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WEED SPECIES DIVERSITY IN THE CZECH REPUBLIC UNDER DIFFERENT FARMING AND SITE CONDITIONS

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Abstract

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The aim of this study was to explore the composition of weed vegetation on arable land in selected areas of the Czech Republic and to determine the level of γ-diversity. Our survey was conducted at 27 conventional and 35 organic farms from 2006–2008. In each sampled field, one phytocoenological relevé of a standard size of 100 m^2 was recorded in the central part of the field. The species cover was estimated. The total γ-diversity was expressed as the total number of weed species recorded. γ-diversity of different farming systems, altitudes and crops was calculated. Subsequently, the species were divided on the basis of their perenniality. In total, 172 weed species were found – 123 and 162 in conventional and organic farming, respectively. The highest number of species was found in winter cereals and at medium altitudes. *Chenopodium album* was recorded as the species with the highest constancy in both types of farming. In total, 89 annuals, 17 biennials and 15 perennials were observed in conventional farming, and 109 annuals, 23 biennials, 28 perennials and 2 semiparasitic annuals were found in organic farming.

Keywords: species richness, conventional farming, organic farming, altitude, crop

INTRODUCTION

When exploring the species diversity at the community level, one possible way is to quantify how many taxa (e.g. species) are present within a certain spatial scale. The total species diversity within an ecological landscape is called the γ-diversity (Booth *et al.*, 2003; Magurran, 2004).

The crop is dominant in agrophytocoenoses, which has the main (edificatory) role in energy fluxes. The other plant species present are usually understood as undesirable (weeds) and/or beneficial plants with various ecological roles. In recent decades, much attention has been given to changes in weed vegetation because of their dynamics. Many authors have identified species impoverishment and the increasing occurrence of difficult-to-control weed species. Some weeds have become rare over the decades and are included on national "red lists" (Eggers & Zwerger, 1998; Holub & Procházka, 2000) for their need to be conserved (e.g. Hofmeister, 1992; van Elsen *et al.*, 2006).

The reasons for the changes in weed communities have been analysed in many studies across Europe (e.g. Andreasen *et al.*, 1996; Sutcliffe & Kay, 2000; Baessler & Klotz, 2006) including the Czech Republic (e.g. Kropáč, 1988; Kohout *et al.*, 2003; Lososová & Simonová, 2008). The species composition of agrophytocoenoses is influenced by natural conditions (e.g. climate and soil properties) but often more by the agricultural practices used. Weed communities have been influenced by man throughout the history of agriculture, but the greatest changes occurred during the 20th century as a consequence of intensive farming, characterised especially by simple crop rotations, reduced soil tillage, effective seed cleaning technology, intensive use of fertilisers and lime, combined harvest and the use of herbicides for weed control (Hilbig & Bachthaler, 1992). Species-rich and dynamically balanced segetal communities autoregulate a balance better than impoverished communities with distinctive and undesirable dominants (Kropáč

& Lecjaksová, 2001). In developed countries, no full eradication of adjacent weed flora but a sustainable weed control systems should be used, which considers the positive effects of weeds as well, e.g., for the conservation of abiotic resources (prevention of soil erosion, leaching of nutrients), livelihood and living space for beneficial organisms, and maintaining the species diversity of segetal coenosis (Altieri, 1999; Marshall *et al.*, 2003).

It is necessary to conduct long-term monitoring of various indicators such as the species diversity in different farming systems and natural conditions to evaluate sustainability (Vačkář, 2005). Research in this area has a long tradition, involving issues such as the relationship between weeds and the temperature, the water regime, the soil pH, the soil texture and type, the nutrient content, etc. (e.g. Ellenberg, 1950; Kühn, 1967; Chirila & Berca, 2002). Within agricultural habitats, the occurrence of weeds has been examined in the Czech Republic in different production areas (Kühn, 1972). One of the very important environmental factors considered in this regard is the effect of altitude, which explains many other ecological habitat parameters (Lososová *et al.*, 2004).

The aim of this study was to assess the γ-diversity in weed vegetation on arable land in selected areas of the Czech Republic and determine differences in the composition of weed flora under the influence of i) applied management systems (conventional and organic farming); ii) crops (winter cereals, spring cereals, wide-row crops), and iii) environmental site conditions characterised by altitude.

