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Research article

Vegetation structure of bio-belts as agro-environmentally-climatic measures to support biodiversity on arable land: A case study

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Abstract: Loss of biological diversity is one of the greatest challenges that our civilization must face nowadays. Reaction to the diminishing biodiversity of agricultural landscapes is various measures promoting free-living organisms. The study deals with the vegetation composition and structure of agro-environmental-climatic measures applied on arable land in operating conditions (intensively farmed regions of the Czech Republic). Additional study focus was applied to a popular measure of the feeding bio-belts. Bio-belts are not only hiding places for free-living animals but can provide them a rich food offer in the period from the harvest of main crops until winter. Thanks to the bio-belts, the landscape gains in biodiversity, and sloping sites can be protected from soil erosion. The vegetation of land parts used as bio-belts was assessed using phytocoenological relevés. Dominant plant species sown in the bio-belts were *Avena sativa, Panicum miliaceum, Brassica oleracea* var. *acephala, Fagopyrum esculentum, Phacelia tanacetifolia,* and *Pisum arvense*. Apart from the sown plants, there were also weeds occurring in the bio-belts, of which the most abundant were *Chenopodium album, Amaranthus retroflexus*, *Setaria verticillata*, *Cirsium arvense*, *Equisetum arvense*, etc. Risks connected with the realization of feeding bio-belts in respect of weeds occurring on arable land are negligible. Weeds from bio-belts have only a limited potential to spread to adjacent arable land. A potential spreading of weeds from the bio-belts to adjacent arable land was not demonstrated. On the contrary, thanks to its composition, the vegetation of bio-belts has the potential to extend the food offer for animals. Thus, bio-belts are useful for supporting biodiversity in regions intensively used for agriculture.

Keywords: agricultural landscape; biological diversity; vegetation composition; weeds

1. Introduction

The biodiversity of native vegetation exhibited a dramatic decrease in the last four decades the agricultural landscape [1–4]. The decrease or total loss of biological diversity is currently conditioned primarily by human civilization activities such as the direct conversion of natural stands into cultivated farmlands [5,6] or land occupation for several types of construction [7]. Losses in the biodiversity of plants cause negative effects at further trophic levels of ecosystems [8,9].

Changes in technologies used for growing field crops resulted in the reduced occurrence of some weed species [10] and in the increasing occurrence of nitrophilous weed species [11,12]. According to Krähmer et al. [13] modern agriculture seems to favor nitrophilous species in principle. Several arable plant species have become endangered in Europe [13]. Consequently, once common annual weeds e.g, *Centaurea cyanus* and *Ranunculus arvensis* were practically eradicated from fields in the lowlands of England and endangered or extinct in many countries [14,15].

Weed richness and abundance in agriculture has indeed declined drastically over the past decades, as documented in Europe [10]. In fact, the occurrence of most field weeds is limited only to field edges where the competition of plants is lower due to the less efficient weed control management [16–19]. Thanks to the limited intensity of cultivation technologies on field edges, annual plants on arable land are promoted in their abundance and diversity [18–20]. The area between the field margin (edges) and first row of crop function as refugia for many weed species e.g, *Anthemis arvensis, Anthriscus caucalis, Papaver rhoeas* [18,19]. The limited use of pesticides and fertilizers on field headlands (protective headlands) increases the diversity of dicotyledonous plants with significant benefits for the populations of invertebrates and field avians [21,22]. Diversity of weeds on the protective headlands is higher when no fertilizers are applied, the degree of crop cover is lower thanks to which more light penetrates the stand that is used by weeds [17]. Another possibility is to retain the winter stubble when a part of the land is taken out of production thanks to which field birds have both food and hiding place on the site although the species diversity of plants usually does not increase [23]. Nevertheless, summer soil cultivation may increase potential for the germination of annual weeds [18]. In case of the prolonged absence of soil cultivation, the annual weed species will be gradually replaced by perennial species with the dominance of grasses [24–26].

Agricultural landscape represents a conflict of two directions. One of these directions is protection of the occurrence of living organisms-conservation [27,28]. The other direction is protection against harmful organisms in agriculture-phytopathology [29–31]. Weeds on arable land have an interesting position in this conflict, being problematic as competitors to field crops reducing their yields [3,32,33] and representing at the same time a source of food for many other taxa in agrosystems e.g, *Galium aparine*, *Fallopia convolvulus, Thlaspi arvense, Viola arvensis* [34–37]. Weeds deserve attention also thanks to significant heterogeneity of their occurrence [37–42].

