1. List of species found per farm, abundance in number of plots per farm. 15 plots were examined on each farm. * indicates organically managed farms.

	Farm																															
Scientific name	1	2*	3	4	5	6	7*	8	9	10	11	12*	13	14*	15	16*	17*	18	19	20	21*	22*	23	24	25	26*	27	28	29	30*	31	32
Equisetum arvense L.				6				1	3	6		3	1	1		1	3					8	4	3		3	2	1	3		1	6
Picea abies (L.) H. Karst								1										1		1									1		4	
Urtica dioica L.																										1						
Urtica urens L.															1																	
Fallopia convolvulus (L.) Á Löve	2	10	13	9	4	7	7	7	14	14	6	6	6	15	10	2	15	5	5		4	14	4	6	9	13	4			12	6	
Persicaria sp. (L.) Mill			4				2	1						4											3			1			2	
Polygonum aviculare (L.)	10	13	12	11	11	15	12	14	12	15	1	13	5	6	4	3	14	8	6	4	8	12	6	1	5	14	8	5	11	12	7	5
Rumex crispus L.						1							1									2				3					2	
Rumex longifolius DC.							2																	1		2						
Atriplex patula L.					3	6			1	8		1	1		4	3		7		9		10	1	6	4	1				1		2
Chenopodium sp. L.						7	6		1			5				3	1			1			2			7			2			
Chenopodium album L.	5	5	6		8		3	9	2		10	9	10	8			9		1		15	5	5	8	3	6		6		8	3	3
Chenopodium polyspermum L.			3																													
Chenopodium suecicum Murr				1								2																				
Arenaria serpyllifolia L.												1																				
Silene latifolia Poir.																														1		
Silene noctiflora L.																	3															
Spergula arvensis L.		1									1	4		1			1	3		2	5	6	3		2							
Stellaria graminea L.												3																				
Stellaria media (L.) Vill	6	12	1	9	1	15	14	10	12	10	3	14	15	12	14	8	15	9	8	3	7	14	12	6	14	14	15	15	14	15	15	
Consolida regalis Gray		5										1								7				2	3	2				3		
Myosurus minimus L.	1					6												1										1	12			
Ranunculus repens L.				1								3	2		1	1						2		1	1							1
Fumaria officinalis L.		1	6	6		5	6		6	2	6	8	2	4	7	6	3	4	3	8	11	8	6	5	9	2			9	12	2	2
Fumaria vaillantii Loisel.	2																							3								
Brassica rapa L.	1				2	3		1		2		1							5		7		2				10				2	
Capsella bursa-pastoris (L.) Medik.	2						2				5	11	1		2				3	7	2	4	3	1	2	1	1	6	6	9		
Erysimum cheiranthoides L.	4		3				5					1	3	3			4				1	15								1		
Sinapis arvensis L.	2	1				2	1	4		2		1			1		4			3			6	5	1	6				2		

Appendix 1. Continued

	Farm																														
Scientific name	1	2*	3	4	5	6	7*	8	9	10	11	12*	13	14*	15	16*	17*	18	19	20	21*	22*	23	24	25	26*	27	28	29	30*	31	32
Thlaspi arvense L.	1		4					5	2			10			3		1	6			1			1		3	4		3	9	1	
Lathyrus pratensis L.						2													1													
Trifolium hybridum L.				1																												
Trifolium pratense L.		3	1				15	1		2	1	9	9	15			1				15	11		1		15				11		2
Trifolium repens L.	1	3	3									1	3				2												3			
Prunus padus L.												1	1																			
Vicia sp. L.								1																					3			
Vicia hirsuta (L.) Gray		3	1	3								2	1				1					4			3					1		
Vicia cracca L.												3																				
Geranium molle L.														1																		
Geranium pusillum L.													1																			
Euphorbia helioscopia L.		3	2	5	1		6			6		1			2		6	6	1				1	3	1	4			3		1	3
Viola sp. L.									1																							
Viola arvensis Murray	13	8	9	8	5	6	5		12	10	5	5	6	9		6	11	5	4	7		14	9	8	9	2	1	8	9	6	5	2
Viola tricolor L.		1																														
Aethusa cynapium L.																								1								1
Galium sp. L.					3				9																							
Galium aparine L.	4	10	6	9	5	3	15	13	5	12	9	10	12	5	7		15	8	8	10	15	15	15	5	8	9	6	14	11	13	12	10
Galium spurium L.		3			1	9					3		2												1							
Convolvulus arvensis L.		1										3													3						3	
Anchusa arvensis (L.) M. Bieb																			3													
Buglossoides arvensis (L.) I.M. Johnst.	1	1																														
Myosotis arvensis (L.) Hill	8	9	7	7	4	14	15	6	13	8	3	15	6	6	2	1	11	8	9	5	14	8	14	4	9	6	3	5	13	7	5	
Galeopsis sp. L.	1	3	3		4	1	6	2	2	7		2	2	12	1		10	1	3			6		6		1		1	3	2	5	2
Galeopsis speciosa Mill.		4	6	3			5	1					4	7			11					9									6	
Galeopsis tetrahit L./*bifida* Boenn.				1						1				2			1					3										
Lamium sp. L.	6	2	3	1	4		8	6	13	5		3	2	7	2		7	3		11			3			8	5		7	10	6	
Lamium album L.														2																		
Lamium amplexicaule L.						12						4		1					4		12										3	