MATERIALS AND METHODS

In 2006–2008, a phytocoenological survey was conducted in the Czech Republic. Totally, 62 farms (27 conventional farms with common chemical weed control and 35 organic farms applying methods according to appropriate valid legislation without the use of herbicides and at least 2 years of organic management practices) were chosen for the research. Winter cereals (winter wheat, winter barley, rye, spelt, triticale), spring cereals (spring barley, oat, naked oat, spring wheat) and wide-row spring crops (sugar beet, potatoes, maize, oil pumpkin, feeding carrots, fodder beet, beet-root) were selected for the sampling. One phytocoenological relevé 100 m^2 in size was recorded in the central part of each field. The species cover was estimated using the nine-degree Braun-Blanquet cover-abundance scale (Braun-Blanquet, 1964; modified by Barkman *et al.*, 1964). This method uses the following scale intervals: *r* – rare, solitary, with small cover; + – less than 1%; *1* – cover 1–5%; *2m* – many individuals but cover less than 5%; *2a* – cover 5–12.4%; *2b* – cover 12.5–25%; *3* – cover 25–50%; *4* – cover 50–75%; and *5* – cover 75–100%. Fungi, non-vascular plants and self-seeded seedlings of trees were not evaluated. The nomenclature followed that of Kubát *et al.* (2002).

Monitoring was performed for cereals in June and July and for wide-row crops in August and September during the period of full vegetation. Each relevé was assigned with corresponding values of altitude. The extent of the elevation was 175–650 m above sea level and represented a fundamental part of the arable land of the Czech Republic in this regard. In the frame of a land verticality, relevés were divided into 3 groups (less than 250 m above sea level, 250–350 m, and more than 350 m) characterising complexes of environmental conditions suitable for the development of certain vegetation types and for the growth of specific crops (Tab. I).

The total number of weed species was recorded, as well as the number of species in different types of farming, at different altitudes and in different crops. Subsequently, species were ranked on the basis of their perenniality – annuals (semiparasitic annuals were assessed separately), biennials, and perennials.

I: *Characteristics of natural conditions (Němec, 2001)*

Altitude	< 250 m	250–350 m	> 350 m
Terrain relief	Planar to slightly undulating	Planar to slightly undulating	Slightly undulating to very steep
Average annual air temperature (°C)	9–10	8–9	5–8
Average annual rainfall totals (mm)	500–600	500–650	550–900
Sum of temperatures > 10 °C	2800–3100	2400–2800	2000–2800
Main soil units	chernozems, phaeozems, fluvisols	chernozems, haplic luvisols	cambisols
Percentage of arable land (%)	> 80	> 80	> 60
Woodiness	very low	low	low to high
Common crops	grain maize, sugar beet, high-quality wheat, malting barley, grape-vine, sunflower, fruits and vegetables	sugar-beet, early potatoes, high-quality wheat, malting barley, sunflower, root vegetables, hops	fodder cereals, ware and seed potatoes, oil-seed rape

In this ranking, volunteers and those weeds which were classified only in the genus are not included. The perenniality of weeds was determined according to Kohout (1988). Two graph types presenting the share of each group in the total number of species were created – one of them considers only the number of species, and the second considers the constancies of species (the sum of the constancies of all the species in the group).

RESULTS

A total of 172 weed species (155 dicotyledonous, 16 monocotyledonous and 1 pteridosperm) were found. In conventional and organic farms, 123 and 162 species were found, respectively. Regardless of the farming system, most species were found in winter cereals. With regard to the type of farming, most species were recorded in spring cereals in both management systems. The highest number of species was found at medium altitudes (250–350 m). An increase of the species number with increasing altitude was observed in conventional farming, while in organic farming, the highest number of weed species was present at medium altitudes and the lowest number at the lowest altitudes; see Tab. II.

