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BIODIVERSITY OF SEGETAL FLORA IN POTATO FIELDS (*SOLANUM TUBEROSUM* L.) IN SELECTED MUNICIPALITIES OF THE ZAMOŚĆ REGION

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K e y w o r d s: potato, weed infestation, soil-agricultural complexes.

A b s t r a c t

The research was conducted on weed infestation of potato crops in fields with different soils in several (9) municipalities in the Zamość region in 2014–2015 were compared with the results of research carried out in 1991–1995. The phytosociological photos were created by Braun-Blanquet's method, of which 87 representative images were selected for analysis. The photos were taken on three complexes of agricultural suitability of soils: good wheat, defective wheat and good rye.

Generally identified 55 species of weeds (43 annual and biennial and 12 perenial). The cultivation of potato less were infested on the complex good wheat and defective than good rye. One photo in the first research period (1991–1995) accounted from 45 to 52 species, while in the second period (2014–2015) from 41 to 49 species. In potato canopy dominated nitrophilous species: *Chenopodium album, Echinochloa crus-galli, Matricaria maritima subsp. inodora, Stellaria media, Galinsoga parviflora, Elymus repens* and *Equisetum arvense.*

In general, irrespective of the soil complex, the resumption of testing after 20 years in selected locations in various municipalities of the Zamość region indicates is very limited of certain taxa, such as *Galeopsis tetrahit*, *Veronica persica*, *Papaver rhoeas, Avena fatua, Sinapis arvensis*, *Spergula arvensis*, *Fallopia convolvulus* and *Polygonum persicaria,* in addition to *Galium aparine* and *Stellaria media* on poorer soil complexes. An increase in infestation of potato was noted for *Chenopodium album*, *Echinochloa crus-galli*, *Setaria pumila*, *Anthemis arvensis*, *Atriplex patula* and *Lamium purpreum*. Among perennial taxa, crops are infested in the highest degree by *Elymus repens* and *Equisetum arvense*.

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BIORÓŻNORODNOŚĆ FLORY SEGETALNEJ W UPRAWACH ZIEMNIAKA (*SOLANUM TUBEROSUM* L.) W WYBRANYCH GMINACH ZAMOJSZCZYZNY

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S ł o w a k l u c z o w e: uprawa ziemniaka, zachwaszczenie, kompleksy glebowo-rolnicze.

A b s t r a k t

Badania nad zachwaszczeniem upraw ziemniaka przeprowadzono na polach uprawnych na różnych glebach w kilku gminach (9) na Zamojszczyźnie w latach 2014–2015 i porównano je z wynikami badań z lat 1991–1995. Wykonano zdjęcia fitosocjologiczne metodą Braun-Blanqueta, z których do analizy wybrano 87 reprezentatywnych zdjęć. Zdjęcia te wykonano na trzech kompleksach rolniczej przydatności gleb: pszenny dobry, pszenny wadliwy i żytni dobry.

Ogólnie rozpoznano 55 gatunków chwastów (32 krótkotrwałe i 12 wieloletnich). Pola uprawne z ziemniakiem były mniej zachwaszczone na kompleksie pszennym dobrym niż pszennym wadliwym i żytnim dobrym. Na jedno zdjęcie w I okresie badań (1991–1995) przypadało od 45 do 52 gatunków chwastów, podczas gdy w II okresie (2014–2015) od 41 do 49 taksonów. W łanach ziemniaka dominowały gatunki nitrofilne: *Chenopodium album, Echinochloa crus-galli, Matricaria maritima subsp. inodora, Stellaria media, Galinsoga parviflora, Elymus repens* i *Equisetum arvense.*

Niezależenie od kompleksu rolniczej przydatności gleb po wznowieniu badań po 20 latach w wybranych lokalizacjach gmin Zamojszczyzny stwierdza się bardzo ograniczone występowanie niektórych taksonów, jak: *Galeopsis tetrahit, Veronica persica, Papaver rhoeas, Avena fatua, Sinapis arvensis, Spergula arvensis, Fallopia convolvulus* i *Polygonum persicaria*, ponadto na kompleksach słabszych – *Galium aparine* i *Stellaria media.* Wzrasta natomiast zachwaszczenie łanów ziemniaka przez: *Chenopodium album, Echinochloa crus-galli, Setaria pumila, Anthemis arvensis, Atriplex patula* i *Lamium purpreum.* Ponadto z taksonów wieloletnich uprawy obecnie zachwaszczane są w najwyższym stopniu przez *Elymus repens* i *Equisetum arvense.*

