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Diversity of Segetal Flora in *Salix viminalis* L. Crops Established on Former Arable and Fallow Lands in Central Poland

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Abstract: The flora of willow (*Salix viminalis* L.) plantations consists of various plant groups, including plants related to arable land, called segetal plants. Knowledge of this flora is important for maintaining biodiversity in agroecosystems. The aim of the study was to assess the segetal flora of the willow plantations in central Poland, depending on the land use before the establishment of the plantations (arable land or fallow) and the age of the plantations. Moreover, the aim was also to check for the presence of invasive, medicinal, poisonous and melliferous species. The vegetation accompanying willow was identified based on an analysis of 60 phytosociological relevés performed using the Braun-Blanquet method. For each species, the following parameters were determined: the phytosociological class; family; geographical and historical group; apophyte origin; biological stability; life-form; and status as an invasive, medicinal (herbs), poisonous or melliferous species. The results were statistically processed. Segetal species accounted for 38% of the flora accompanying willow. The plantations on former arable land were richer in segetal species than those on fallow. Mostly, short-lived and native species dominated. In line with the age of the plantations, the number of segetal species decreased. The share of apophytes increased, and anthropophytes decreased. Furthermore, many valuable plants were found among the flora accompanying willow.

Keywords: *Salix viminalis* L. crops; energy crops; segetal flora; dynamic of flora; age of plantation; biodiversity; willow plantation; invasive species; medicinal species; melliferous species

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1. Introduction

Climate change caused by increasing emissions of greenhouse gases into the atmosphere, the depletion of fossil fuel resources and the rising demand for energy [1,2] has led the world to take an interest in renewable energy sources [3,4]. Legal regulations coming into being oblige states to increase the proportion of energy derived from renewable sources [5–8]. According to Directive 2009/28/EC of the European Parliament and of the Council (of 23 April 2009 on the promotion of the use of energy from renewable sources, repealing Directives 2001/77/EC and 2003/30/EC), by 2020, the share of energy from renewable sources (RES) in Poland should be 15% of total energy consumption. In 2018, this share was 11.3% of gross final energy consumption and was 73% of the expected share of RES [9].

One of the sources of renewable energy is biomass obtained from energy plants such as shrubs and trees that grow quickly after cutting, e.g., poplar (*Populus* sp.), willow (*Salix viminalis* L.) and black locust (*Robinia pseudoacacia* L.); perennial forbs, e.g., Virginia mallow *Sida hermaphrodita* (L.) Rusby; and perennial grasses, e.g., *Miscanthus sp*. From these plants, in the northern and central parts of Europe, including Poland, the main energy crop is willow [10]. Poland's willow plantations were established mainly after

2000, and at present, willow is cultivated in Poland on about 8700 ha [11], including about 230 ha in Łódź Province ([12]; authors' estimations). Plantations of *Salix viminalis* L. are established on various soils, especially poor, light (class IV–VI) arable land, including fallow lands, which can be managed in this way [13,14]. These plantations are located in field depressions, among arable land; they are bordered by small rivers, forests and grasslands, thus enriching the agricultural landscape and becoming an important element of the environment for numerous fauna and flora [15–17]. Moreover, the cultivation of *Salix viminalis* L. for energy purposes is one of the activities contributing to stopping climate change (carbon sequestration) [18,19]

The flora of the energy willow plantation includes different groups of plants: meadow, woodland, shrub, ruderal and segetal species, as well as shrubs and tree seedlings. Segetal plants, which are the subject of this work, are plants mainly associated with arable land, especially with cereal crops and root crops. Their occurrence is influenced by a number of factors: climatic, geo-environmental, soil and anthropogenic [20–22]. The introduction of new cultivars of crops; the use of seed material well cleared of diaspora weeds; and improvements in tillage technology, herbicides and mineral fertilizers, as well as changes in the structure of sown crops and the simplification of crop rotation, all define the structure of segetal flora [23–27]. Its biodiversity decreases with the intensification of agricultural production and the emergence of monocultural, large-area crops, and as research findings show, many species have already disappeared irretrievably [28]. On *Salix viminalis* L. plantations, segetal plants have different conditions for their development than in typical fields due to the different technology for cultivating this species. The long period of time (2–3 years) between successive willow harvests often has an effect on the limited light conditions, and also on the thermal and humidity conditions, which prevents the plant community from stabilizing [29]. Moreover, the flora of willow plantations grown for energy purposes depends on factors such as crop age and soil conditions [30,31], as well as the land use before the plantation was established [30,32].

Although *Salix* sp. has been cultivated in Poland for many years, to date, segetal plants occurring on willow plantations have only been dealt with sporadically. The vegetation accompanying willow was usually assessed in the first years of cultivation and presented as a whole [33–35]. The flora of older *Salix viminalis* L. plantations is particularly poorly researched. Knowledge of segetal plants present on willow plantations is important for maintaining the biodiversity of native flora in agroecosystems [27]. Moreover, they are an important element of agrobiocenoses, as many are valuable medicinal and melliferous species [36,37]. The aims of this study were as follows: (1) to determine and analyse, in a broad sense, the species composition of segetal flora on plantations of *Salix viminalis* L. in central Poland, depending on the land use before establishing plantations (arable land and fallow land); (2) to assess the formation of segetal flora depending on the age of *Salix viminalis* L. plantations; (3) to analyse the flora accompanying energy willow crops and the choice of factors that are important for biodiversity plant species: invasive, medicinal, poisonous and melliferous.

2. Materials and Methods

2.1. Study Area and Characteristics of the Plantations

The study area is located in Łódź Province in the central part of Poland. It is, like most of the Łódź region, situated on a plain area. The study was carried out on eight commercial *Salix viminalis* L. plantations, in five localities: Dmosin (1 plantation: N 51.542775; E 19.451714; altitude: 157 m a.s.l. (above sea level)), Okołowice (1 plantation: N 51.431806; E 19.193768; altitude: 180 m a.s.l.), Piwaki (2 plantations: N 51.124068; E 19.453671; altitude: 224 m a.s.l. and N 51.131197; E 19.461013; altitude: 222 m a.s.l.), Podole (2 plantations: N 51.532193; E 19.30404; altitude: 166 m a.s.l. and N 51.533847; E 19.303854; altitude: 162 m. a.s.l.), Świątniki (2 plantations: N 51.425982; E 19.191872; altitude: 188 m a.s.l. and N 51.424868; E 19.194597; altitude: 183 m a.s.l.) (Figure 1). In total, the study was carried out in approx. 60% of all the localities of Łódź Province, where energy willow plantations, established on former arable (land under temporary crops) and fallow (arable land temporarily, for at least two growing seasons, excluded from agricultural production) lands, were located.

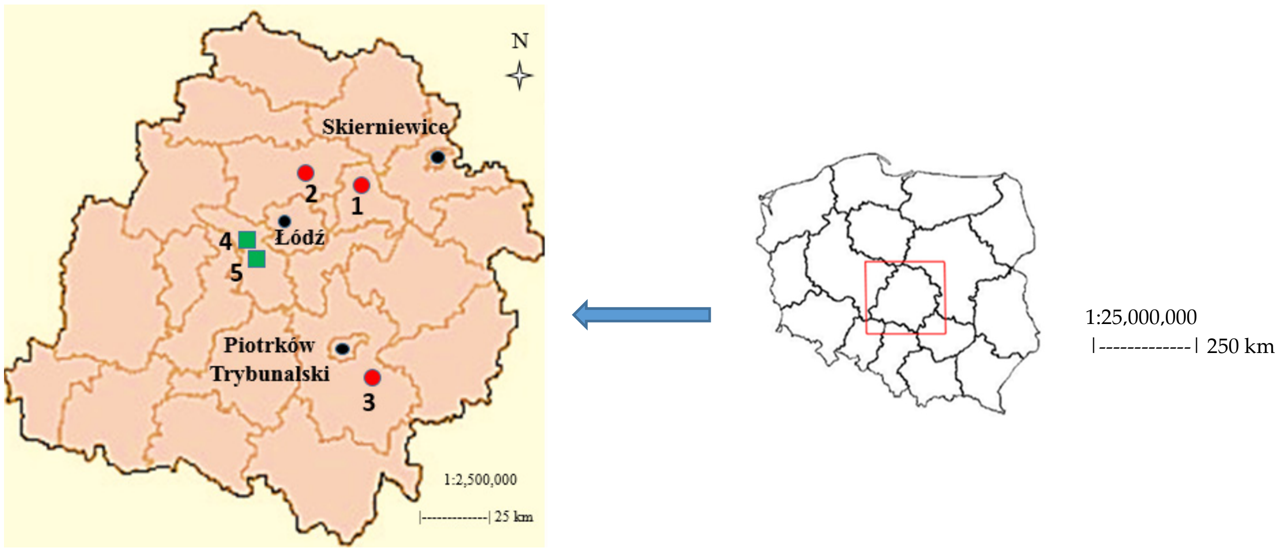

Figure 1. Location of the study area in Poland and Łódź Province. Explanations: ● Plantations established on former arable lands (AR): 1—Dmosin; 2—Podole; 3—Piwaki. ■ Plantations established on former fallow lands (FA): 4—Okołowice; 5—Świątniki.

The energy willow plantations that were studied differed in terms of age and the type of land use before their establishment. Five plantations were established on former arable lands (in 2004–2005) and three, on former fallow lands (in 2006–2008) (Figure 1). Plantations established on former arable land are hereinafter abbreviated as AR, and plantations established on former fallow land, as FA. Before the establishment of the *Salix viminalis* L. plantations (AR and FA), cereals (rye and oats) were mainly cultivated and an extensive farming system was used. One-year sprouts, at a density of 26,000 sprouts per ha, were planted on each plantation. Before planting the sprouts, the lands were ploughed and harrowed. The AR plantations were located among arable land, whereas the FA plantations were located among arable land and mixed forests. In subsequent years, all the plantations were managed in a similar manner. During the study period, they were not fertilized and no pesticides were used. There were also no treatments such as ploughing or mowing. Willow was harvested every 2–3 years in the same years on all the plantations.