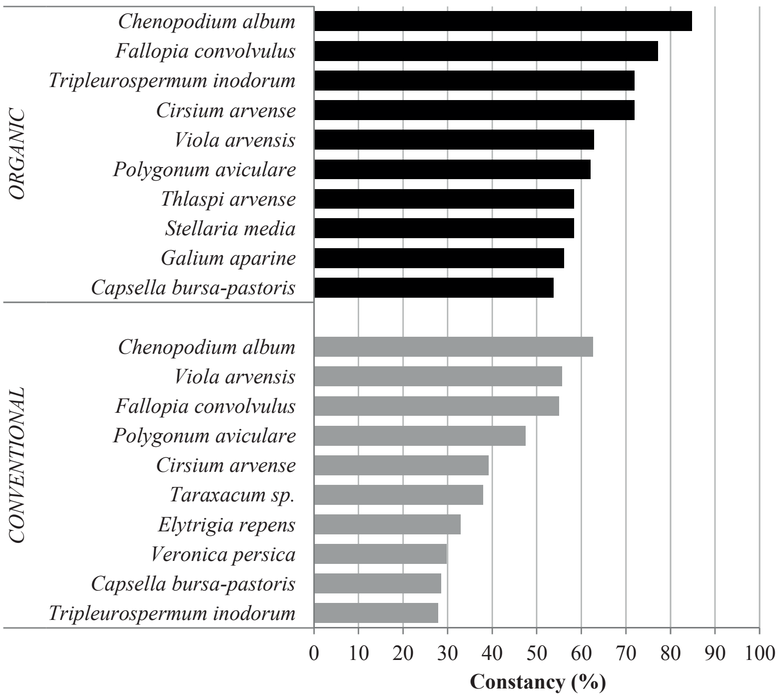
Chenopodium album was the species with the highest constancy in both types of farming. *Viola arvensis*, *Fallopia convolvulus*, *Polygonum aviculare* etc. were among species with the highest constancies in conventional farming, while *Fallopia convolvulus*, *Cirsium arvense*, *Tripleurospermum inodorum* etc. had the highest constancies in organic farming (Fig. 1).

In conventional farming, *Chenopodium album* was the most common species occurring in spring cereals (78.00% of recorded relevés) and wide-row crops (78.18%) and at the lowest altitudes (70.18%). *Viola arvensis* occurred most frequently (see Figs. 2 and 4) in winter cereals (67.92% relevés) and at medium (59.62%) and high altitudes (83.67%).

In organic farming, *Tripleurospermum inodorum* and *Fallopia convolvulus* (81.48%) were species that occurred in most relevés in winter cereals. *Fallopia convolvulus* was the most common species in spring

II: *Number of species in weed communities in individual crops and at different altitudes (total number of weed species found, including crop volunteers)*

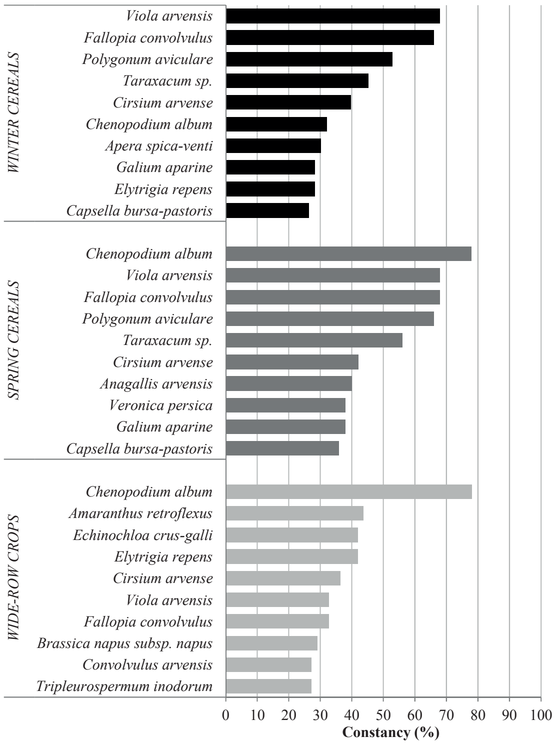
Total number of species in		both farming types	type of farming	
			conventional	organic
Crop	winter cereals	163	84	148
	spring cereals	160	101	149
	root crops	147	92	135
Altitude	< 250 m	123	73	114
	250–350 m	163	88	155
	> 350 m	155	95	137