Introduction

Potato plants are highly vulnerable to weed infestation because they are grown in wide rows, which creates favourable conditions for weed development. Secondary weed infestation in particular significantly reduces potato yields, by as much as 10–70%. An increase of one plant per square meter decreases the yield of potato tubers by 0.05–0.15 t ha^{-1} (ZARZECKA et al 2004). Weeds are highly competitive with potato for nutrients, water and light, and reduce the quality of harvested crops. Potato crops in Poland are infested with about 200 weed species, of which only a few play a dominant role among the weeds. The floristic composition of weed communities and the degree of infestation in crop fields depends on numerous natural and artificial habitat factors. Characteristic weed species are known to be associated with particular crop plants, soil types, soil pH, moisture, and content of humus and minerals

(BUJAK and FRANT 2006, KRASKA et al. 2006, RÓŻYŁO and PAŁYS 2008, ZARZECKA et al. 2009, SAWICKA et al. 2011, GARGAŁA and TRĄBA 2014, GUGAŁA et al. 2014). Besides natural factors, anthropogenic factors, such as the type and intensity of cultivation procedures, including herbicide application, play an equally important role (KLIKOCKA and WESOŁOWSKI 2002, ZARZECKA et al. 2013). Suitably chosen crop protection products ensure nearly complete destruction of the weeds infesting the crop and at the same time effectively eliminate segetal flora diversity (ROLA and ROLA 2001). Dicotyledonous species are eliminated first, particularly on the poorest soils and rendzinas.

The aim of the study was to evaluate the degree of changes in secondary weed infestation of potato in the years 1991–1995 and 2014–2015 on arable fields in selected municipalities of the Zamość region.

Material and Methods

A phytosociological analysis was performed by Braun-Blanquet's method (BRAUN-BLANQUET 1964) in two periods, I – 1991–1995 and II – 2014–2015, in the municipalities of Józefów, Susiec, Adamów, and Tomaszów Lubelski (Central Roztocze), Radecznica (West Roztocze), Obsza (Sandomierz Basin), and Hrubieszów, Werbkowice, and Tyszowce (Lublin Upland). Characterization of the weed infestation of individual soil types was based on 87 representative phytosociological relevés, were selected for analysis. An attempt was made to distribute the research plots in such a way as to represent the spatial diversity of ecological conditions in the area. Complexes of agricultural suitability of soils were identified on the basis of agricultural soil maps with a scale of 1:5,000, prepared by the Provincial Bureau of Surveying and Agricultural Areas in Zamość.

Phytosociological relevés in the potato crops were prepared in the second half of August. Weed species were recorded from an area of about 100 m^2, selecting the most homogeneous and uniform patches in terms of density of crop plants and weeds. The phytosociological constancy and cover index of species was determined in the segetal communities of the potato crop. Phytosociological constancy (S) is the frequency of occurrence of individual species in the relevés, on Braun-Blanquet's five-point scale (I–V) (BRAUN-BLANQUET 1964, PAWŁOWSKI 1982). The cover index (*D*) was calculated using Braun-Blanquet's seven-point scale: 5 = 87.5%; 4 = 62.5%; 3 = 37.5%; 2 = 17.5%; 1 = 2.5%; + up to 1.0%, and r up to 0.1%. The species posing the greatest threat to the potatoes were identified using a 5-degree weed infestation scale (BOROWIEC 1984, KORNIAK 1992) – Table 1. It takes into account both the degree of constancy (S) and the cover index (*D*) of the weeds. The

dominance index and the Shannon total diversity index were calculated according to ODUM (1982). Species nomenclature was given according to MIREK et al. (2002).