The study was carried out between 2011 and 2015 and in 2018 on the same plantations in the subsequent years of research (Table 1). The species composition of the segetal flora depending on the land use before establishing the plantation was analysed on the basis of an assessment of AR plantations in 2011–2012 and 2013–2014 (6–7 years old and 9–10 years old, respectively) and FA plantations in 2014–2015 (6–7 years old) and 2018 (10 years old). The different study periods in the FA plantations (6–7 and 9–10 years old) compared to the AR, which was due to the later year of their establishment, did not affect the results (the number of species or coverage), because the vegetation developed in similar weather conditions (Table 2). Only 2013 was characterized by a higher sum of precipitation, although only single relevés (three) were included from this year.

Table 1. Number of phytosociological relevés carried out in individual localities of energy willow plantations.

Year of the Study	Age of Plantations	Type of Plantations/Locality				
		Plantations established on former arable lands (AR)				
		Dmosin	Podole 1	Podole 2	Piwaki 1	Piwaki 2
2011–2012	6–7 years old	6	1	1	1	1
2013–2014	9–10 years old	5	2	1	1	1
		Plantations established on former fallow land (FA)				
		Okołowice	Świątniki 1	Świątniki 2		
2011–2012	3–4 years old	5	2	3		
2013	5 years old	5	3	2		
2014–2015	6–7 years old	6	3	1		
2018	9–10 years old	6	3	1		

Table 2. Weather conditions in the growing seasons in the years 2011–2015 and 2018 (Meteorological Station in Bratoszewice).

Year Month	Average Monthly Air Temperature (°C)						
	2011	**2012**	**2013**	**2014**	**2015**	**2018**	**1971–2000**
IV	10.5	9.2	7.3	10.2	8.1	13.2	7.7
V	13.7	14.8	14.2	13.3	12.9	16.5	13.4
VI	17.9	16.5	17.6	15.7	16.4	18.3	16.1
VII	17.7	19.9	19.4	20.6	19.5	20.2	17.7
VIII	18.6	18.7	18.7	17.6	22.1	20.5	17.6
IX	15.0	14.3	11.7	14.6	14.6	15.3	13.0
X	8.9	8.2	9.8	9.9	7.3	9.9	8.2
IV-X	14.6	14.5	14.1	14.5	14.4	16.2	13.3
	Sums of Monthly Precipitation (mm)						
Month	**2011**	**2012**	**2013**	**2014**	**2015**	**2018**	**1971–2000**
IV	22.3	54.2	48.8	43.3	32.8	34.7	36.0
V	46.1	21.4	112.0	106.3	37.2	44.2	51.0
VI	58.8	70.9	131.4	61.2	29.7	24.7	68.0
VII	165.2	117.6	68.4	50.4	70.9	146.6	88.0
VIII	92.4	41.1	78.2	84.9	17.9	83.9	61.0
IX	6.5	58.1	89.8	31.9	61.1	29.4	51.0
X	23.1	36.7	25.1	24.4	52.6	58.2	40.0
IV-X	414.4	400.0	553.7	402.4	302.2	421.7	395.0

The dynamics of segetal flora were analysed on FA plantations starting in 2011 (3–4 years old) for 7 consecutive years (2011–2018). The paper presents the results of flora from these plantations when they were 3–4 years old, 5 years old, 6–7 years old and 9–10 years old.

2.2. Soil Conditions

All the *Salix viminalis* L. plantations were located on soils that, according to Polish Soil Classification 2019 [38] and WRB Classification 2015 [39], were categorised as Cambisols. According to "Particle size distribution and textural classes of soils and mineral material-Classification of Polish Society of Soil Science 2008" [40], these soils were sand (FA) and loamy sand (AR). The soils had a very acid reaction (pH $_{KCl}$ 4.1–4.4), with a medium to high phosphorous content (53.1–81.9 mg·kg^{-1} soil), but were very poor and poor in their potassium (30.7–63.0 mg·kg^{-1} soil) and magnesium (11.0–17.0 mg·kg^{-1} soil) concentrations. The content of organic matter ranged from 1.97 to 2.28%.

The soils on which the AR plantations were located belonged to the soil agricultural complexes 5 and 6, whereas the soils, on which the FA plantations were located were classified into complexes 6 and 7. Soil agriculture complex 5 (soils suitable for rye) includes soils slightly sensitive to droughts. This is underlying loam material that reduces the permeability and retains the water supply in the soil, thus providing favourable conditions for plants. Soil agriculture complex 6 (soils less suitable for rye) includes soils often too dry. On complex 6 soils, plants only provide satisfactory yields in wet years. Soil agriculture complex 7 (soils very bad for rye) includes very dry sandy soils.

The information about the soil type and soil agriculture complex is based on agricultural maps on a scale of 1:5000 obtained from the Voivodeship Geodesy Office in Łódź (Solna St. 14, 91–423 Łódź, Poland), the Łódź Voivodeship Geoportal [41] and Polish Soil Classification 2019 [38]. Soil samples were taken with an Egner–Riehm stick (up to a depth of 20 cm) in accordance with the methods for soil study material. Topsoil analysis was carried out at the Regional Chemistry–Agriculture Station in Łódź and Warsaw. The contents of available phosphorus and available potassium were determined according to the Egner–Riehm (DL) method in calcium lactate extract, and the magnesium content was determined according to the Schatschabel method in calcium chloride extract. In addition, the soil pH in KCl and the content of organic matter according to the Tiurin method were identified. The soil texture according to research procedure (PB 40 ed. 3, 14.02.2011) was also identified.

2.3. Weather Conditions

The weather conditions during the study period were determined based on the dates recorded at the Meteorological Station of the Institute of Soil Science and Plant Cultivation, located in Bratoszewice, near Łódź. The long-term data were recorded for Łódź. The sum of precipitation in the vegetation period in the years 2011, 2012, 2014 and 2018 was similar and was 400.0–421.7 mm (Table 2). However, in 2013, it was about 40% higher than the long-term mean, and in 2015, it was about 24% lower than the long-term mean (Table 1). The greatest sum of precipitation was noted in May and June of that year (2015). The mean air temperatures between April and October in 2011–2015 were similar to each other (14.1–14.6 °C) and about 0.8–1.3 °C higher than the long-term mean. In 2018, the temperature was about 2.9 °C higher than the long-term mean. Detailed data regarding the average monthly air temperatures and the sums of monthly precipitation are shown in Table 2.

2.4. Methods

The vegetation accompanying willow (*Salix viminalis* L.) energy crops was identified based on an analysis of 60 phytosociological relevés (descriptions of vegetation patches—phytocenoses), i.e., ten relevés carried out in each group of plantations mentioned above. The number of phytosociological relevés carried out on an individual plantation depended on its area and soil diversity; i.e., if the plantation was located on two different soil complexes, separate relevés were taken on each of them. Details of the number of relevés taken on individual plantation is presented in Table 1. Each relevé had an area of 100 m^2, was roughly square-shaped, and was made using the Braun-Blanquet [42] method. This method simultaneously captures the number and degree of coverage of a given species in what is called a phytosociological relevé. When producing such a relevé, the first stage involved selecting a uniform, typical patch of vegetation, i.e., one without any unusual places, e.g., hills and hollows. In turn, a list was made of all the species that were present in the area, and the coverage of a given plant species was estimated (plant image on the surface) using the Braun-Blanquet scale (1–5, +, r); the meaning of individual symbols is presented in Table 3 [43,44]. The research was mainly carried out in June and July each year.

Table 3. Quantitative scale of Braun-Blanquet coverings.

Symbol	Cover (%)
5	75–100
4	50–75
3	25–50
2	5–25
1	Less than 5 % of the test area
+	Rarely, with slight coverage
r	Very rarely, one or more specimens

Plant communities were distinguished by characteristic and differential species according to Matuszkiewicz [45], affiliated to phytosociological classes, and analysed in each group where they occurred. Subsequently, the number and proportions of species were determined. The proportion of each plant species was determined based on constancy class (S): V—80–100% of all phytosociological relevés; IV—60–80%; III—40–60%; II—20–40%; I—0.01–20%. The cover coefficient (D) was calculated according to the following formula: the sum of the average percentage of species cover that occurred in all the phytosociological relevés divided by the total number of phytosociological relevés and multiplied by 100 [43].

For each species, the following parameters were determined: family; geographical and historical groups; apophyte (i.e., synanthropic species of local origin) origin; biological stability; life-form; and status as an invasive, medicinal (herb), poisonous or melliferous species. The geographical and historical groups, apophyte origins, biological stability and life-form were mainly identified based on the following sources: Anioł-Kwiatkowska [46], Korniak [47], Mirek et al. [48], Rutkowski [49], Sowa and Warcholińska [50], Szafer et al. [51], Zając and Zając [52,53], and Zając [54]. Invasive species status was determined based on Tokarska-Guzik et al. [55]. Medicinal and poisonous plants were identified based on Rutkowski [49]. Melliferous plants were determined based on Sulborska [56]. Tree seedlings were not classified as melliferous plants. The Latin names of the vascular plants are in accordance with those presented by Mirek et al. [48], and the phytosociological classifications follow Matuszkiewicz [45].

2.5. Statistical Analysis

Canonical correspondence analysis (CCA, constrained ordination) was used to visualize the main differences in species composition occurring in the six groups of plantations (the age of the plantations and the type of land use before establishing the plantations) that were studied [57,58]. The relative species abundance was analysed by this method. The explanatory variable (categorical) was the phytosociological relevé's affiliation to one of the six groups. The significance of constraints (with plantation types treated as the dummy variables) was tested by means of the permutation test [59].

Cluster analysis based on the mean species coverage was conducted for each of the six plantation groups. The Euclidean measure and Ward method were used. The coverage of each species was averaged for each of the plantation types. This 2-dimensional table (plantation type by species) was analysed by cluster analysis. The similarities between the age influence and previous land use influence on the plant composition are shown in the dendrogram chart.

The species richness was calculated according to the first-order jackknife species richness estimator [60,61]. This statistic introduces a correction for species not recorded in the abundance table during the study.

These statistical analyses were conducted with the use of the R software [62]. The CCA analysis was performed by the "cca" function contained in the R "vegan" package. The cluster analysis was performed by the "dist" and "hclust" functions. The "specpool" function from the "vegan" package was used for the estimated species richness.