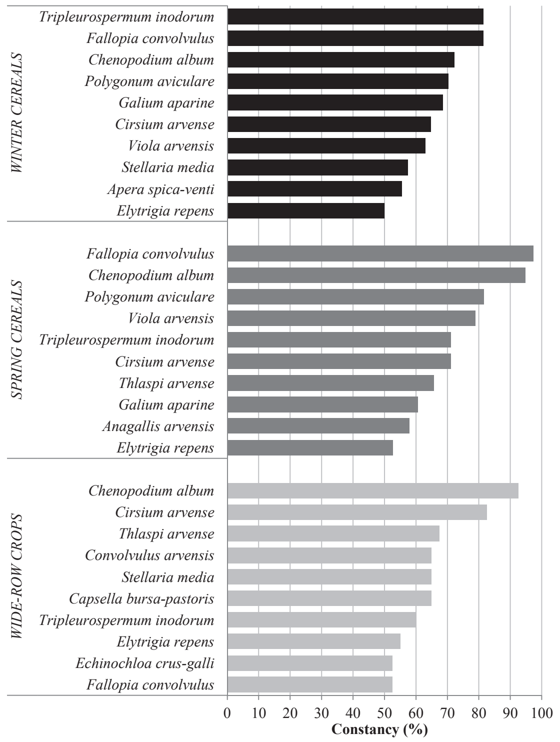
1: *Ten weed species with the highest constancies in different types of farming* cereals (97.37%) and at the highest altitudes (94.87%). In wide-row crops (92.50%) and at medium (83.78%) and low elevations (89.29%), *Chenopodium album* occurred most often (see Figs. 3 and 5).

Species Perenniality

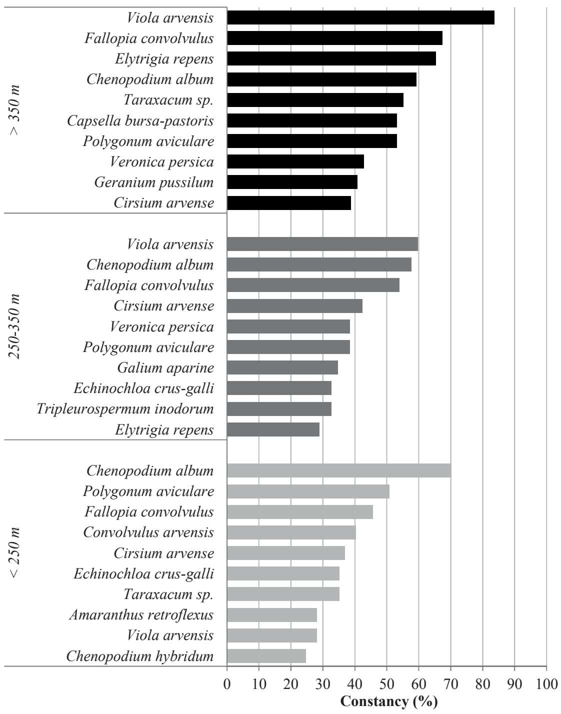
In conventional farming, a total of 89 annuals, 17 biennials and 15 perennials were found. Proportions



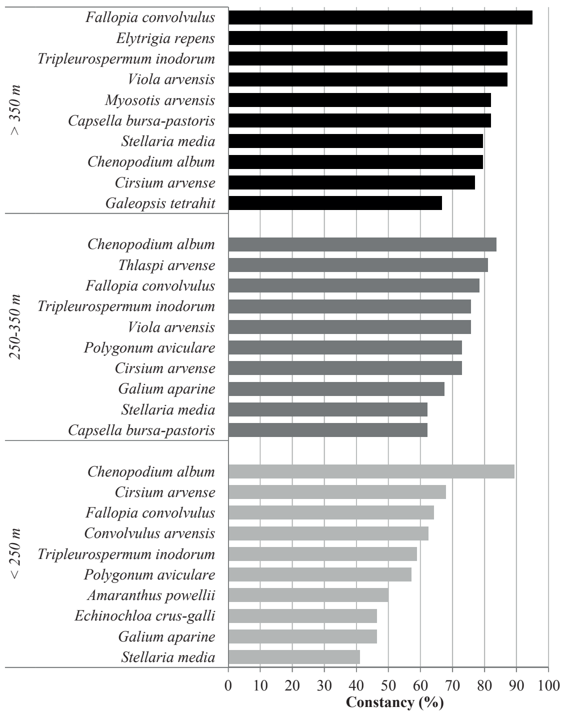
2: *Ten weed species with the highest constancies in different crops in conventional farming*