It has been demonstrated that bio-belts can support biodiversity and associated ecosystem services, biodiversity colonization effects have rarely been studied [43]. In this paper, we introduce the assessment of agro-environmental-climatic (AEC) measures established on arable land in the Czech Republic (CR), area intensively used for agriculture. Parameters assessed included overall diversity and structure of vegetation on arable land and bio-belts. The aim of the work was to evaluate the species composition of the vegetation of field crop stands and the vegetation of the bio-belts. The goal was to confirm the potential of the vegetation of AEC measures as a source of food for animals as well as to verify the risk of weeds spreading from the areas of AEC measures to arable land. The vegetation was assessed based on the representation of plant species significant for animals as a source of food and their capability of spreading in agricultural landscapes.

2. Materials and methods

The studied site is situated in the cadastral area of Morkovice-Slížany and in its close surroundings, in the Zlín Region, CR (49°14′53″ north latitude and 17°12′28″ east longitude). The area belongs to the Central Moravian Carpathians, and the geomorphological region falls in the sub-province of Outer Western Carpathians. Mean altitude of the area is 282 m a medium slope is 4°33′. The Central Moravian Carpathians belong in the Morava River basin. Geological bedrock is formed by prevailing Paleogene clay stones, sand stones and sporadically occurring conglomerates. The studied site exhibits a clear dominance of arable land which occupies about a half of the cadastral area, which is accustomed also by the high representation of moderately deep to deep fertile soils (brown soils, chernozems and luvisols). Prevailing soil types are heavy and moderately heavy soils. The long-term mean total annual precipitation is 564 mm, and the long-term mean temperature is 8.6 ℃.

The Agrodružstvo Morkovice agricultural enterprise applies selected AE and climatic measures referred to as bio-belts. Bio-belts serve not only as hiding places for free living animals but can provide a rich food offer for them in the period from the main crop harvest to winter. Bio-belts contribute to the diversity of landscapes and may help to control soil erosion on sloping lands. Agro-environmental-climatic measures (previously only agro-environmental measures) were part of the Agricultural Policy of the Ministry of Agriculture of the Czech Republic, and it belonged to subsidies under the Rural Development Program. Among their goals was to support biodiversity in an intensively used agricultural landscape.

Bio-belts are strip fields located on the edge or inside soil blocks. The dimensions of the bio-belt are 6–24 m wide and at least 30 m long. The bio-belt had to be established by May 31st of the calendar year at the latest. Additionally, they had to be sown with a specified seed mixture the composition of which had to be in accordance with the regulation of the Ministry of Agriculture of the CR [44]. The mixture used for the sowing of the monitored bio-belts included: *Avena sativa* Bingo variety (49.7%), *Panicum miliaceum* Jagna variety (11.5%), *Brassica oleracea* var. *acephala* Boma variety (0.6%) and Astera variety (0.3%), *Fagopyrum esculentum* Pyra variety (11.5%), *Phacelia tanacetifolia* Větrovská variety (3.8%) and *Pisum arvense* Eso variety (22.9%). The residual biomass of the annual bio-belts was mulched in the spring of the following year, then a deep ploughing, and followed by a repeated sowing of the seed mixture. All preparations for plant protection, such as pesticides, are forbidden on the bio-belts.

There were 5 bio-belts on the cultivated arable land of the agricultural enterprise sized 104,39 ha, a total area of which was 3,63 ha. The width of the bio-belts was 24 m and was determined by the seeding machine. The area and dimensions of the bio-belts met the requirements of the Ministry of Agriculture of the CR. The selected bio-belts were established on the edge of the plot and are adjacent to linear features (borders, tree lines). These bio-belts were chosen for the monitoring (Table 1). The vegetation composition was analyzed using phytocoenological relevés taken in two seasons of the year—in summer (July) and autumn (October) of 2018 and 2019.

Table 1. Characteristics of selected sites and bio-belts.