Table 1

Degrees of an infestation of crops by weed species

The degree of an infestation	Phytosociological constancy (S)	Cover index (*D*)
1 – very large	V, IV	>500
2 – large	V, IV, III	300–499 >500
3 – average	V, IV III	100–299 200–499
4 – small or large locally	V, IV III II	< 100 100–199 > 100
5 – occasional	I, II	< 100

Physical and geographical characteristics of the area

The Zamość region is situated in south-eastern Poland. Its precise location is defined by the following coordinates: east longitude from 11°24'' to 24°09'' and north latitude from 50°15'' to 51°00''. Its longitudinal distance is 86 km and its latitudinal distance is 122 km. The total area of the Zamość region is 6,307 km^2, which is 1.6% of the area of Poland. The following macroregions are distinguished in the Zamość region: the Lublin Upland, Roztocze, the Sandomierz Basin, Volhynian Polesie, the Zachodnio-Wołyńska Upland and Pobuże (KONDRACKI 1980).

As bedrock of arable soils Quaternary and Pleistocene materials (loess, silt, sand and loam) predominate, occupying 65% of the surface area. Their average thickness ranges from 10 to 15 m. Older Cretaceous (Senon) and Tertiary (Miocene) sediments cover about 15% of the area, with younger Holocene deposits (alluvial and fluvial sands and peat deposits) accounting for the remaining 20% (KONDRACKI 1980).

The percentages of particular soil types in the surface area of agricultural land are as follows: Haplic Podzol and Haplic Luvisol – 14.6%, Haplic Cambisol (Eutric) – 12.1%, Haplic Cambisol – 34.4%, Calcic Chernozem and Haplic Chernozem – 14.6%, and other soils (Gleyic Chernozem, Haplic Gleysol, Haplic Fluvisol, Fluvic Cambisol, Cambic Leptosol, Rendzic Phaeozem) (PTG 2011) – 24.3%. Very light soils account for 7%, light soils 53%, moderately heavy 30.4%, and heavy or very heavy 9.6%. In terms of granulometric composition, loess soils occupy the largest area of agricultural land (66%), followed by

cretaceous limestone (7.6%), loam (6.4%), loamy sand (5.2%), loose sand and weak clay (7.2%) and organogenic material (7.6%). About 70% of arable land in the Zamość region is characterized by relatively optimal moisture levels; 12% of soils are periodically or permanently wet, while 19% are periodically or permanently dry (KERN et al. 1990, GUS 2015).

In the Lublin Upland wheat complex soils dominate: good (2), very good (1) and defective (3). Roztocze is characterized by a predominance of poorer soils, specifically good (5) and very good (4) rye complex soils, as well as defective wheat complex (3). In the Sandomierz Basin very good rye complex soils (4) are dominant.

In the former Zamość Voivodeship very good wheat complex soils, according to polish agricultural soil classification occupy 22.2% of the total area of arable land, while good wheat complex soils occupy 27.4%, and defective wheat complex soils account for only 9.3%. The percentage share of rye complexes is lower: very good – 13.7%, good 16.5%, poor 5.8%, and very poor rye complex just 2.7%.

Agricultural land occupies 71.8% of the area of the Zamość region and arable land accounts for 58.6%. The percentage shares of soil complexes in the selected municipalities were quite varied, as shown in Table 2. The agrochemical properties of the soils in the municipalities are presented in Table 3.

The Zamość region has little surface water. The entire area is included in the catchment of the Vistula, a first-order river. The main river is the Wieprz, a second-order river, together with its tributaries. The eastern part of the

Table 2

Characteristics of the soil in the Zamość region (KERN et al. 1990)

Physiographic region	Municipality	The complex of agricultural suitability of soils [%]			Quality index of agricultural production space*
		good wheat (2)	defective wheat (3)	good rye (5)	
Roztocze Środkowe	Józefów	0.8	6.5	26.9	60.5
	Susiec	0.0	12.2	28.8	60.3
	Adamów	31.0	48.5	4.7	79.8
	Tomaszów Lub.	15.9	25.9	19.2	75.1
Roztocze Zachodnie	Radecznica	33.1	45.9	12.7	81.7
Kotlina Sandomierska	Obsza	7.9	0.1	11.3	74.4
Wyżyna Lubelska	Hrubieszów	17.7	1.4	1.1	104.5
	Werbkowice	45.2	2.7	0.8	93.5
	Tyszowce	40.8	9.0	4.9	88.3

* Evaluation of agro-ecological conditions in 50–100 points

Table 3

Agrochemical characterization of soils in the Zamość region (KERN et al. 1990)