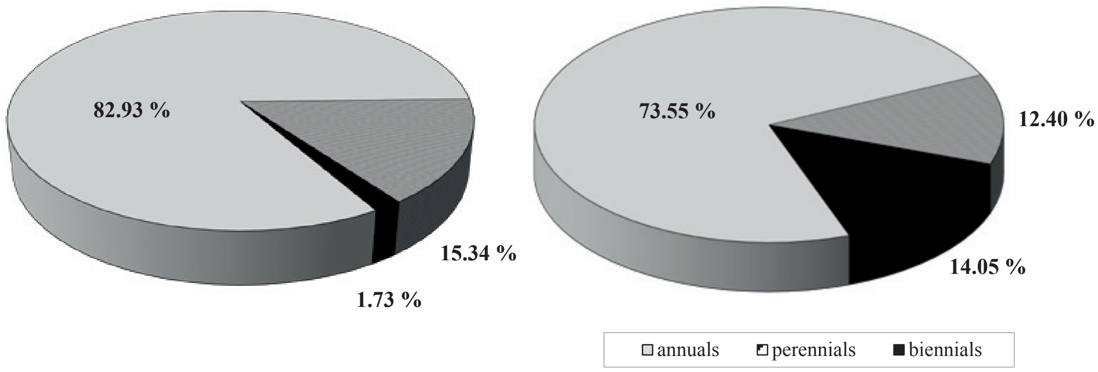
3: *Ten weed species with the highest constancies in different crops in organic farming*



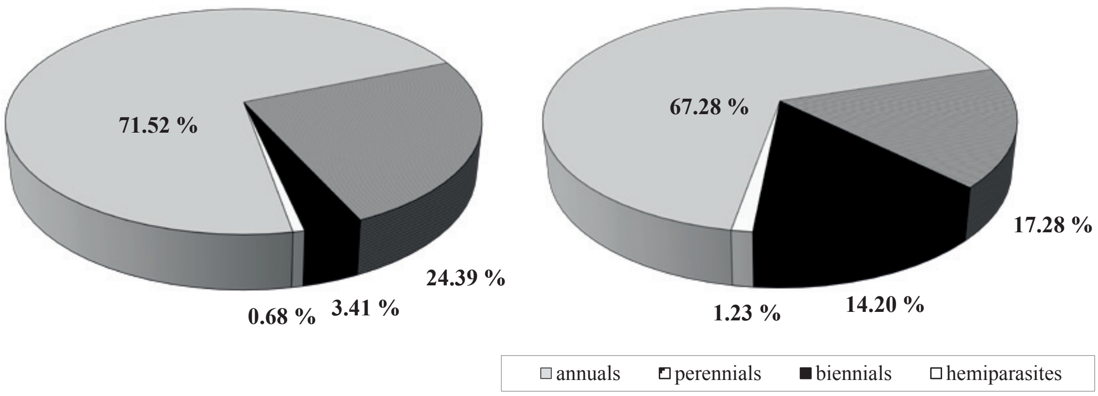
4: *Ten weed species with the highest constancies at different altitudes in conventional farming*



5: *Ten weed species with the highest constancies at different altitudes in organic farming*



6 and 7: *Weed species in conventional farming on the basis of perenniality (left – with regard to their constancies, right – only the number of species regardless of their constancies)*



8 and 9: *Weed species in organic farming on the basis of their perenniality (left – with regard to their constancies, right – only the number of species regardless of their constancies)*

of individual groups to the total number of species are shown in Fig. 6 (with regard to their constancies) and Fig. 7 (only the number of species, regardless of their constancies).

In organic farming, a total of 109 annuals, 23 biennials, 28 perennials and 2 semiparasitic annuals were found. Proportions of individual groups to the total number of species are shown in Fig. 8 (with regard to their constancies) and Fig. 9 (only the number of species regardless of their constancies).