Site	Name	Land area (ha)	Bio-belt area (ha)
1	Kameňák Uhřice	53.9	0.71
2	Věžky	6.89	0.64
3	Malý gret	3.13	0.64
4	Dřínov	33.16	1.26
5	Telák dolní	7.31	0.38

The analysis of vegetation composition at the monitored sites in the crop stands and, in the bio-belts was made using phytocoenological relevés. Phytocoenological relevé is a form of record about the species composition of the vegetation and cover of plant species. One relevé was sized 3×3 meters (9 m^2). When the sites were delimited, the occurring plant species were recorded, and their cover determined using the Braun-Blanquet cover-abundance scale. Each site had 5 phytocoenological relevés recorded in the bio-belt and 5 phytocoenological relevés recorded in the stand of the crop grown on most land. Data obtained from the relevés were processed using multivariate analyses of ecological data. The analysis of main components - Detrended Correspondence Analysis (DCA) was used to calculate gradient length (Lengths of Gradient) and the redundancy analysis (RDA) followed [45]. Significance was evaluated using the Monte-Carlo test in which 999 permutations were calculated. The calculations were made by Canoco 5.0. computer programme [46].

Scientific names of individual plant species originate from the Pladias database of Czech flora and vegetation [47]. Based on the Pladias database, the plant species were divided into several groups according to selected two characteristics. The first one was the method of pollination to express a potential source of food for insects. The second one was the method of fruit and seed dispersal as an indirect expression of the potential of spreading within the agricultural landscape.

The method of pollination is ensured by abiotic vectors (anemophilia, hydrophilia), or biotic vectors such as for example insects (entomophilia), and there are also alternative methods of pollination (autogamy, cleistogamy, etc.). The information about pollination methods was taken from the BiolFlor database [48]. Plant species spread by various vectors and methods. The classification of species into dispersal categories was taken from Sádlo et al. [49]. The species were classified into the following categories: (i) Allium—primarily autochory, more rarely anemochory, endozoochory and epizoochory. This is the most common dispersal strategy. About a half of the included taxa are generalists without any clear adaptation to anemochory or zoochory; (ii) Bidens—primarily autochory and epizoochory, less frequently endozoochory. This strategy combines two basic methods of dispersal of which autochory is more significant one even despite the presence of morphological structures suggesting epizoochory; (iii) Cornus—primarily autochory and endozoochory. The strategy is typical of herbs, shrubs, and lower trees with pulpy fruits. The category includes also taller trees with large, heavy, and nutrient-rich seeds; (iv) Epilobium—primarily anemochory and autochory, less frequently endozoochory and epizoochory. Plants with this strategy of dispersal are characteristic for mesic and dry sites; (v) Lycopodium—primarily anemochory, less frequently autochory, endozoochory, epizoochory and hydrochory. This dispersal strategy relies upon light and very small spores and seeds that are dispersed and also omit various other vectors in addition to airborne distribution; (vi) Zea—taxa with this strategy are distributed by generative diaspores only exceptionally or not at all and do not form above-ground vegetative diaspores.

3. Results

There were 30 plant species identified on the selected five sites on which 4 crops were grown (*Brassica napus, Hordeum vulgare, Triticum aestivum* and *Zea mays*). In the bio-belts, 7 intentionally grown plant species were identified and 19 weed species. The numbers of plant species recorded on the respective sites are presented in Table 2.

Table 2. Numbers of plant species on the monitored sites.

Site	Site part	Main crop	Plants sown in bio-belts	Weeds
1	Bio-belt	1	7	15
	Arable land	1	1	3
2	Bio-belt	1	7	16
	Arable land	1	1	2
3	Bio-belt	1	5	15
	Arable land	1	0	2
4	Bio-belt	0	7	15
	Arable land	1	0	3
5	Bio-belt	0	7	16
	Arable land	1	0	2

The vegetation species composition in the bio-belts according to cover is shown in Figure 1. Species names of deliberately sown crop are marked in green. The names of weeds are marked in red. The highest proportions of the sown crops were *Phacelia tanacetifolia* and *Avena sativa*. Among weeds, *Chenopodium album, Setaria verticillata* and *Amaranthus retroflexus* had the highest proportion.

The representation of plants sown on the bio-belts and weeds on the respective sites is shown in Figure 2. The vegetation cover on arable land is made up of cultivated crops and there is little weed cover. The proportion of weeds is significantly higher in bio-belts, where the use of herbicides is prohibited.