Physiographic region	Municipality	Bonitation indicator negative [%]* (arable land)			Acidic soils share [%] (agricultural land)
		phosphorus	potassium	magnesium	
Roztocze Środkowe	Józefów	81	67	76	89.0
	Susiec	90	60	78	96.8
	Adamów	49	79	83	91.7
	Tomaszów Lub.	69	75	76	85.5
Roztocze Zachodnie	Radecznica	53	65	53	77.1
Kotlina Sandomierska	Obsza	77	93	89	99.0
Wyżyna Lubelska	Hrubieszów	42	67	29	51.8
	Werbkowice	41	68	44	38.8
	Tyszowce	49	67	42	52.4

* Percentage of the soil requires increased fertilization

Zamość region is drained by the Bug River, and especially by its left tributary the Huczwa. From the south-western part the surface waters flow directly into the San, a second-order river, by way of the Tanew and its tributaries (Sopot, Szum, Czarna Łada and Biała Łada). The Pobuże region is drained to the east by the Solokiya River, a left tributary of the Bug. At the foot of Roztocze there are numerous springs.

The occurrence of groundwater is associated with the geological structure of the area. In the Zamość region we can distinguish areas with the following groundwater depths: from 0 m to 5 m (south-western part of the region included in the Biłgoraj Plain, the Tarnogród Plateau, east of the Huczwa River Valley, and the Bug River Valley); from 5 m to 20 m (areas outside of valleys covered with silty sand and till, the Zamość Depression, and Roztocze); over 20 m (the Giełczew Elevation, the Grabowiec Interfluves, the Lublin Upland, Western Roztocze, and the eastern part of the Sokal Ridge).

The current climate of the Zamość region can be characterized as transitional, shaped by an influx of oceanic or continental air masses, predominantly continental, of variable range. Mean precipitation is 417 mm during the growing season and 172 mm in the autumn and winter. The mean air temperature is 7°C. Temperatures are below 0°C in December, January and February, on average from –1 to –4°C. Summers are hot, particularly in June, July and August, on average 17°C (KLIKOCKA et al. 2015).

Results

In the selected municipalities of the Zamość region 55 weed species were noted in the potato crops. Among these 43 were annuals and biennials taxa and 12 were perennial (Table 4). Irrespective of the soil complex, there were 45 to 52 species per relevé in the first period of the study (1991–1995) and from 41 to 49 species in the second period (2014–2015). This means that 20 years after the first part of the study the number of segetal species in the potato crops had decreased. The weed infestation was dominated by annuals and biennials species (on average 68.6%) and dicotyledonous species (on average 87.8%) over perennial species (31.4%) and monocotyledonous species (12.3%) – Table 4. The mean cover index (*D*) ranged from 318 to 555 and was higher during the second period of the study (2014–2015) and on the good rye complex soils (5). A similar tendency was observed for the ecological indices, the dominance index and Shannon's diversity index, with higher values in 2014–2015.

Table 4

Diversity of segetal weeds in potato canopy

Specification	I period (years 1991–1995)			II period (years 2014–2015)			CV%**
Complex of agricultural suitability of soils*	2	3	5	2	3	5	–
Number of phytosociological photo	14	14	14	15	15	15	–
Total number of species (no)	46	45	52	41	41	49	9.56
Means cover index (*D*)	318	354	358	355	432	555	21.92
Dicotylodonus (no)	41	40	47	36	36	46	11.54
Monocotylodonus (no)	5	5	5	5	5	3	17.50
Annuals and bienials (no)	35	35	41	30	31	38	11.85
Perennials (no)	11	10	11	11	10	11	4.84
Dominance index	0.116	0.095	0.096	0.141	0.115	0.125	15.29
Shannon's total diversity index	0.667	0.610	0.614	0.698	0.678	0.709	6.32

* Complex of agricultural suitability of soils: 2 – good wheat, 3 – defective wheat, 5 – good rye
** CV% – coefficient of variation

Stellaria media and *Chenopodium album* were present in the highest (1) and a high (2) degree of infestation in the first period of the study (1991–1995) on all three complexes. In the second period of the study (2014–2015) the degree of infestation was very high only for *Chenopodium album*, while *Stellaria media* decreased to a sporadic level (5). *Echinochloa crus-galli* most heavily infested the potato plantations on the good wheat and good rye complexes, but did not pose a threat (5th degree of infestation) on the defective wheat complex. Markedly reduced infestation with this taxon was observed in 2014–2015, where it decreased to the 4th degree on the good wheat complex and to the second degree on the good rye complex. The defective wheat complex remained unchanged (Table 5).