Appendix 1. Continued

	Farm																														
Scientific name	1	2*	3	4	5	6	7*	8	9	10	11	12*	13	14*	15	16*	17*	18	19	20	21*	22*	23	24	25	26*	27	28	29	30*	31	32
Lamium moluccellifolium (Fr.)	3	1							6	3	1	2						1	1	2				1	15	5	5	3	4	3		
Lamium hybridum Vill.	8				1	3		8	5	9	2	1	3	1	14				1							1		13	1			
Lamium purpureum L.	3	4	1		7	12	6	8	13		15	6	9		9	6	7	7	8	3	13	3	15	10	15	6	9	8	9	3	4	8
Glechoma hederacea L.																	1															
Solanum nigrum L.												1																				
Veronica sp.						1		2	1																							
Veronica agrestis L.	11				3				1		9							2	4	1	7				8	2		9	2	2		
Veronica arvensis L.	9	5				8	1	1	10	2	3	5			2	5	1	6		1			4			1	2		2	8	2	
Veronica hederifolia L.												2														1					1	
Veronica persica Poir.										2		3	4						1	2											6	1
Plantago major L.																					3										4	
Achillea millefolium L.																						3		2	1							1
Arctium minus Bernh.								2			1															1						
Carduus crispus L.																										2						
Centaurea cyanus L.	1	3							2													4							5			
Cirsium arvense (L.) Scop.	2	5		3		5	6	7	1	3	2	4	7	2	3	6	11	1	2		10	5	4	8	5	13	1	4	1	2	1	9
Crepis tectorum L.																													1			
Lapsana communis L.	3	12	5			1	4	4	1	3		4		3	1	1	2	5	2	1	6	11	8	6	5	3	1	8	1	3	2	3
Chamomilla suaveolens (Pursh) Rydb												1				1														1		
Chamomilla recutita (L.) Rauschert	12	10				1	15	2	11	14		10	3		2	3	3		4		9	9	14			7		9	9	12	7	
Senecio vulgaris L.		2												2			3															
Sonchus arvensis L.	1		3		2		2	2				4					6		1			1	3	5		4						
Sonchus asper (L) Hill				2				1	2	3							6					1			1	2				2		
Sonchus oleraceus L.							7					1											1									
Taraxacum sect. Ruderalia Krischner, H. Ollg. & Stepanek		9	10			3	10				6	5	5	14	1	3	15	3	5		15	7	8	7	1	4	9	3	1	4	4	1
Matricaria perforata (Merat)			9	3	3	14		8	1		5	8	5	7	1		2	5	4	5	2	3		3	3	11	9	2	2	3	5	
Tussilago farfara (L.)						1																										
Unknown herb species 1		1																														
Unknown herb species 2				3																												

Appendix 1. Continued

	Farm																														
Scientific name	1	2*	3	4	5	6	7*	8	9	10	11	12*	13	14*	15	16*	17*	18	19	20	21*	22*	23	24	25	26*	27	28	29	30*	31	32
Unknown herb species 3												1																				
Unknown herb species 4																		3														
Unknown herb species 5																						1										
Unknown herb species 6																								2								
Unknown herb species 7																								1								
Unknown herb species 8																										1						
Unknown herb species 9																																1
Unknown herb species 10																																2
Alopecurus pratensis L.					1									9								5										
Apera spica-venti (L.) P. Beauv.					2							1																				
Elymus repens (L.) Gould	1	6	3			1	6	5		1	2	3		6		7	7	2	2	10	5	1	6	12	1					5		8
Festuca rubra L.		1					4																									
Hordeum vulgare L.														1			1															
Phleum pratense L.							2							1			2	2			2	8		6								
Poa annua L.	3		1		1	6		1	2			6	1					3	1		4	3			1			3	4	7		2
Poa trivialis L.																		1														
Secale cereale L.						2															15				1	2						
Unknown grass species 1															1																	
Unknown grass species 2																			1													
Unknown grass species 3																					1											
Unknown grass species 4																															1	
Total number of species per farm	30	34	26	19	22	30	30	29	28	24	22	50	30	29	24	17	36	28	29	22	27	34	25	32	31	38	17	20	29	32	30	21