DISCUSSION

A total of 172 weed species were found. *Chenopodium album* was recorded as the species with the highest constancy; *Viola arvensis*, *Fallopia convolvulus*, *Polygonum aviculare*, *Cirsium arvense*, *Capsella bursa-pastoris* and *Tripleurospermum inodorum* were among 10 other species with the highest constancy. Schroeder *et al.* (1993) previously presented the 20 most important weed species in Europe. *Chenopodium album* and *Stellaria media* appeared in first two positions, followed by *Cirsium arvense*, *Polygonum aviculare*, *Poa annua*, *Echinochloa crus-galli*, *Elytrigia repens*, *Convolvulus arvensis*, *Galium aparine*, etc. In conditions of the Czech Republic, Kropáč (1985) presented the following 7 most important weeds: *Chenopodium album*, *Cirsium arvense*, *Convolvulus arvensis*, *Elytrigia repens*, *Fallopia convolvulus*, *Galium aparine* and *Tripleurospermum inodorum*. Approximately 20 years later, Lososová *et al.* (2008) reported that *Viola arvensis* was the species with the highest constancy for the Czech Republic, followed by *Stellaria media*, *Capsella bursa-pastoris* and *Fallopia convolvulus*. Many of these species also occupy leading positions among the species with the highest constancies within this study. They typically have a wide ecological amplitude and are eurycoenotic species, i.e., they occur in most weed communities of cereals and wide-row crops as constant dominants and can also be found outside of arable land as ruderal species (Kropáč, 1985).

As expected, approximately 30% more weed species were found for organic farming compared to conventional farming. Similar findings were also presented for example by Moreby *et al.* (1994), Hald (1999) and Hyvönen *et al.* (2003). Higher species diversity in organic farming was also reported by Roschewitz *et al.* (2005) and Hyvönen *et al.* (2003), who found a higher diversity in organic farming than in conventional systems in 9 out of 15 monitored localities.

Besides species already mentioned at the beginning of this figure, for example *Taraxacum* sp., *Elytrigia repens* and *Veronica persica* were among species with the highest constancies in conventional farming, and *Stellaria media*, *Thlaspi arvense* and *Galium aparine* in organic farming. Also Rydberg & Milberg (2000) reported that weed flora from conventional and organic farms differed. Species associated with conventional farming were for example *Brassica* spp., *Lapsana communis*, *Fumaria officinalis*, *Galeopsis* spp. and *Viola arvensis*, while the species most clearly associated with organic farming were for example *Thlaspi arvense*, *Vicia hirsuta*, *Centaurea cyanus*, *Sinapis arvensis* and *Tripleurospermum inodorum*. The results partially correspond with the findings of Mohammad & Pallut (2006), who observed a higher occurrence of *Cirsium arvense* and *Vicia hirsuta* in organic farming systems. Glemnitz *et al.* (2006) also reported *Cirsium arvense*, *Chenopodium album* and *Galium aparine* as the most frequently occurring weeds in organic farming (Europe) as well as *Elytrigia repens,* which was found to be one of 10 species with the highest constancy in conventional agriculture within this study. The results of Glemnitz *et al.* (2006) were also confirmed by Becker & Hurle (1998) for Germany and Salonen *et al.* (2001) for Finland. Rydberg & Milberg (2000) noted that these species occur very frequently in the conventional farming system; however, the frequency can reach much higher levels in organically farmed fields, which is evident even in our results, e.g., for *Cirsium arvense*, *Galium aparine*, or *Chenopodium album*. According to Callauch (1981), the differences between weed communities in conventional and organic fields are first of a quantitative character, i.e., the differences are expressed by different distributions depending on the farming type. The absence or the application of herbicides in individual types of farming is a very important factor that influences the spread of weed species (Leeson *et al.*, 2000). If we compare the ranking order of the most important weeds in both types of farming, we observe a much stronger occurrence of *Tripleurospermum inodorum* in organic farming (10^{th} position in conventional farming and 3^{rd} in organic farming). The strong dominance of this species in organic fields has also been documented by Týr *et al.* (2001).