Table 5

A statement of the degree of phytosociological constancy (S), cover index (*D*) and the degree of an infestation (*Z*) of potato cultivation on good wheat complex (2)

No.	Species	Years of study					
		1991–1995			2014–2015		
		S	*D*	*Z*	S	*D*	*Z*
1	2	3	4	5	6	7	8
Annuals and biennials							
1.	*Stellaria media* (L.) Vill.	V	938	1	I	79	5
2.	*Chenopodium album* L.	IV	538	1	IV	606	1
3.	*Echinochloa crus-galli* (L.) P. Beauv.	IV	658	1	II	579	4
4.	*Galinsoga parviflora* Cav.	III	493	3	I	79	5
5.	*Setaria pumila* (Poir.) Roem. & Schutt.	III	393	3	III	579	2
6.	*Galium aparine* L.	III	63	4	I	97	5
7.	*Galeopsis tetrahit* L.	III	161	4	I	2	5
8.	*Polygonum persicaria* L.	II	19	5	I	3	5
9.	*Fallopia convolvulus* (L.) H. Löve	II	20	5	II	34	5
10.	*Spergula arvensis* L.	II	69	5	–	–	–
11.	*Matricaria maritima* L. *subsp.inodora* (L.) Dostal	II	374	4	II	368	4
12.	*Veronica persica* Poir.	II	46	5	I	6	5
13.	*Papaver rhoeas* L.	II	20	5	–	–	–
14.	*Sinapis arvensis* L.	I	10	5	–	–	–
15.	*Atriplex patula* L.	I	2	5	III	634	2
16.	*Amaranthus retroflexus* L.	I	2	5	I	118	5
17.	*Lamium purpureum* L.	I	3	5	I	95	5
18.	*Thlaspi arvense* L.	I	4	5	–	–	–
19.	*Avena fatua* L.	I	4	5	I	1	5
20.	*Anagalis arvensis* L.	I	5	5	I	4	5
21.	*Viola arvensis* Murray	I	5	5	I	4	5
22.	*Vicia hirsuta* (L.) S.F. Gray	I	2	5	I	1	5
23.	*Vicia tetrasperma* (L.) Schreb.	I	3	5	I	2	5
24.	*Vicia angustifolia* L.	I	2	5	I	1	5
25.	*Apera spica-venti* (L.) P.B.	I	1	5	I	1	5
26.	*Geranium pussilum* Burm. f. ex L	I	2	5	I	1	5
27.	*Centaurea cyanus* L.	I	1	5	I	1	5
28.	*Anthemis arvensis* L.	–	–	–	–	–	–
29.	*Veronica arvensis* L.	I	4	5	I	3	5
30.	*Sonchus asper* (L.) Hill.	I	2	5	I	1	5
31.	*Sonchus oleraceus* L.	I	1	5	–	–	–
32.	*Capsella bursapastoris* (L.) Medik.	I	2	5	I	1	5
33.	*Myosotis arvensis* (L.) Hill	–	–	–	–	–	–
34.	*Polygonum aviculare* L.	–	–	–	–	–	–
35.	*Galinsoga cilliata* (Raf.) S. F. Blake	–	–	–	–	–	–
36.	*Thlapsi arvense* L.	I	1	5	I	1	5
37.	*Erodium cicutarium* (L.) L'H.	I	1	5	I	1	5
38.	*Poa annua* L.	I	2	5	I	1	5
39.	*Senecio vulgaris* L.	–	–	–	–	–	–
40.	*Scleranthus annus* L.	–	–	–	–	–	–
41.	*Setaria viridis* (L.)P. Beauv.	I	2	5	I	2	5
42.	*Melandrium album* (Mill.) Garcke	–	–	–	–	–	–
43.	*Conyza canadensis* (L.) Cronquist	–	–	–	–	–	–