The representation of plant species according to the method of pollination and dispersal mode is presented in Figure 3. On arable land, where there is a significant representation of the crop, the relevant method corresponding to the crop always prevails. Bio-belts have a more varied species composition and more varied methods of pollen dispersal. There is also a more pronounced representation of species with entomophilia.

Species representation according to the method of fruit and seed dispersal on the monitored sites is presented on Figure 4. The predominant way of dispersing fruits and seeds is the Allium strategy on all monitored areas. This type of fruit and seed dispersal is the most common strategy. The exception is plot No. 4, where Zea is the predominant propagation strategy on arable land.

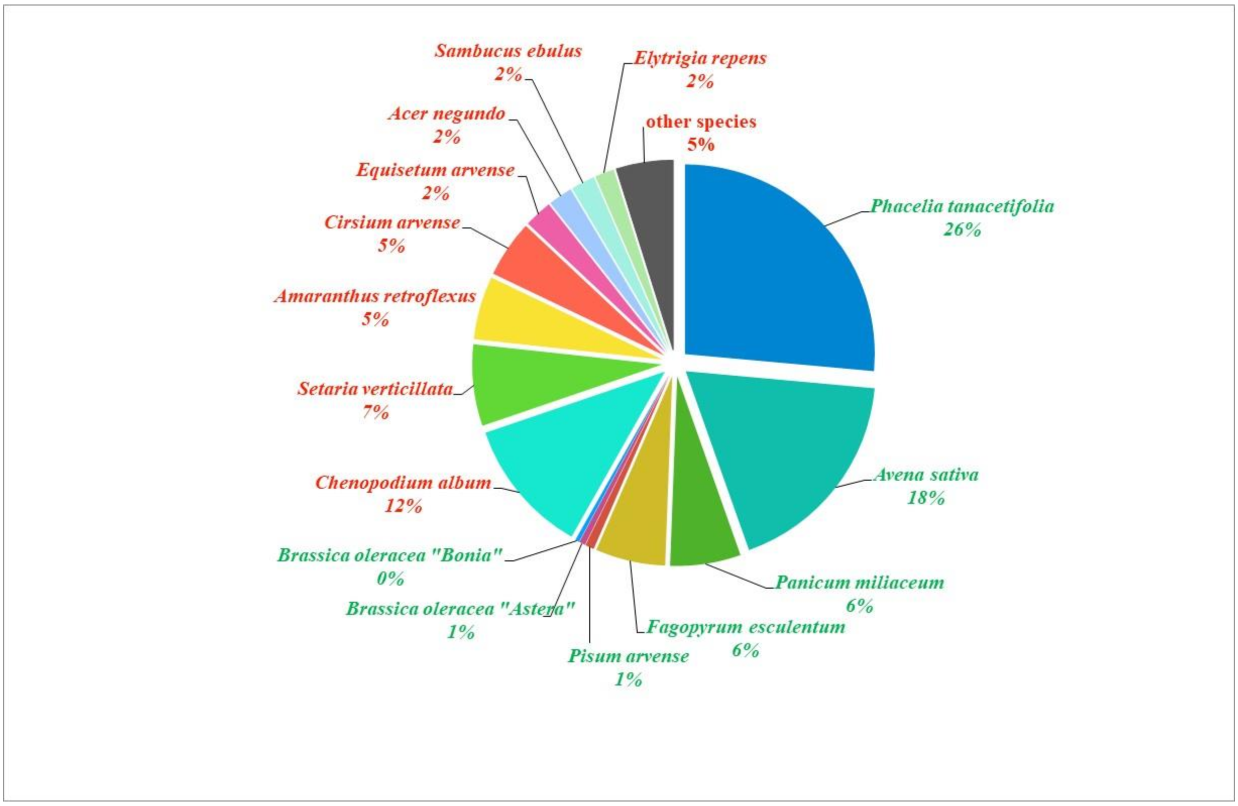

Figure 1. Species composition of vegetation from bio-belts (green—sown crops; red—weeds).