The species diversity is often closely connected with altitude, which is related to the landscape structure and the intensity of agriculture production. The agriculture landscape complexity can be indicated for instance by the percentage of arable land, which is lower at higher altitudes in our country. An increase of species diversity with increasing altitude was clearly documented for conventional farming. On the contrary, this trend was not confirmed for organically cultivated fields. In addition, Roschewitz *et al.* (2005) show that γ-diversity can be significantly affected by the complexity of the landscape in conventionally cultivated fields. The species diversity decreased as the percentage of arable land increased, i.e., the diversity was higher in more diversified landscapes. On the contrary, the species diversity of organically cultivated fields was only slightly affected by the complexity of the landscape in this study. One possible reason for the increase of γ-diversity with increasing altitude in conventional farming systems may be the fact that only field centres were sampled, not the edges. The centres of larger fields in more fertile lowlands are better preserved from the introduction of diaspores from field margins and edges than smaller fields at higher altitudes. Wilson & Aebischer (1995) showed that several weed species in conventional fields declined with increasing distance from the field edges, and Hald (1999) found a gradient in species density from the edge to the centre in conventional but not organic fields. In organically cultivated fields, the differences in the intensity of weed occurrence between the field edges and centres were not substantial, which may be because these fields are more or less independently functioning, species rich ecosystems and are less dependent on the immigration of species from the surroundings. The occurrence of each weed taxa assessed in terms of the altitude is closely related to the climate and soil characteristics of these areas. Of course, the metamorphic effects of agricultural technologies are also reflected here, especially in terms of the management intensity related to these natural conditions.

In our research, the lowland localities were generally characterised by thermally demanding annual late-spring weed species, such as *Amaranthus* spp., *Echinochloa crus-galli* and *Chenopodium hybridum*. The higher altitudes were represented by species that are characteristic of colder areas and poor, humid, and acidic soil types, such as Cambisols (e.g., *Galeopsis tetrahit*, *Myosotis arvensis*). *Viola arvensis* clearly increases its constancy with increasing altitude. In addition, Kühn (1972) noted a higher frequency of this species in agricultural areas in higher elevations on the basis of several thousands of phytocoenological relevés of weed vegetation in Moravia. According to Jursík *et al.* (2011), the crops often create sparse stands on poor soils, and *Viola arvensis* (as a minor weed of lower vegetation etage) can better succeed here. The stronger affiliation of *Chenopodium album* with lower altitudes despite its wide ecological amplitude can be related to its nitrophilous character (Ellenberg, 1950) and thus the higher nutrient content of lowland soils.

From the point of view of individual crops, the highest values of species diversity were found in cereals and the lowest mainly in wide-row crops. According to Himstedt & van Elsen (2006), winter and spring cereals show the complete development of weed communities, in contrast to root crops. For winter cereals, the species with the highest constancy were *Viola arvensis*, *Tripleurospermum inodorum* and *Fallopia convolvulus*. In spring cereals, *Chenopodium album, Fallopia convolvulus*, *Viola arvensis* and *Polygonum aviculare* were the species with the highest constancies. *Chenopodium album* occurred most frequently in wide-row crops, followed by *Amaranthus retroflexus*, *Echinochloa crus-galli* and *Cirsium arvense*. The association of weeds and crops is determined largely by the degree of competition between a particular crop and a weed. It is also determined by agricultural interventions and the rotational practices associated with each crop (Zimdahl, 1999). The high occurrence of *Chenopodium album* in spring cereals can be explained by the fact that even though it is a summer annual species, it is able to emerge in early spring and throughout the whole year (Koch, 1970). Similar results were reported by Lososová *et al.* (2008), who noted *Viola arvensis*, *Stellaria media, Fallopia convolvulus* and *Tripleurospermum inodorum* as the species with the highest constancies in cereals and *Chenopodium album*, *Stellaria media*, *Capsella bursa-pastoris* and *Cirsium arvense* as the species with the highest constancy in root crops (wide-row crops). Rather different results in cereals were reported by Schroeder *et al.* (1993), who noted *Galium aparine* as the most important species in winter cereals in Europe, *Cirsium arvense* and *Avena fatua* in spring cereals, *Chenopodium album* in potatoes and sugar beets, and *Echinochloa crus-galli* in maize. Chancellor & Froud-Williams (1984) identified *Viola arvensis, Galium aparine, Stellaria media, Myosotis arvensis* etc. as the most wide-spread dicotyledonous weeds in cereals (South England).