3. Results

The flora of all eight *Salix viminalis* L. plantations that were studied totalled 114 vascular plant species. A large proportion of them were segetal species, i.e., 43 species (38%). The characteristics of this group of plants on 6–7-year-old and on 9–10-year-old energy willow plantations established on former arable (AR) and fallow (FA) lands are presented below. Then, the dynamics of the segetal flora on 3–10-year-old willow plantations established on former fallow lands were analysed in terms of four age groups (3–4, 5, 6–7 and 9–10 years old). In turn, the invasive, medicinal, poisonous and melliferous species accompanying the *Salix viminalis* L. plantations were discussed.

3.1. Characteristics of the Segetal Flora Depending on the Land Use before Establishing Plantations

The flora of the *Salix viminalis* L. plantations (6–7-year-old and 9–10-year-old) established on former arable (AR) and fallow land (FA) had a total of 103 vascular plant species. The species richness estimated by the jackknife method for the 6–7-year-old and 9–10-year-old plantations established on the arable land (AR) was 87.1 and 82.1, respectively. That is, the estimated species number included missed species was a little higher for 6–7-year-old plantations. Among the observed species, 61 and 56 (for 6–7-year-old and 9–10-year-old plantations, respectively) segetal species, which occurred mainly in cereal and root crops, accounted for 37% (38 species) (Table 4). On the plantations, the species characteristics for cereal crops such as *Anthoxanthum aristatum* Boiss., *Matricaria maritima subsp. inodora* (L.) Dostál, *Vicia hirsuta* (L.) Gray, *Vicia tetrasperma* (L.) Schreb. and *Vicia villosa* Roth. were recorded, while the species characteristics were also recorded for root crops including *Chenopodium album* L. and *Sonchus arvensis* L. The segetal species belonged to 15 botanical families. The most numerous family was *Asteraceae* (eight species), *Fabaceae* (seven species) and *Poaceae* (five species) (Table 4).

The study shows that more segetal species were on the AR plantations than on the FA (Table 4). On 6–7-year-old AR plantations, their number was 30% higher than on the FA, but on 9–10-year-old plantations, the difference was greater (41%) (Table 4). In both groups of 6–7-year-old plantations (AR and FA), the same 12 species were recorded, i.e., 32% of the segetal flora, and on older plantations (9–10 years old), eight species (21% of the segetal flora) were the same. These were mostly perennial plants, mainly reproducing vegetatively through rhizomes or stolons, such as *Achillea millefolium* L. s.str., *Artemisia vulgaris* L., *Cirsium arvense* (L.) *Scop*., *Convolvulus arvensis* L., *Elymus repens* (L.), *Rumex acetosella* L., and two short-lived (1–2 years) species, i.e., *Trifolium arvense* (L.) and invasive species *Conyza canadensis* (L.) Cronquist, characterised by high seed production. The remaining species occurred differently on both types of plantations (Table 4).

In line with the age of the plantations, the number of segetal plants decreased in both groups of plantations—on the AR, from 27 to 22, and on the FA, from 19 to 13 species. Only in younger plantations (6–7 years old) were there species such as *Anthoxanthum aristatum* Boiss., *Galeopsis bifida* Boenn., *Matricaria maritima subsp. inodora* (L.) Dostál, *Medicago lupulina* L., *Setaria pumila* (Poir.), *Vicia tetrasperma* (L.) and *Vicia villosa* Roth. They were mainly short-lived, photophilous species. On plantations established on former arable land, 37% of the species disappeared, while nearly half (47%) disappeared on formerly fallow land. They were replaced with new species (found only on older 9–10-year-old plantations), which constituted 23% of each group of plantations (Table 4). They were also mainly short-lived species reproducing from seeds, e.g., *Polygonum hydropiper* L., *Sonchus asper* L. and *Veronica arvensis* L. on AR and *Thlaspi arvense* L. and *Chenopodium album* L. on FA.

In the segetal flora, regardless of the type of land use before establishing the energy willow plantations, species of native origin (apophytes) dominated. With older plantations, the proportion of native species increased and that of anthropophytes decreased; this was more visible on the FA plantations (Figure 2).

Table 4. Constancy classes, botanical families, phytosociological classes, life-forms, and geographical and historical groups of segetal species occurring on 6–7-year-old and 9–10-year-old *Salix viminalis* L. plantations established on former arable land and fallow.

Species	Arable Land		Fallow		Botanical Family	Phytosociological Class	Life-Form	Geographical and Historical Group
	Plantation Age in Years							
	6–7	9–10	6–7	9–10				
Elymus repens (L.) Gould	V	IV	I	II	*Poaceae*	Agr int-rep	G	Anw
Artemisia vulgaris L.	IV	II	IV	II	*Asteraceae*	Artemi	C	Al
Cirsium arvense (L.) Scop	IV	II	I	I	*Asteraceae*	Artemi	G	Al
Achillea millefolium L.s. str.	III	III	IV	IV	*Asteraceae*	Moll-Arr	H	Ał
Conyza canadensis (L.) Cronquist	III	I	II	II	*Asteraceae*	Stel med	T	An
Poa annua L.	III	I			*Poaceae*	Artemi	T	Ał
Vicia hirsuta (L.) Gray	II	III	III		*Fabaceae*	Stel med	T	An
Digitaria ischaemum (Schreb.) H.L. Mühl.	II	I			*Poaceae*	Stel med	T	An
Equisetum arvense L.	II	I			*Equisetaceae*	Agr int-rep	G	Ał
Convolvulus arvensis L.	II	I	I	I	*Convolvulaceae*	Agr int-rep	H	Amk
Matricaria maritima subsp.inodora (L.) Dostál	II				*Asteraceae*	Stel med	T	An
Galeopsis tetrahit L.	I	II			*Lamiaceae*	Stel med	T	Al
Rumex acetosella L.	I	I	III	II	*Polygonaceae*	Stel med	G	Ap
Chenopodium album L.	I			I	*Chenopodiaceae*	Stel med	T	Anw
Galeopsis bifida Boenn.	I		I		*Lamiaceae*	t	T	Al
Galium aparine L.	I	I			*Rubiaceae*	Artemi	T	Al
Medicago lupulina L.	I				*Fabaceae*	t	T	Amk
Melandrium album (Mill.) Garcke	I	I			*Caryophyllaceae*	Artemi	T	Ał
Myosotis arvensis (L.) Hill	I	I			*Boraginaceae*	Stel med	T	An
Plantago major L.	I				*Plataginaceae*	Moll-Arr	H	Al
Setaria pumila (Poir.) Roem. and Schult.	I		I		*Poaceae*	Stel med	T	An
Sonchus oleraceus L.	I				*Asteraceae*	Stel med	T	An
Stachys palustris L.	I				*Lamiaceae*	Moll-Arr	G	Ał
Stellaria media (L.) Vill.	I	I			*Caryophyllaceae*	Stel med	T	Ał
Trifolium arvense L.	I	I	II	I	*Fabaceae*	Koele-Coryne	T	Ap
Vicia angustifolia L.	I			I	*Fabaceae*	Stel med	T	An
Vicia cracca L.	I		I	I	*Fabaceae*	Moll-Arr	H	Ał
Anthoxanthum aristatum Boiss.			I		*Poaceae*	Stel med	T	An
Cardaminopsis arenosa (L.) Hayek			II	I	*Brassicaceae*	t	H	Ap
Cerastium holosteoides Fr. emend. Hyl.		I			*Caryophyllaceae*	Moll-Arr	T	Ał
Polygonum hydropiper L.		I	II		*Polygonaceae*	Bident	T	Anw

Table 4. *Cont.*

Species	Arable Land		Fallow		Botanical Family	Phytosociological Class	Life-Form	Geographical and Historical Group
	Plantation Age in Years							
	6–7	9–10	6–7	9–10				
Sonchus arvensis L.		I	I		*Asteraceae*	Stel med	H	Anw
Sonchus asper (L.) Hill		I			*Asteraceae*	Stel med	T	An
Thlaspi arvense L.				I	*Brassicaceae*	Stel med	T	An
Veronica arvensis L.		I	I		*Scrophulariaceae*	t	T	An
Vicia tetrasperma (L.) Schreb.			I		*Fabaceae*	Stel med	T	An
Vicia villosa Roth			I		*Fabaceae*	Stel med	T	An
Viola arvensis Murray			II		*Violaceae*	Stel med	T	An
Number of species	27	22	19	13	-	-		

Explanations: I–V constancy classes, empty space—species did not occur. Phytosociological classes: Agr int-rep—Agropyretea intermedio-repentis; Artemi—Artemisietea vulgaris; Bident—Bidentetea tripartiti; Koele-Coryne—Koelerio glaucae-Corynephoretea canescentis; Moll-Arr—Molinio-Arrhenatheretea; Stel med- Stellarietea mediae; t—Sporadic species. Life-forms according to Raunkiaer: C—herbaceous chamaephyte; G—geophyte; H—hemicryptophyte; T—terophyte. Geographical and historical groups: Al—woody-shrub apophyte; Ał—meadow apophyte; Amk— xerothermic apophyte; Anw—waterside and wetside apophyte; Ap—sandyside apophyte; An—antropophyte.

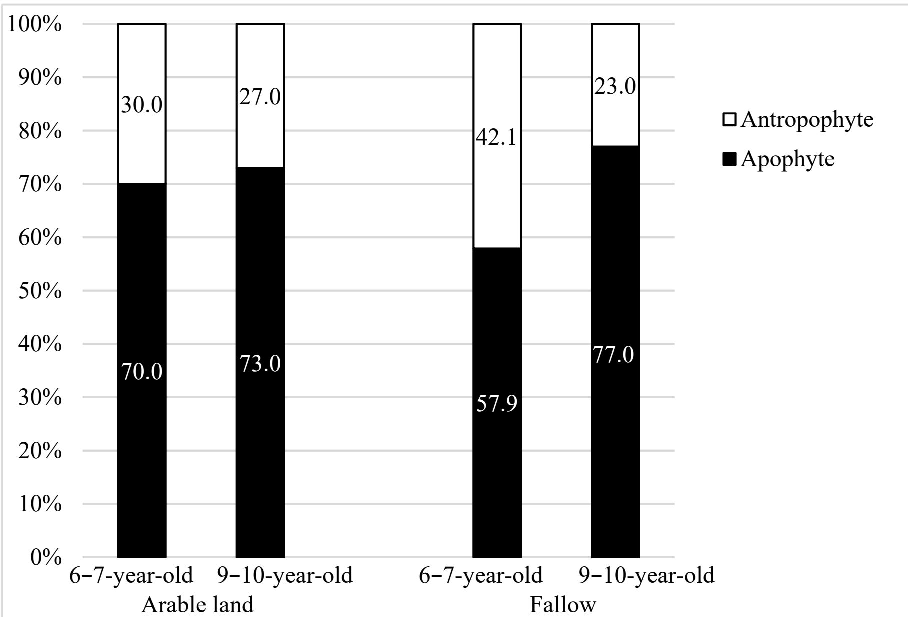

Figure 2. The origin of segetal species (%) occurring on 6–7-year-old and 9–10-year-old *Salix viminalis* L. plantations established on former arable land and fallow.