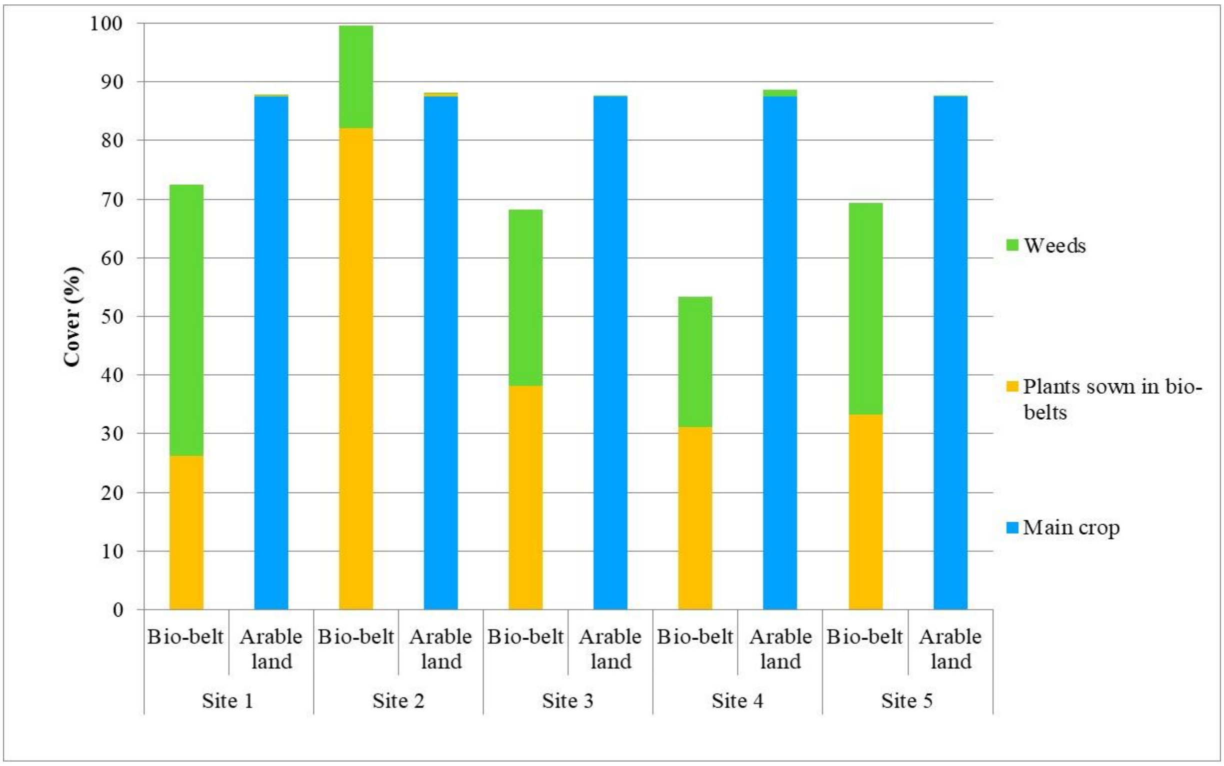

Figure 2. Representation of plant groups on the monitored sites.