cont. table 5

1	2	3	4	5	6	7	8
Perenials							
44.	*Elymus repens* (L.) Gould	III	159	4	V	1514	1
45.	*Equisetum arvense* L.	III	299	3	III	164	4
46.	*Convolvulus arvensis* L.	III	98	4	II	205	4
47.	*Cirsium arvense* (L.) Scop.	II	30	5	III	136	4
48.	*Plantago maior* L.	I	2	5	I	2	5
49.	*Plantago lanceolata* L.	I	1	5	I	1	5
50.	*Taraxacum officinale* F.H. Wigg.	I	1	5	I	1	5
51.	*Rumex acetosella* L.	I	2	5	I	1	5
52.	*Trifolium repens* L.	I	1	5	I	1	5
53.	*Lotus corniculatus* L.	I	1	5	I	1	5
54.	*Trifolium arvense* L.	–	–	–	–	–	–
55.	*Artemisia campestris* L.	I	1	5	I	1	5

The good wheat complex (2) in the first period of the study (1991–1995) was also heavily infested with *Galinsoga parviflora*, *Setaria pumila*, *Galeopsis tetrahit*, *Spergula arvensis* and *Galium aparine*. Among perennial taxa, the highest infestation was caused by *Elymus repens*, *Equisetum arvense* and *Convolvulus arvensis*. In the second period of the study (2014–2015) there was a reduction in the occurrence of *Galinsoga parviflora* and *Galium aparine* (1st degree of infestation), whereas an increase was noted in infestation by *Matricaria maritima* ssp. *indora* (1st degree of infestation). Among perennial taxa, higher frequency was noted for *Equisetum arvense*, *Elymus repens* and *Convolvulus arvensis*. Overall, 46 taxa were observed on the complex 2 soils (good wheat) in 2010–2011, including 35 annuals and biennials and 11 perennial species, and 41 dicotyledonous and 5 monocotyledonous species. In the second period of the study, conducted in 2014–2015, 41 taxa were counted (30 annuals and biennials and 11 perennial species; 36 dicotyledonous and 5 monocotyledonous species). In the second period of the study, in contrast with the first, *Spergula arvensis*, *Papaver rhoeas*, *Sinapis arvensis*, *Thlaspi arvense* and *Sonchus oleraceus* were not recorded.

The annuals and biennials taxa *Anthemis arvensis*, *Myosotis arvensis*, *Polygonum aviculare*, *Senecio vulgaris*, *Sclaranthus annus*, *Melandrium album*, *Conyza canadensis* and the perennial taxon *Trifolium pretense* were not observed in the defective wheat complex or good rye complex soil.

The defective wheat complex (3) in the first period of the study was heavily infested with *Stellaria media*, *Chenopodium album*, *Galium aparine*, *Fallopia convolvulus*, *Veronica persica*, *Papaver rhoeas*, *Sinapis arvensis* and *Avena fatua* (Table 6). Among perennial weeds, the potatoes were most heavily

Table 6

A statement of the degree of phytosociological constancy (S), cover index (*D*) and the degree of an infestation (*Z*) of potato cultivation on defective wheat complex (3)