Woody-shrub apophytes (native species of natural forest and shrub community origin, well-established in anthropogenic habitats) dominated in the structure of the agrophytocenoses in both types of plantation. On AR, their share was slightly higher than on FA (Figure 3). Besides woodland-shrub apophytes, meadow apophytes make up a high proportion on AR plantations, and sandyside apophytes (native species of sandy habitat, where soils are light, dry, low in nutrients and often acidic) constitute a high proportion on FA plantations. Among these, the following have the highest coverage: *Achillea millefolium* L. s.str and *Artemisia vulgaris* L. (Table 5).

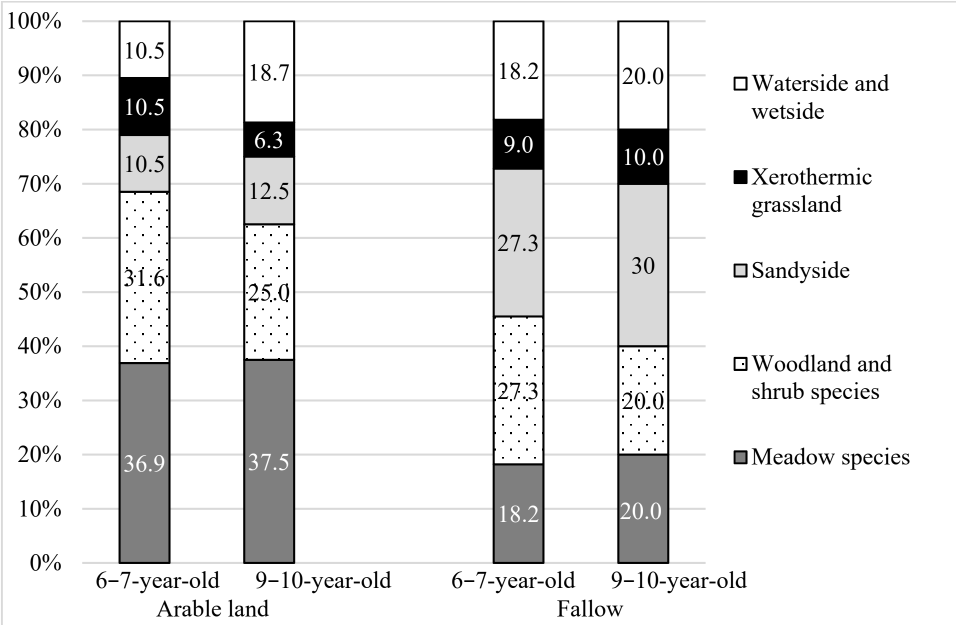

Figure 3. The origin of segetal apophytes (%) occurring on 6–7-year-old and 9–10-year-old *Salix viminalis* L. plantations established on former arable land and fallow.

Table 5. Constancy classes (S) and cover coefficient (D) of segetal species, which occurred with the highest constancy classes in all groups of *Salix viminalis* L. plantations established on fallow and arable land.

Species	Fallow								Arable Land			
	Plantation Age in Years											
	3–4		5		6–7		9–10		6–7		9–10	
	S	D	S	D	S	D	S	D	S	D	S	D
Rumex acetosella L.	IV	204	III	153	III	202	II	102	I	50	I	50
Artemisia vulgaris L.	III	152	III	54	IV	253	II	4	IV	203	II	151
Elymus repens (L.) Gould	IV	650	IV	725	I	425	II	325	V	2451	IV	1750
Achillea millefolium L. s. str.	IV	551	V	780	IV	650	IV	725	III	201	III	277
Vicia hirsuta L. (Gray)	II	3	IV	204	III	250	0	0	II	276	III	54
Viola arvensis Murray	II	4	III	5	II	151	0	0	0	0	0	0
Convolvulus arvensis L.	II	53	IV	55	I	51	I	1	II	101	I	50
Trifolium arvense L.	II	101	III	327	II	151	I	2	I	175	I	50
Conyza canadensis (L.) Cronquist	I	2	I	3	II	52	II	150	III	152	I	100
Cirsium arvense (L.) Scop	I	50	0	0	I	1	I	50	IV	203	II	150
Poa annua L.	0	0	0	0	0	0	0	0	III	152	I	175

The study shows considerable diversity in the flora in terms of the share of life forms and biological stability. Regardless of the type of former land use, before the establishment of willow plantations, therophytes dominated in the communities (Figure 4). However, on AR, their proportion was higher than on FA, especially on older plantations (9–10 years old) by approx. 35% (i.e., by nine species). Taking into account the biological stability of plants, on AR plantations, over 63% of the species were short-lived species (Figure 5), whereas on the FA ones, the proportion of short-lived species was lower, especially on older plantations. The shading of the soil caused by the willow plants and the lack of arable land use (ploughing) meant that perennial plants dominated in line with the age, and on 9–10-year-old FA, these plants constituted approx. 54% of plants. On AR plantations, the proportion of perennial plants was at a similar level.

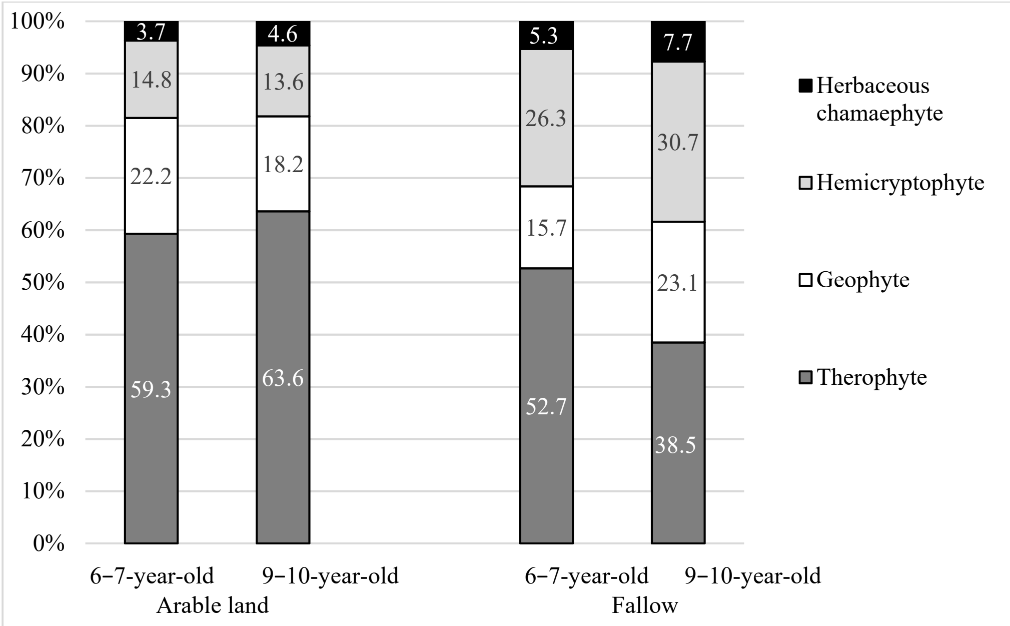

Figure 4. Raunkier life-forms (%) of segetal species occurring on 6–7-year-old and 9–10-year-old *Salix viminalis* L. plantations established on former arable land and fallow.

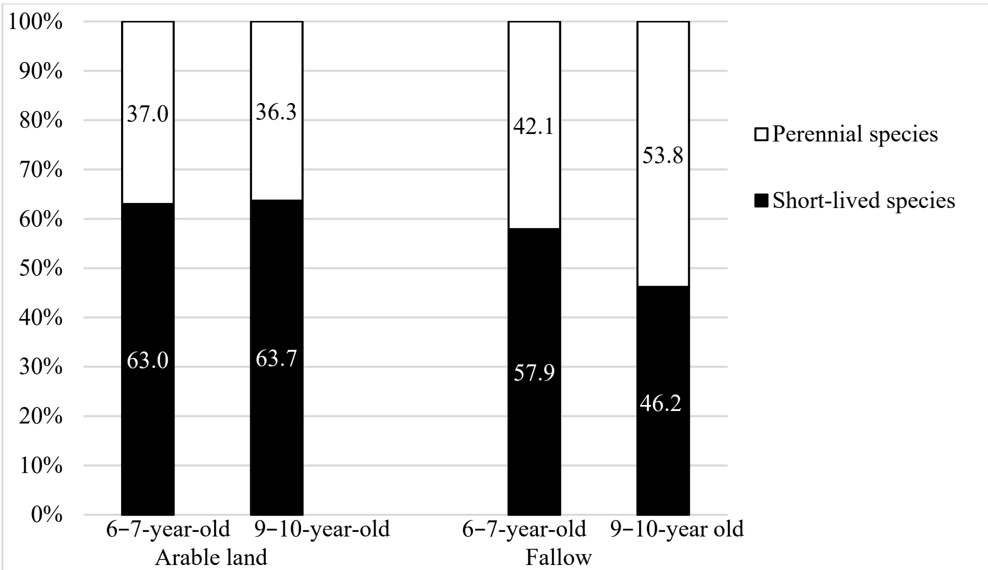

Figure 5. Biological stability (%) of segetal species occurring on 6–7-year-old and 9–10-year-old *Salix viminalis* L. plantations established on former arable land and fallow.