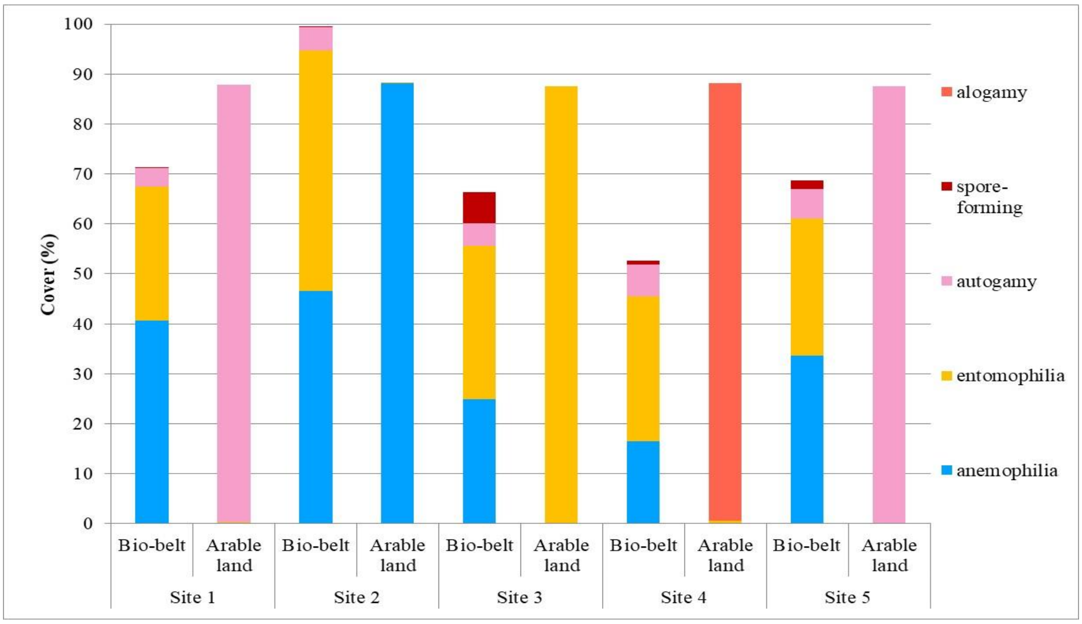

Figure 3. Species representation according to the method of pollination on the monitored sites.

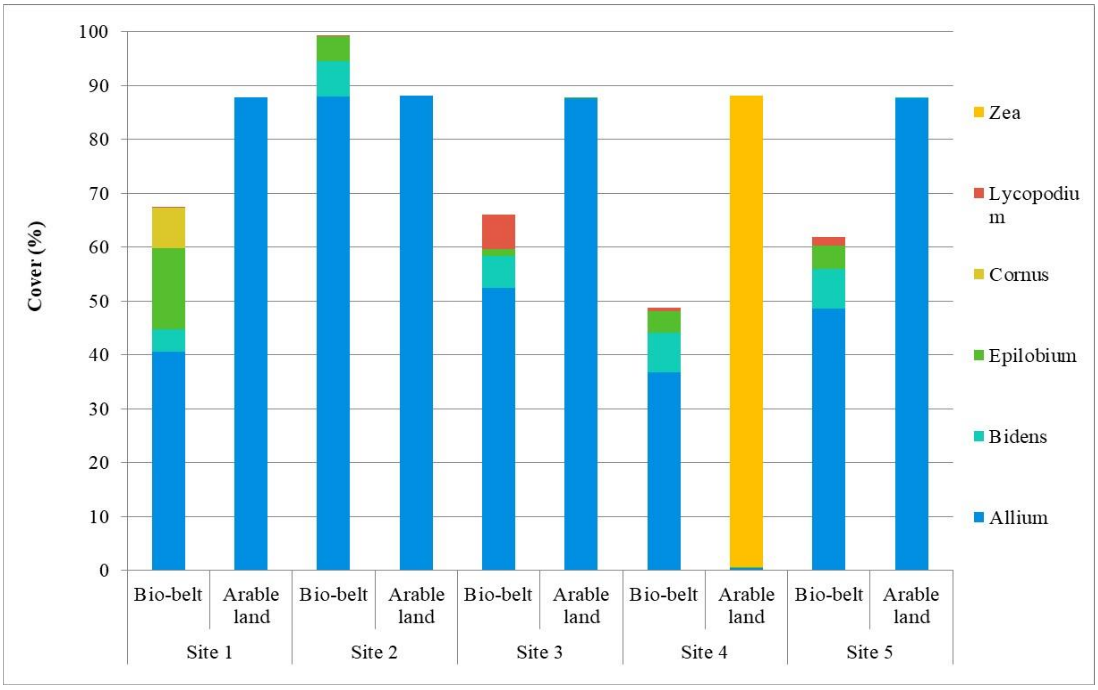

Figure 4. Species representation according to the method of fruit and seed dispersal on the monitored sites.

Results of RDA analysis which was used to assess the cover of plant taxa on the monitored sites were significant for all canonical axes at a significance level of $\alpha = 0.001$. The graphical illustration of RDA results is presented in Figure 5.

Based on the RDA analysis, the identified plant taxa can be divided into three groups. The division of taxa into groups according to the RDA analysis is shown in Table 3.