The weediness of cereals in different production areas (different altitudes) has previously been studied. Buryšková (1999) mentions *Tripleurospermum inodorum* and *Chamomilla* spp. as species with the highest constancies in cereals in maize production areas (the lowest altitudes), *Tripleurospermum inodorum* and *Chamomilla* spp. and *Galium aparine* in sugarbeet production areas (low altitudes) and *Tripleurospermum inodorum*, *Chamomilla* spp. and *Elytrigia repens* in potato production areas (higher altitudes). The highest occurrence of *Elytrigia repens* in higher altitudes is quite interesting. In the past, *Elytrigia repens* occurred predominantly at low altitudes. However, with agricultural intensification in the second half of the 20th century, especially due to high nitrogen fertilisation, this species has spread to higher elevations with relatively poor and often stony soils, where its control is more difficult. A deeper tillage cannot be applied under these conditions, and an effective control is difficult without herbicides (Kohout, 1995). In contrast, other perennial weeds such as *Cirsium arvense* and *Convolvulus arvensis* tend to have a higher constancy in lower altitudes. Similar results were also presented by Lososová *et al.* (2008). *Cirsium arvense* prefers primarily deep, fertile and cultivated soils. *Convolvulus arvensis* is also more common in warmer areas and on deep soils rich in nutrients with a higher content of calcium (Jursík *et al.*, 2011).

A higher proportion of perennial weed species was found in organically cultivated fields. Callauch (1981) also showed that perennial weeds are more common in organically managed areas. In his observations, the proportion of perennial species was 33% in organically cultivated cereals, while this proportion was only 18% in conventionally managed cereals. Böhm & Verschwele (2004) reported a higher occurrence of *Cirsium arvense* and *Rumex* sp. after conversion to organic farming. Plakolm (1989) also showed that perennial species such as *Equisetum arvense*, *Cirsium arvense* and *Sonchus arvensis* cause problems in organic fields. In addition, Pupaliene (2004) states that the methods applied in organic farming allow the development of suitable conditions for the spread of perennial weed species, especially *Cirsium arvense* and *Sonchus arvensis*. Similarly, Lacko-Bartošová & Krošlák (2001) stated that the occurrence of perennial species *Cirsium arvense* and *Convolvulus arvensis* is a common characteristic of ecological systems.

It can be concluded that results of this survey confirmed a higher species richness of weed vegetation in organic farming. Cereals and partly also increasing elevation were other important factors enhancing diversity. Further survey of gamma diversity in extended study area or including more organic farms in current studied area can be seen as a future research direction.

CONCLUSION

In 2006–2008, a phytocoenological survey was conducted in the Czech Republic. Totally, 62 conventional and 35 organic farms were chosen for the research. Winter cereals, spring cereals and wide-row spring crops were selected for the sampling. One phytocoenological relevé 100 m^2 in size was recorded in the central part of each field. The species cover was estimated using the nine-degree Braun-Blanquet cover-abundance scale. Monitoring was performed for cereals in June and July and for wide-row crops in August and September during the period of full vegetation. The total number of weed species was recorded, as well as the number of species in different types of farming, at different altitudes and in different crops. Subsequently, species were ranked on the basis of their perenniality – annuals, biennials, and perennials.

A total of 172 weed species were found. In conventional and organic farms, 123 and 162 species were found, respectively. Regardless of the farming system, most species were found in winter cereals. With regard to the type of farming, most species were recorded in spring cereals in both management systems. The highest number of species was found at medium altitudes. An increase of the species number with increasing altitude was observed in conventional farming, while in organic farming, the highest number of weed species was present at medium altitudes and the lowest number at the lowest altitudes.

Chenopodium album was the species with the highest constancy in both types of farming. In conventional farming, *Chenopodium album* was the most common species occurring in spring cereals and wide-row crops and at the lowest altitudes. *Viola arvensis* occurred most frequently in winter cereals and at medium and high altitudes. In organic farming, *Tripleurospermum inodorum* and *Fallopia convolvulus* were species which occurred in most relevés in winter cereals. *Fallopia convolvulus* was the most common species in spring cereals and at the highest altitudes. In wide-row crops and at medium and low elevations, *Chenopodium album* occurred most often. In conventional farming, a total of 89 annuals, 17 biennials and 15 perennials were found. In organic farming, a total of 109 annuals, 23 biennials, 28 perennials and 2 semiparasitic annuals were observed.

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