The vast majority of the segetal plants on both types of plantations belonged to the *Stellarietea mediae* class, which is characteristic of arable land (with an average of about 43%) (Table 4). Species from the *Artemisietea vulgaris* class characteristic of nitrophilous communities, perennials and climbers found in ruderal habitats were noted more often on AR plantations than on FA (Figure 6). The next groups, in order, were species from the *Molinio-Arrhenatheretea* class, characteristic of semi-natural and anthropogenic meadow communities, and species from the *Agropyretea intermedio-repentis* class, characteristic of rhizome and stolon plants. Moreover, the willow plantations were accompanied by several species from other classes: *Bidentetea tripartiti*; *Koelerio glauce—Corynephoretea canescentis;* and species not classified as being in any of the phytosociological classes but enriching the floristic composition of communities (Figure 6).

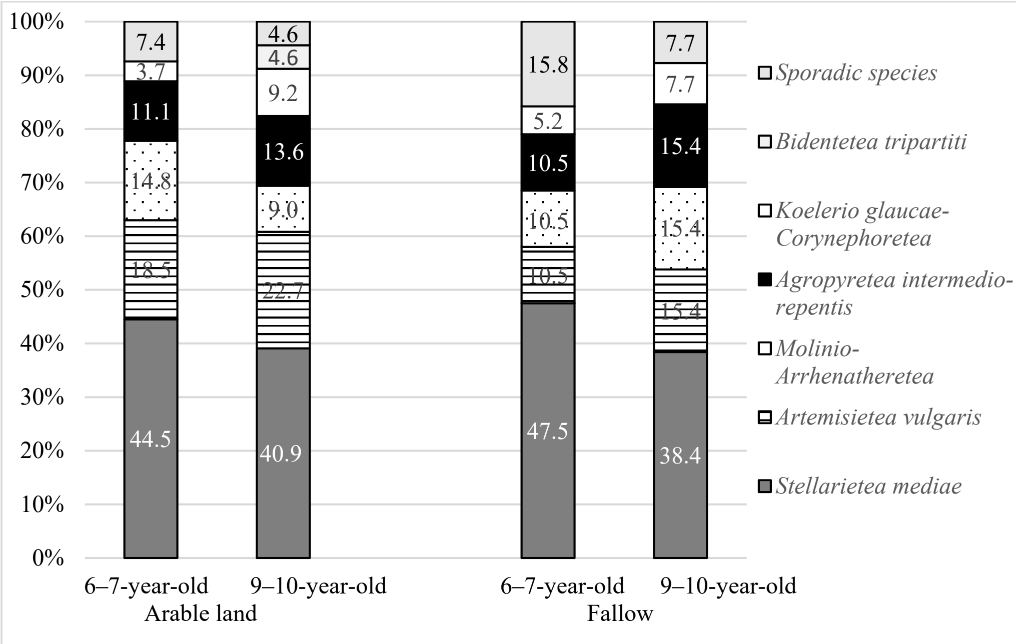

Figure 6. Phytosociological classes (%) of segetal species occurring on 6–7-year-old and 9–10-year-old *Salix viminalis* L. plantations established on former arable land and fallow.

The species from the *Agropyretea intermedio-repentis* class had the highest share of soil coverage on AR plantations, among which *Elymus repens* (L.) Gould played an important role. On the other hand, on FA, the highest share was of species from the *Molinio-Arrhenatheretea* and *Stellarietea mediae* classes, the coverage of which was mainly determined by *Achillea millefolium* L. s. str. and *Rumex acetosella* L. (Tables 5 and 6). Species from the *Stellarietea mediae* class, despite making up a considerable proportion, were characterised by a low cover coefficient. Among the species from this class, *Rumex acetosella* L. occurred more frequently and with greater coverage on FA plantations, and *Vicia hirsuta* (L.) Gray and *Conyza canadensis* (L.) Cronquist. occurred more frequently on AR plantations (Table 5).

Table 6. Cover coefficients (D) of phytosociological classes and their shares (%) in phytosociological classes on *Salix viminalis* L. plantations established on fallow and arable land.

Class	Fallow						Arable Land					
	Plantation Age in Years											
	6–7		9–10		Total (6–10)		6–7		9–10		Total (6–10)	
	D	% D	D	% D	D	% D	D	% D	D	% D	D	% D
Stellarietea mediae	857	32.4	255	18.7	1112	27.8	692	16.0	457	13.3	1149	14.8
Artemisietea vulgaris	254	9.6	54	4	308	7.7	712	16.5	626	18.2	1338	17.2
Molinio-Arrhenatheretea	751	28.4	727	53.3	1478	36.9	254	5.8	278	8	532	6.8
Agropyretea intermedio-repentis	476	18	326	23.9	802	20	2503	57.7	1801	52.4	4304	55.4
Koelerio glaucae-Corynephoretea canescentis	151	5.8	2	0.1	153	3.8	175	4	50	1.5	225	2.9
Bidentetea tripartiti	0	0	0	0	0	0	0	0	50	1.5	50	0.6
Sporadic species	153	5.8	1	0	154	3.8	2	0	176	5.1	178	2.3
Total	2642	100	1365	100	4007	100	4338	100	3438	100	7776	100

An analysis of the constancy classes and the cover coefficients showed that most of the segetal species in both types of plantations were in the I and II constancy classes. Only 25% of species on FA and 28% on AR were in higher constancy classes, i.e., III, IV and V (Table 4). It was found that segetal species achieved much higher cover coefficients on AR plantations (D = 7776) compared to FA (D = 4007) (Table 5).

The species that were in higher constancy classes and had cover coefficients above 600 were perennial plants that produced numerous rhizomes and stolons: *Achillea millefolium* L. s.str. on FA (sum of D = 1375) and *Elymus repens* (L.) Gould on AR (sum of D = 4201). In accordance with the ages of the plantations, all the species except *Achillea millefolium* L. s.str. were lowered in their constancy classes and cover coefficients. Due to the many years of willow cultivation, some species of the *Stellarietea mediae* class, usually accompanying cultivation on arable land, did not occur on 9–10-year-old plantations, e.g., *Matricaria maritima subsp. inodora* (L.) Dostál, *Setaria pumilla* (Poir.) Roem and Schult., and *Vicia tetrasperma* (L.) Schreb. (Table 3). The coverage with species from this class decreased in both types of plantation (Table 4).

3.2. Changes in the Segetal Flora on Salix viminalis L. Plantations Established on Fallow, Depending on the Age of the Plantation

With the aim of determining changes in the species composition of the segetal flora accompanying the willow with time, the flora of *Salix viminalis* L. plantations of different ages, i.e., 3–10 years old, and established on fallow land were analysed. The species richnesses estimated by the jackknife method were 66.3, 72.9, 73.6 and 64.0 for 3–4-, 5-, 6–7- and 9–10-year-old plantations, respectively. A total of 91 vascular plants species were recorded on these plantations, including 34 segetal species, which accounted for 37% of the total flora. The species belonged to six phytosociological classes and 14 botanical families. The most numerous were *Asteraceae* (six species), *Fabaceae* (six species) and *Poaceae* (five species). The remaining families consisted of 1–3 species (Table 7). On the youngest (3–5 years old) willow plantations, the proportion of segetal species was the highest (approx. 40.0%) and decreased with the age of the plantation; on 6–7-year-old plantations, it constituted 34.5%, and on 9–10-year-old ones, 27.6%. The species that were not confirmed in the flora of the 9–10-year-old plantations were short-lived anthropophytes: *Vicia hirsuta* (L.) Gray, *Vicia villosa* Roth, and *Viola arvensis* Murray.

Table 7. Segetal species that occurred on 3–10-year-old *Salix viminalis* L. plantations established on fallow, and their affiliations to botanical families and phytosociological classes.

Name of Species	Plantation Age in Years				Family	Phytosociological Classes
	3–4	5	6–7	9–10		
Achillea millefolium L. s.str.	+	+	+	+	*Asteraceae*	*Molinio-Arrhenatheretea*
Anchusa arvensis (L.) M. Bieb.		+			*Boraginaceae*	*Stellarietea mediae*
Anthoxanthum aristatum Boiss.			+		*Poaceae*	*Stellarietea mediae*
Apera spica-venti (L.) P. Beauv.		+			*Poaceae*	*Stellarietea mediae*
Arenaria serpyllifolia L.		+			*Caryophyllaceae*	*Sporadic species*
Artemisia vulgaris L.	+	+	+	+	*Asteraceae*	*Artemisieta vulgaris*
Cardaminopsis arenosa (L.) Hayek			+	+	*Brassicaceae*	*Sporadic species*
Chenopodium album L.		+		+	*Chenopodiaceae*	*Stellarietea mediae*
Chenopodium polyspermum L.	+				*Chenopodiaceae*	*Stellarietea mediae*
Cirsium arvense (L.) Scope	+		+	+	*Asteraceae*	*Artemisieta vulgaris*
Convolvulus arvensis L.	+	+	+	+	*Convolvulaceae*	*Agropyretea intermedio-repentis*
Conyza canadensis (L.) Cronquist	+	+	+	+	*Asteraceae*	*Stellarietea mediae*
Elymus repens (L.) Gould	+	+	+	+	*Poaceae*	*Agropyretea intermedio-repentis*
Equisetum arvense L.	+	+			*Equisetaceae*	*Agropyretea intermedio-repentis*
Galeopsis bifida Boenn.			+		*Lamiaceae*	*Sporadic species*
Galeopsis tetrahit L.		+			*Lamiaceae*	*Stellarietea mediae*
Galium aparine L.	+	+			*Rubiaceae*	*Artemisieta vulgaris*
Matricaria maritima subsp. inodora (L.) Dostál	+				*Asteraceae*	*Stellarietea mediae*
Melandrium album (Mill.) Gracke		+			*Caryophyllaceae*	*Artemisieta vulgaris*
Myosotis arvensis (L.) Hill	+	+			*Boraginaceae*	*Stellarietea mediae*
Rumex acetosella L.	+	+	+	+	*Polygonaceae*	*Stellarietea mediae*
Setaria pumila (Poir.) Roem & Schult.	+		+		*Poaceae*	*Stellarietea mediae*
Setaria viridis (L.) P. Beauv.	+	+			*Poaceae*	*Stellarietea mediae*
Sonchus arvensis L.			+		*Asteraceae*	*Stellarietea mediae*

Table 7. *Cont.*

Name of Species	Plantation Age in Years				Family	Phytosociological Classes
	3–4	5	6–7	9–10		
Stachys palustris L.	+				*Lamiaceae*	*Molinio-Arrhenatheretea*
Thlaspi arvense L.				+	*Brassicaceae*	*Stellarietea mediae*
Trifolium arvense L.	+	+	+	+	*Fabaceae*	*Koelerio glauce-Corynephoretea*
Veronica arvensis L.			+		*Scrophulariaceae*	*Sporadic species*
Vicia angustifolia L.	+	+		+	*Fabaceae*	*Stellarietea mediae*
Vicia cracca L.	+	+	+	+	*Fabaceae*	*Molinio-Arrhenatheretea*
Vicia hirsuta (L.) Gray	+	+	+		*Fabaceae*	*Stellarietea mediae*
Vicia tetrasperma (L.) Schreb.			+		*Fabaceae*	*Stellarietea mediae*
Vicia villosa Roth	+	+	+		*Fabaceae*	*Stellarietea mediae*
Viola arvensis Murray	+	+	+		*Violaceae*	*Stellarietea mediae*
Number of species	21	22	19	13		

+ means the species was present; empty space—species did not occur.