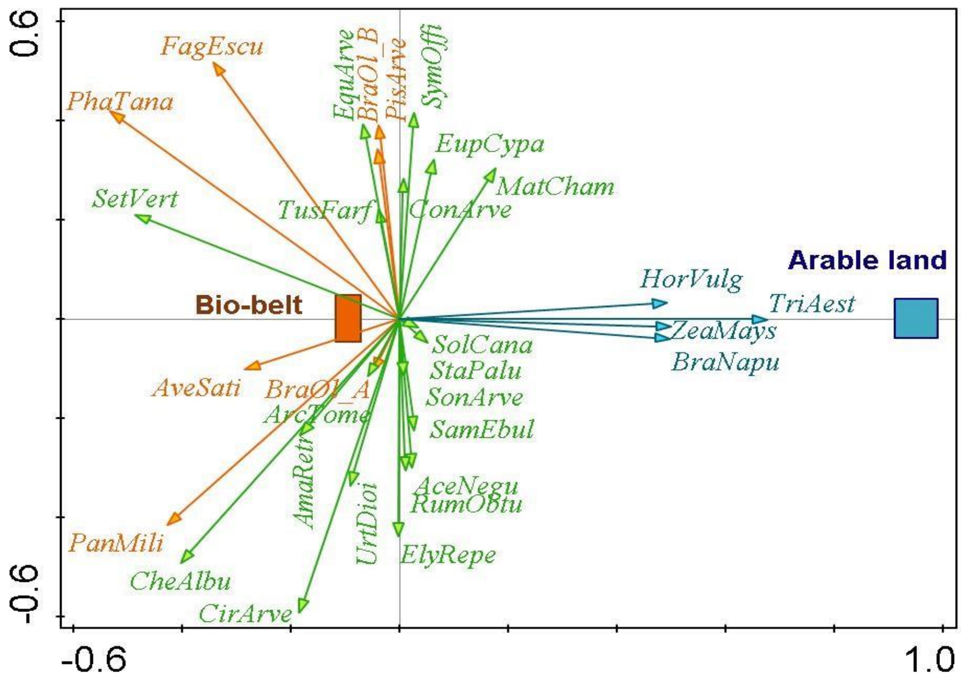

Figure 5. Occurrence of identified plant species on the sites of different use (result of RDA analysis; overall explained variability = 10.1%; F-ratio = 5.9; P-value = 0.001).

Table 3. Groups of plant species according to RDA analysis.

Group species		Species
Arable land (Group 1)	Crops	*Brassica napus (BraNapu), Hordeum vulgare (HorVulg), Triticum aestivum (TriAest), Zea mays (ZeaMays).*
Bio-belts (Group 2)	Bio-belt crops	*Brassica oleracea* convar. Bonia (*BraOl_B), Fagopyrum esculentum (FagEscu), Phacelia tanacetifolia (PhaTana), Pisum arvense (PisArve).*
	Weeds	*Convolvulus arvensis (ConArve), Equisetum arvense (EquArve), Euphorbia cyparissias (EupCypa), Matricaria chamomilla (MatCham), Rumex obtusifolius (RumObtu), Setaria verticillata (SetVert), Symphytum officinale (SymOffi), Tussilago farfara (TusFarf).*
Bio-belts (Group 3)	Bio-belt crops	*Avena sativa (AveSati), Panicum miliaceum (PanMili), Brassica oleracea* convar. Astera *(BraOl_A).*
	Weeds	*Acer negundo (AceNegu), Amaranthus retroflexus (AmaRetr), Arctium tomentosum (ArcTome), Cirsium arvense (CirArve), Elytrigia repens (ElyRepe), Chenopodium album (CheAlbu), Sambucus ebulus (SamEbul), Solidago canadensis (SolCana), Sonchus arvensis (SonArve), Stachys palustris (StaPalu), Urtica dioica (UrtDioi).*

4. Discussion

The results show that bio-belts represent plant communities markedly more diverse than the crop stands on arable land. Studies confirmed [50–53] that non-cropped elements such as semi-natural vegetation, grassland strips and hedgerows provide high-quality habitats for various taxa and their positive impact on biodiversity. The greater species diversity of vegetation creates a potential for a higher offer of food for animals [44,54,55]. The significant share of entomophilous plant species (Figure 3) is a food source for insects [56], which is spatially available and in terms of time longer available thanks to limited cultivation measures. On arable land, the source of food for pollinating insects is given by the grown crop, and in terms of time is limited to the period of its flowering. Crochard et al. [57] analysis provided evidence that pollinators are shared between flowering crops, as well as between flowering crops and associated weeds. Theirs results suggest that arable weeds (field edges weeds), flowering or not potential levers for enhancing pollination services in an agricultural landscape. This is in line with other studies highlighting arable weeds as important resources for wild pollinators [58–60].

The diversity of vegetation in bio-belts (Figures 1 and 2) is given by the sown mixture of plants but also by the higher share of weeds. The representation of weeds in the weed vegetation is varied and the monitored sites markedly differ from one another. While weeds clearly dominate on Sites 1 and 5, sown crops succeed in being a serious competition to weeds on Sites 2 and 4. Weeds spread between fields and adjacent lands in agricultural landscapes, and some weeds growing on boundaries may spread into the stands of main crops e.g, *Artemisia vulgaris, Cirsium arvense, Lactuca serriola* [4,61–63]. This is usually the reason omit landowners often perceive field edges as a source of weeds occurring in the main crops [64–66]. A type dominating in terms of spreading fruits and seeds in the vegetation of bio-belts is Allium (Figure 3). This type has a limited dispersal into the surroundings, and most seeds enrich the soil seed bank. When the site with the bio-belt returns to common cultivation of crops, the seeds of weeds can germinate and affect the growing crops. A elevated risk of subsequent weeding exists particularly in *Chenopodium album* and *Amaranthus retroflexus*. In bio-belts, plant species were found with a high potential of spreading to adjacent lands, representatives of *Asteraceae* family (*Cirsium arvense, Tussilago farfara*). Therefore, bio-belts should not be established on sites with the occurrence of these species.

It further follows from the ordination diagram (Figure 5, Table 3) that the occurrence of weeds on arable lands is successfully controlled mainly by herbicides and therefore sown crops have a dominant representation on them. However, the vegetation of bio-belts exhibits more complex competitive and synergic relationships, e.g. the synergic relationship of *Brassica oleracea* convar. Bonia, *Fagopyrum esculentum*, *Phacelia tanacetifolia*, and *Pisum arvense*. This group competes with the weed species of *Convolvulus arvensis, Equisetum arvense, Euphorbia cyparissias, Matricaria chamomilla, Rumex obtusifolius, Setaria verticillata, Symphytum officinale* and *Tussilago farfara* only with some difficulties.

The second group with synergic relationships is represented by *Avena sativa, Panicum miliaceum,* and *Brassica oleracea* convar. Astera. These plant species are difficult to compete with *Acer negundo, Amaranthus retroflexus, Arctium tomentosum, Cirsium arvense, Elytrigia repens, Chenopodium album, Sambucus ebulus, Solidago canadensis, Sonchus arvensis, Stachys palustris* and *Urtica dioica.* It follows that the composition of plant mixtures used in bio-belts is also particulary important for the suppression of weeds and reduction of their future development.

Human activities have been found to be responsible for enhancing biological invasion, in particular by increasing pressure on propagule, and cropping areas [67]. Attention should also be given to the occurrence of invasive plant species such as *Acer negundo* and *Solidago canadensis*. Neither of them is a common field weed, and their occurrence and cover in the bio-belt is exceptionally low. Nevertheless, their occurrence should be regulated. It would be useful to extend the rules for AE-measures and to permit the application of herbicides in case that an invasive plant species occurs.

5. Conclusions

Bio-belts as agro-environmentally-climatic measures increase the species diversity of vegetation in agricultural landscapes. The vegetation of bio-belts has a potential to improve the food offer and to enhance spatial and time availability of food sources for animals. On the other hand, bio-belt also represent a certain risk of weeds enriching the soil seed bank, which can later show as increased weed infestation of crops when the bio-belt area is returned to common use. Additionally, the occurrence of species from the *Asteraceae* family with the Epilobium type of fruit and seed dispersal is problematic omit. Bio-belts may become sources of diaspores of those species and adjacent lands can become infested with weeds. The composition of seed mixture used for sowing the bio-belts appears no less important. Suitable combinations can ensure higher competition of crops and hence lower weed infestation. The conditions and parameters of bio-belts will be another area of research that will seek common solutions to support biodiversity and reduce risks for agricultural production. Vegetation of bio-belts is a welcome contribution to the maintenance and support of biodiversity in intensively used agricultural landscapes. Nevertheless, the risks connected with bio-belts for agricultural production must be financially compensated. The compensation is important to mitigate worries and unwillingness of farmers to adopt agro-environmentally-climatic measures.

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Conflict of interest

The Authors declare that there is no conflict of interest.

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