The species that occurred in all the age groups of the plantations studied were *Achillea millefolium* L. s.str., *Artemisia vulgaris* L., *Convolvulus arvensis* L., *Elymus repens* (L.), *Rumex acetosella* L., *Trifolium arvense* (L.), *Vicia cracca* and the invasive species *Conyza canadensis* (L.) Cronquist. Among these, four occurred in higher constancy classes (IV and III) (Table 5): *Achillea millefolium* L. s.str, *Artemisia vulgaris* L., *Elymus repens* (L.) and *Rumex acetosella* L.

On all the willow plantations, native species predominated over foreign species. Their share increased with the age of the plantations and ranged from 57% on 3–4-year-old plantations to 77% on 9–10-year-old ones (Table 8, Figure 2). Among the apophytes on 3–4-year-old plantations, species of meadow origin (33.3%) and woodland-shrub origin (25%) predominated. On 9–10-year-old plantations, their share decreased and amounted to 20% of each plantation (Table 8, Figure 3).

Table 8. Characteristics of segetal flora occurring on different age (3–4-, 5-, 6–7- and 9–10-year-old) *Salix viminalis* L. plantations established on fallow.

Category	Plantation Age in Years							
	3–4		5		6–7		9–10	
	No.	%	No.	%	No.	%	No.	%
Geographical and Historical Groups								
Antropophytes	9	43	9	41	8	42.1	3	23
Apophytes	12	57	13	59	11	57.9	10	77
Apophyte origin								
Meadow species	4	33.3	4	30.8	2	18.2	2	20
Woodland and shrub species	3	25.0	3	23.0	3	27.3	2	20
Sandyside	2	16.7	2	15.4	3	27.3	3	30
Xerothermic grasslands	1	8.3	2	15.4	1	9.0	1	10
Waterside and wetside	2	16.7	2	15.4	2	18.2	2	20
Biological stability								
Perennial species	9	43	7	32	8	42.1	7	53.8
Short-lived species	12	57	15	68	11	57.9	6	46.2
Life-form								
Hemicryptophyte	3	14.3	3	13.6	5	26.3	4	30.7
Therophyte	12	57.1	15	68.2	10	52.7	5	38.5
Geophyte	5	23.8	3	13.6	3	15.7	3	23.1
Herbaceous chamaephyte	1	4.8	1	4.6	1	5.3	1	7.7

An analysis of the biological stability showed that on 3–7-year-old plantations, short-lived species dominated (60% on average), while on older 9–10-year-old plantations, perennial species did (53.8%). In the biological spectrum, therophytes dominated on the 3–5-year-old plantations (constituting, on average, about 62%). Their share decreased in line with the age of the plantations, and on 9–10-year-old plantations, it was 38.5%. On the other hand, the share of hemicryptophytes increased, on average, from 17 to 30.7% (Table 8, Figure 2).

In all the groups of plantations (from 3 to 10 years old), species from the *Stellarietea mediae* class made up the highest proportions, with the following classes next, in order: *Artemisieta vulgaris*, *Agropyretea intermedio-repentis* and *Molinio-Arrhenatheretea*. On 9–10-year-old plantations, the proportion of species from the *Stellarietea mediae* class decreased, and species from the classes *Artemisieta vulgaris*, *Molinio-Arrhenatheretea* and *Agropyretea intermedio-repentis* increased (Table 9).

Table 9. The share of phytosociological classes (%) and cover coefficients (D) and their shares (D%) on 3–4-year-old, 5-year-old, 6–7-year-old and 9–10-year-old *Salix viminalis* L. plantations established on fallow.

Class	Plantation Age in Years											
	3–4			5			6–7			9–10		
	%	D%	D	%	D%	D	%	D%	D	%	D%	D
Stellarietea mediae	52.4	14.2	274	54.6	19.6	475	47.5	32.4	857	38.4	18.7	255
Artemisietea vulgaris	14.3	13.2	256	13.6	2.3	56	10.5	9.6	254	15.4	4	54
Molinio-Arrhenatheretea	14.3	33.7	653	9	32.3	782	10.5	28.4	751	15.4	53.3	727
Agropyretea intermedio-repentis	14.3	33.7	651	13.6	32.3	781	10.5	18	476	15.4	23.9	326
Koelerio glaucae-Corynephoretea canescentis	4.7	5.2	101	4.6	13.5	327	5.2	5.8	151	7.7	0.1	2
Sporadic species	0	0	0	4.6	0	1	15.8	5.8	153	7.7	0	1
Total	100	100	1935	100	100	2422	100	100	2642	100	100	1365

Most of the segetal species were characterised by low constancy classes (I–II). Only eight species were in higher constancy classes (III–V): *Achillea millefolium* L. s.str., *Artemisia vulgaris* L., *Convolvulus arvensis* L., *Elymus repens* (L.), *Rumex acetosella* L., *Trifolium arvense* (L.), *Vicia hirsuta* and *Viola arvensis* (Table 5). In total, in all the study periods, the species from the *Molinio-Arrhenatheretea* class had the highest cover coefficient (D-2913), and the lowest was seen in the species from the *Koelerio glauce-Corynephoretea canescentis* class (D-581). On older plantations (over 7 years old), a great reduction in the D index value was found in the *Stellarietea mediae* and *Artemisieta vulgaris* classes (Table 9). On 9–10-year-old plantations, the number of species in higher constancy classes visibly decreased, or the species disappeared (Table 5).

3.3. Similarities and Differences between the Species Compositions of Six Groups of Salix viminalis L. Plantations Proved by Statistical Methods

The flora of all six groups of *Salix viminalis* L. plantations totalled 114 vascular plant species. There were 47 (9–10-year-old FA plantations) to 61 (6–7-year-old AR plantations) species. Among these species, there were 13 to 27 segetal plant species (Figure 7).

Cluster analysis allowed the groups of plantations in question to be connected. Two main groups were distinguished. The first group contains the plantations established on former arable land, and the second one consists of plantations established on formerly fallow land. The abundance of segetal species was similar in each of these groups (Figure 8).

The constrained components retained 14.9 percent of the relative species abundance (Figure 9). Of that 14.9 percent, 7.3 percent were related to the first component (CCA 1) and 3.1 percent, to the second one (CCA 2). The permutation test of the significance of the plantation types confirmed the significance of the CCA model (the P p-value statistic was equal to 0.001), and the first two axes (the P p-value statistic was equal to 0.001 and 0.026 for the first axis and for the second axis, respectively, whereas the third axis was not significant at the 0.05 level).

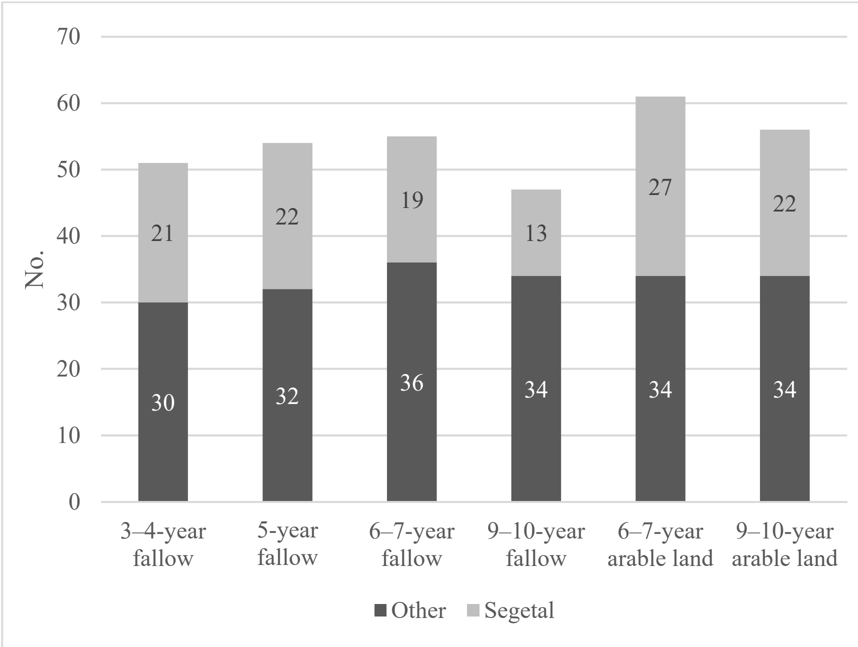

Figure 7. The numbers of species accompanying *Salix viminalis* L., including segetal species, recorded on 3–10-year-old plantations established on former arable land and fallow.

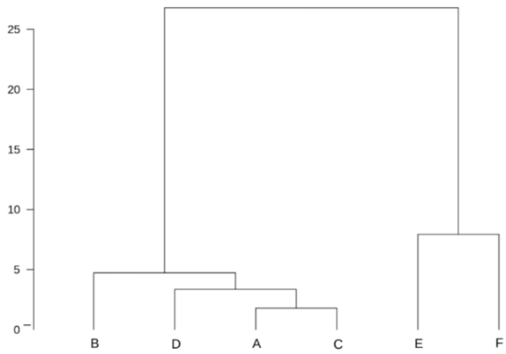

Figure 8. The dendrogram constructed by the Ward method of cluster analysis for mean segetal species coverage of six plantation groups (A–F). A—3–4-year-old FA plantations; B—5-year-old FA plantations; C—6–7-year-old FA plantations; D—9–10-year-old FA plantations; E—6–7-year-old AR plantations; F—9–10-year-old AR plantations.

The similarities between the groups of relevés according to the CCA analysis suggests that the plant communities on the plantations established on the arable lands had similar species abundances. The plantations established on fallow lands also had similar relative species abundance. This is in accordance with the cluster analysis (Figure 8). The CCA analysis also showed that the oldest plantations (9–10 years old) established on fallow areas were different from the rest of the plantations studied but were more similar to younger plantations on FA than those on AR (Figure 9).

3.4. Invasive Species Accompanying *Salix viminalis* L. Plantations

Among the 114 species of vascular flora of *Salix viminalis* L. crops, there were nine invasive species (Table 10). These were four segetal species: *Anthoxanthum aristatum* Boiss., *Conyza canadensis* (L.) Cronquist., *Setaria pumila* (Poir.) Roem and Schult., *Setaria viridis* (L.) P. Beauv. and five other species, i.e., *Echinocystis lobata* (F. Michx.) Torr. and A. Gray, *Erigeron annuus* (L.) Pers, *Padus serotina* (Ehrh.) Borkh, *Solidago canadensis* L. and *Solidago gigantea* Aiton.

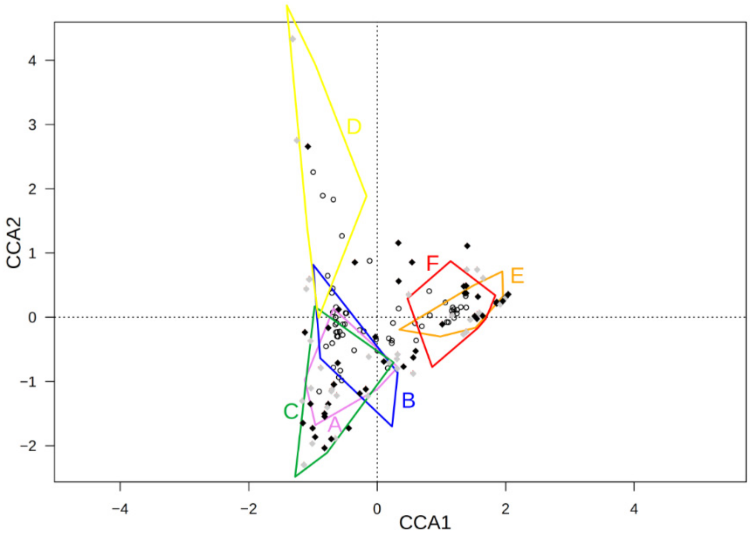

Figure 9. The biplot for the canonical correspondence analysis for relative species abundance (black rhombus—segetal species; grey rhombus—other species; circle—phytosociological relevés) in the relevés with plantation group (A–F) as the explanatory variable; 7.3 percent of the variability was related to the first CCA axis, and 3.1 percent, to the second CCA axis. A—3–4-year-old FA plantations; B—5-year-old FA plantations; C—6–7-year-old FA plantations; D—9–10-year-old FA plantations; E—6–7-year-old AR plantations; F—9–10-year-old AR plantations.

Table 10. Constancy classes (S) and cover coefficients (D) of invasive (I), medicinal (L.), poisonous (P) and melliferous (M) species occurring in flora accompanying *Salix viminalis* L. plantations established on fallow and arable land.

Species	Fallow								Arable Land				Properties
	Plantation Age in Years												
	3–4		5		6–7		9–10		6–7		9–10		
	S	D	S	D	S	D	S	D	S	D	S	D	
Achillea millefolium L. s.str.	IV	551	V	780	IV	650	IV	725	III	201	III	277	L
Anchusa arvensis (L.) M. Bieb.	-	-	I	50	-	-	-	-	-	-	-	-	L
Anthoxanthum aristatum Boiss.	-	-	-	-	I	50	-	-	-	-	-	-	I
Arctium minus (Hill) Bernh.	-	-	-	-	-	-	-	-	-	-	I	51	L
Artemisia absinthium L.	-	-	-	-	-	-	-	-	I	50	I	1	L,P
Artemisia campestris L.	-	-	-	-	II	52	I	1	-	-	-	-	L,P
Artemisia vulgaris L.	III	152	+		IV	253	II	4	IV	203	II	151	L,P
Centaurea jacea L.	-	-	II	100	I	1	-	-	-	-	-	-	M
Chenopodium album L.	-	-	+	-	-	-	I	1	I	1			M
Convolvulus arvensis L.	II	53	+		I	51	I	1	II	101	I	50	P
Conyza canadensis (L.) Cronquist	I	2	II	3	II	52	II	150	III	152	I	100	I,L
Crataegus monogyna Jacq.	-	-	-	-	-	-	-	-	-	-	I	1	L
Daucus carota L.	III	103	II	101	III	152	III	251	-	-	-	-	L
Echinocystis lobata (F.Michx)Torr. and A.Gray	-	-	-	-	-	-	-	-	-	-	I	50	I
Erigeron annuus (L.) Pers.	II	151	III	5	I	2	II	3	II	101	I	175	I
Frangula alnus Mill.	-	-	-	-	-	-	I	1	-	-	-	-	L,P
Fraxinus excelsior L.	-	-	-	-	I	1	-	-	-	-	-	-	L
Galeopsis bifida Boenn.	-	-	-	-	I	50	-	-	I	1	-	-	L
Galeopsis tetrahit L.	-	-	I	2	-	-	-	-	I	1	II	101	L,M
Geum urbanum L.	-	-	-	-	-	-	-	-	III	201	II	150	L
Helichrysum arenarium (L.) Moench	-	-	I	1	-	-	-	-	-	-	-	-	L
Hieracium pilosella L.	IV	600	III	451	IV	775	III	375	I	50	I	50	L
Hypericum perforatum L.	II	2	II	3	II	53	I	1	I	50	I	100	L,M
Jasione montana L.	III	5	I	2	I	51	I	2	I	50	-	-	M
Lotus corniculatus L.	-	-	-	-	I	1	-	-	-	-	-	-	M

Table 10. *Cont.*

Species	Fallow								Arable Land				Properties
	Plantation Age in Years												
	3–4		5		6–7		9–10		6–7		9–10		
	S	D	S	D	S	D	S	D	S	D	S	D	
Melilotus alba Medik.	-	-	-	-	-	-	-	-	I	1	I	1	L,M
Oenothera biennis L.	II	151	III	103	IV	253	III	153	-	-	-	-	M
Padus serotina (Ehrh.) Borkh.	II	2	IV	6	IV	351	V	901	-	-	-	-	I
Plantago lanceolata L.	I	50	-	-	I	50	I	1	-	-	-	-	L
Plantago major L.	-	-	-	-	-	-	-	-	I	1	-	-	L
Plantago media L.	-	-	-	-	-	-	I	1	I	1	-	-	L,M
Potentilla anserina L.	-	-	-	-	-	-	-	-	-	-	I	50	L
Potentilla argentea L.	-	-	-	-	I	1	-	-	-	-	I	50	L
Quercus petraea (Mat.) Liebl.	I	1	-	-	I	1	I	2			1	1	L
Quercus robur L.	I	1	III	r	II	53	II	52	I	r	-	-	L
Rubus caesius L.	-	-	-	-	-	-	I	50	-	-	-	-	M
Rumex acetosa L.	-	-	-	-	-	-	II	4	I	100	I	225	M
Rumex acetosella L.	IV	204	III	153	III	202	II	102	I	50	I	50	M
Senecio jacobaea L.	I	51	I	r	II	101	III	54	II	52	1	175	L,P
Setaria pumila (Poir.) Roem. and Schult.	I	1			I	51	-	-	I	1	-	-	I
Setaria viridis (L.) P. Beauv.	I	2	I	1	-	-	-	-	-	-	-	-	I
Solidago canadensis L.	I	51	II	151	III	326	IV	427	II	52	II	228	I,L,M
Solidago gigantea Aiton	-	-	-	-	-	-	I	100	-	-	-	-	I,L,M
Sonchus arvensis L.	-	-	-	-	I	50	-	-	-	-	I	1	P
Sonchus asper (L.) Hill.	-	-	-	-	-	-	-	-	-	-	I	1	P
Sonchus oleraceus L.	-	-	-	-	-	-	-	-	I	1	-	-	P
Sorbus aucuparia L. emend. Hedl.	-	-	-	-	-	-	-	-	I	1	-	-	L
Stachys palustris L.	I	50			-	-	-	-	I	2	-	-	L,M
Taraxacum officinale F.H. Wigg.	III	5	II	3	II	52	III	103	IV	279	+		L,M
Thlaspi arvense L.	-	-	-	-	-	-	I	1	-	-	-	-	L
Trifolium pratense L.	-	-	-	-	I	1	-	-	-	-	-	-	M
Trifolium repens L.	-	-	-	-	-	-	-	-	I	50	-	-	M
Urtica dioica L.	-	-	-	-	-	-	I	50	II	53	II	150	L
Verbascum densiflorum Bertol.	I	50	I	50	I	2	-	-	-	-	-	-	M
Vicia cracca L.	II	52	I	2	I	100	I	2	I	50	-	-	M
Viola arvensis Murray	II	4	III	5	II	151	-	-	-	-	-	-	L

Regardless of the type of land use, before the willow plantations were established (AR and FA), the following species occurred: *Conyza canadensis* (L.) Cronquist., *Erigeron annuus* (L.) Pers, *Setaria pumila* (Poir.) Roem and Schult., and *Solidago canadensis* L. Two of these species were always present, regardless of the age of the plantation: *Conyza canadensis* (L.) Cronquist. and *Solidago canadensis* L.

In line with the age of the plantations, *Padus serotina* (Ehrh.) Borkh., a species that grows quickly after being cut down and whose fruits are willingly eaten by birds and spread over long distances, increased its coverage on FA plantations. However, on both types of plantations (AR and FA), with time, the coverage of *Solidago canadensis* L. increased. It is an expansive, perennial species with a high productivity of seeds dispersed by the wind, thus forming dense canopies, which prevented the development of other plants. On the FA plantations, this species had higher coverage (Table 10).

3.5. Medicinal, Poisonous and Melliferous Species of Flora Accompanying the Salix viminalis L. Plantations

Among the flora accompanying the willow energy crops, 34 medicinal, 9 poisonous and 20 melliferous plant species were found (Table 10). These groups of plants accounted for 50% of all the plant species occurring on the willow plantations. In the groups of medicinal and mellifluous plants, segetal species made up considerable proportions, i.e., 29% and 25%, respectively.

The vast majority of the plants from the groups discussed here were perennial, native species that had low degrees of stability and low coverage (Table 10). Only *Achillea millefolium* L. s.str. had higher degrees of constancy and higher coverage. Of the remaining species, *Artemisia vulgaris* L. occurred with higher degrees of constancy but with low coverage.

Among the plants in this group, it is worth noting those species providing valuable raw materials for medicines: *Achillea millefolium* L. s.str., *Hypericum perforatum* L., *Taraxacum officinale* F.H.Wigg. and *Urtica dioica* L. [63]. Poisonous species included *Artemisia absinthium* L., *Convolvulus arvensis* L., *Senecio jacobaea* L., *Sonchus arvensis* L. and *Sonchus asper* (L.) Hill. It should be emphasized that with the development of various fields of science, it becomes increasingly difficult to assess whether a species has healing properties or is poisonous.

Among the melliferous plants on the willow plantations, the following species were reported: *Melilotus alba* Medik., a species providing large amounts of nectar and pollen with a high nutritional value, and *Verbascum densiflorum* Bertol., a species valuable for nectar because of its extended flowering. Moreover, *Chenopodium album* L., *Rumex acetosella* L., *Stachys palustris* L. and *Vicia cracca* L. also have melliferous properties.

4. Discussion

The vascular flora of the *Salix viminalis* L. plantations established in central Poland, amounting to 114 species, is rich and diverse compared to the willow flora found in other areas [29,64,65]. This large species diversity results from the different geographical location, the soil conditions in which the plantations were established and their locations with regard to diverse ecosystems and different types of landscape. Discussion on segetal flora is difficult because in the literature, the vegetation accompanying the energy willow is usually presented as a whole, without separating out segetal plants, and detailed data are often not included.

The 38% share of segetal species (43 taxa) on the *Salix viminalis* L. plantations found in this author's own research is high compared to the results obtained by Krechowski et al. [66], who recorded only 8.2% of typical cereal and root crop species on plantations of *Salix viminalis* L. of various ages, established on former arable and meadow land. This share is similar to the results obtained by Feledyn-Szewczyk et al. [27] in their research on the flora accompanying 10 species of energy crops, including *Salix viminalis* L. These authors found the occurrence of segetal species to be 38–39%.

The results of the author's own research showed that the species composition of segetal plants and their structure depend on the type of land use before the plantations were established. This is consistent with earlier studies by Piórek et al. [67] and Trąba et al. [29]. The lower number of segetal species that were found on FA plantations than on AR may be the result of a longer period of the non-use of cultivation treatments that stimulate plant diasporas. Trzcińska-Tacik [68] and Luzuriaga et al. [69] emphasize the importance of agrotechnical factors in shaping the species composition of arable crops. The cessation of mechanical soil cultivation causes the accumulation of diasporas in the soil. It was found that the soil seed bank is much larger in fallow soil compared to in the soil of arable land [70,71]. However, in the plant canopy, these relationships may be opposite [71]. It was found that over the years, the species similarity (in the plant canopy) of fallow land and arable land decreases [72]. In our research, in line with the age of the plantation, the influence of the land use before the establishment of a *Salix viminalis* L. plantation on the composition of flora became progressively smaller. This confirms the findings obtained by Baum et al. [73], according to which the history of a field may only have an impact on the phytodiversity of short rotation coppice (SRC) plantations in the initial period after establishing the plantation. Similarly, for energy poplar (*Populus* sp.) crops, an effect of earlier land use was only found in young plantations [32].

The transformations in the flora on energy willow plantations in the following years indicate that the structure of vegetation is mainly influenced by the nutrient content and light conditions [73]. The growth and development of willow plants causes greater soil shading and intensifies the competition between plants. As a result, with time, there is a decrease in the number of species accompanying the willow plantation, including segetal plants, as shown by our study results. It should be emphasized that among the segetal plants, apart from the common species, species rarely found on willow plantations in other regions of Poland were also noted, such as *Anthoxanthum aristatum* Boiss., *Digitaria ischaemum* (Schreb.) H.L. Mühl., and *Sonchus oleraceus* L. [29,74,75].

The predominance of native species (apophytes) among the segetal plants; their proportion, which increases with the age of the plantation; and, at the same time, the decreasing proportion of anthropophytes, regardless of the type of land use before the plantations were established, all confirmed the directions of flora development in *Salix viminalis* L. crops shown by other authors [33,74,76,77]. Moreover, these transformations confirmed that with a lack of arable land use (ploughing and soil cultivation treatments), perennial energy willow monoculture does not favour the development of alien species [78].

Many years of willow cultivation resulted in a large proportion of woodland and shrub apophytes in the agrophytocenosis structure. Besides, meadow apophytes (on AR plantations) and sandysite apophytes (on FA plantations) constituted a great proportion of the agrophytocenoses. Similarly, Korniak et al. [74] and Janicka et al. [77], studying willow, and Birmele et al. [79], analysing poplar, found a predominance of meadow, woodland and shrub species.

The results of our studies confirm changes in the biological stability of segetal flora on plantations established on fallow lands. An increase in the proportion of perennial species in the whole flora accompanying energy willow plantations and, at the same time, a decrease in the proportion of short-lived species in line with the age of the plantations were shown previously (in plantations more than 3 years old) by Korniak et al. [74] and Trąba et al. [29]. On the older plantations, mainly perennial, rhizomatous and stolon species developed, which was also found by Korniak et al. [74] and Baum et al. [30]. The frequent occurrence of *Elymus repens* (L.) Gould., which grows intensively on willow energy plantations, is also consistent with the findings of Rowe et al. [80] and Baum et al. [30].

The phytosociological affiliation of the segetal flora presented in this paper is fundamentally different to the phytosociological structure of the whole flora of *Salix viminalis* L. presented in the literature. The segetal species of the plantations assessed here mainly belonged to the *Stellarietea mediae* class, while in the willow flora considered as a whole, species from the *Molinio-Arrhenatheretea* class predominated, and the proportion of plants from the *Stellarietea mediae* class was much smaller [66,81]. This fact may be a result of the age of the plantations in question. According to Trąba et al. [29], species from the *Stellarietea mediae* class on perennial plantations do not have suitable conditions for development, due to the fact that the soil surface is largely covered with plants. The dominance of the *Stellarietea mediae* class on willow and poplar plantations was found by Ziaja and Wnuk et al. [76], but these were young plantations (2–5 years old).

It was found that most of the segetal species on the *Salix viminalis* L. plantations occurred in low constancy classes (I and II), which is consistent with the results of research on willow flora conducted by, for example, Korniak [74], Trąba [29] and Krechowski [66]. These authors claim that this indicates a poor balance of *Salix viminalis* L. flora. This is due to the fact that willow is cut systematically (every 2–3 years), causing a change in light, thermal and humidity conditions, which makes it impossible to balance the flora [29].

An important part of the flora accompanying the *Salix viminalis* L. plantations is medicinal, poisonous and melliferous species. They are important for nature and enrich the biodiversity of agricultural areas, especially in the era of plant protection products being used intensively in agriculture [37,82]. What is worrying, though, is the presence of invasive species, especially those with high constancy classes and coverage, such as *Conyza canadensis* (L.) Cronquist., *Erigeron annuus* (L.) Pers., *Solidago canadensis* L. and

Padus serotina (Ehrh.) Borkh. What needs to be particularly emphasized is that *Conyza canadensis* (L.) Cronquist. is an invasive species in many different habitats [83], and in Poland, it now has the status of an epoecophyte (a species settled in segetal and ruderal habitats). The presence of this species on energy willow plantations was previously confirmed by Wróbel et al. [84], Duer and Feledyn-Szewczyk [85], Feledyn-Szewczyk et al. [27] and Janicka et al. [31], and in *Sida hermaphrodita* (L.) Rusby by Bacieczko and Borcz [86]. Feledyn-Szewczyk [87] also recorded a considerable proportion of this species in the willow harvested each year. A particularly undesirable element of the flora is *Solidago canadensis* L., which was found on FA plantations. *Solidago spp*. is known to be a species typical for fallow lands [88]. The presence of these and other non-native and invasive plant species on willow plantations should be monitored. In conclusion, it should be emphasized that research on the biodiversity of energy willow and other plants used for bioenergy should be continued in the future, as these crops are important in the context of climate change and the increase in greenhouse gas emissions to the atmosphere.

5. Conclusions

Segetal species, occurring mainly in cereal and root crops, constitute a considerable proportion of the flora accompanying *Salix viminalis* L. (38%). It was found that their number depends on the type of land use before the establishment of the plantations. The plantations established on arable land were richer in segetal species than plantations established on fallow. However, both types of plantations were dominated by the same plant species (with the highest constancy classes and coverage), such as *Achillea millefolium* L. s.str, *Artemisia vulgaris* L. and *Elymus repens* (L.).

Regardless of the type of former land use, before the willow plantations were established, species of local origin were predominant among the segetal plants. In line with the age of the plantations, there was a decrease in the number of segetal species, especially from the *Stellarietea mediae* class. The proportion of anthropophytes also decreased, and apophytes increased. The dominant phytosociological classes were *Molinio-Arrhenatheretea* and *Agropyretea intermedio-repentis*.

Among the flora accompanying the willow, medicinal and melliferous plants important for humanity and biodiversity were noted, as well as invasive alien species, whose presence threatens native flora and should be monitored. A considerable part of the medicinal species was made up of segetal species.

To sum up, *Salix viminalis* L. plantations promote the preservation of many arable land plant species and contribute to maintaining the mosaic of the agricultural landscape and also the biodiversity of agroecosystems.

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