No.	Species	Years of study					
		1991–1995			2014–2015		
		S	*D*	*Z*	S	*D*	*Z*
1	2	3	4	5	6	7	8
Annuals and biennials							
1.	Stellaria media (L.) Vill.	V	679	1	I	10	5
2.	*Chenopodium album* L.	V	672	1	V	1118	1
3.	*Echinochloa crus-galli* (L.) P. Beauv.	I	33	5	I	614	5
4.	*Galinsoga parviflora* Cav.	II	84	5	II	432	4
5.	*Setaria pumila* (Poir.) Roem. & Schutt.	II	25	5	II	545	4
6.	*Galium aparine* L.	V	543	1	I	4	5
7.	*Galeopsis tetrahit* L.	I	15	5	I	1	5
8.	*Polygonum persicaria* L.	II	16	5	I	2	5
9.	*Fallopia convolvulus* (L.) H. Löve	V	237	3	I	10	5
10.	*Spergula arvensis* L.	–	–	–	I	1	5
11.	*Matricaria maritima* L. *subsp.inodora* (L.) Dostal	I	6	5	II	931	1
12.	*Veronica persica* Poir.	V	503	1	I	5	5
13.	*Papaver rhoeas* L.	IV	347	2	–	–	–
14.	*Sinapis arvensis* L.	IV	191	3	I	1	5
15.	*Atriplex patula* L.	I	4	5	IV	504	1
16.	*Amaranthus retroflexus* L.	II	267	4	I	160	5
17.	*Lamium purpureum* L.	I	12	5	III	254	3
18.	*Thlaspi arvense* L.	I	38	5	–	–	–
19.	*Avena fatua* L.	IV	222	3	I	1	5
20.	*Anagalis arvensis* L.	I	5	5	I	4	5
21.	*Viola arvensis* Murray	I	5	5	I	4	5
22.	*Vicia hirsuta* (L.) S.F. Gray	I	2	5	I	1	5
23.	*Vicia tetrasperma* (L.) Schreb.	I	3	5	I	2	5
24.	*Vicia angustifolia* L.	I	2	5	I	1	5
25.	*Apera spica-venti* (L.) P.B.	I	1	5	I	1	5
26.	*Geranium pussilum* Burm. f. ex L	I	2	5	1	1	5
27.	*Centaurea cyanus* L.	I	1	5	–	–	–
28.	*Anthemis arvensis* L.	–	–	–	–	–	–
29.	*Veronica arvensis* L.	I	4	5	I	3	5
30.	*Sonchus asper* (L.) Hill.	I	2	5	I	1	5
31.	*Sonchus oleraceus* L.	I	1	5	–	–	–
32.	*Capsella bursapastoris* (L.) Medik.	I	2	5	–	–	–
33.	*Myosotis arvensis* (L.) Hill	I	2	5	I	2	5
34.	*Polygonum aviculare* L.	–	–	–	–	–	–
35.	*Galinsoga cilliata* (Raf.) S. F. Blake	–	–	–	–	–	–
36.	*Thlapsi arvense* L.	I	2	5	I	1	5
37.	*Erodium cicutarium* (L.) L'H.	I	1	5	I	1	5
38.	*Poa annua* L.	I	2	5	I	1	5
39.	*Senecio vulgaris* L.	–	–	–	–	–	–
40.	*Scleranthus annus* L.	–	–	–	–	–	–
41.	*Setaria viridis* (L.)P. Beauv.	I	2	5	I	2	5
42.	*Melandrium album* (Mill.) Garcke	–	–	–	–	–	–
43.	*Conyza canadensis* (L.) Cronquist	–	–	–	–	–	–

cont. table 6

1	2	3	4	5	6	7	8
Perenials							
44.	*Elymus repens* (L.) Gould	III	158	4	V	1119	1
45.	*Equisetum arvense* L.	I	20	5	IV	391	2
46.	*Convolvulus arvensis* L.	V	705	1	IV	305	2
47.	*Cirsium arvense* (L.) Scop.	II	136	4	I	46	5
48.	*Plantago maior* L.	I	2	5	I	2	5
49.	*Plantago lanceolata* L.	I	1	5	I	1	5
50.	*Taraxacum officinale* F.H. Wigg.	I	1	5	I	1	5
51.	*Rumex acetosella* L.	–	–	–	–	–	–
52.	*Trifolium repens* L.	I	1	5	I	1	5
53.	*Lotus corniculatus* L.	I	1	5	I	1	5
54.	*Trifolium arvense* L.	–	–	–	–	–	–
55.	*Artemisia campestris* L.	I	1	–	I	1	5

infested with *Convolulus arvensis* and *Elymus repens*. In the second period of the study (2014–2015) there was a decrease in the occurrence of *Stellaria media*, *Galium aparine* and *Sinapis arvensis* (5th degree of infestation), and a significant increase in the occurrence of *Matricaria maritima* ssp. *indora* (2nd degree of infestation). After 20 years the presence of *Papaver rhoeas*, *Thlaspi arvense*, *Avena fatua*, *Sonchus oleraceus* and *Capsella bursa-pastoris* was no longer observed. Among perennial taxa the frequency of *Convolvulus arvensis* and *Cirsium arvense* was lower, but there was an increase in infestation of the potato crops by *Elymus repens* (1st degree of infestation) and *Equisetum arvense* (3rd degree of infestation). *Plantago major*, *Plantago lanceolata*, *Taraxacum officinale*, *Trifolium repens*, *Lotus corniculatus* and *Artemisia campestris* occurred sporadically (5th degree of infestation). Overall in soil suitability complex 3 (defective wheat) a total of 45 taxa were recorded in the years 1991–1995, including 35 annuals and biennials and 10 perennial taxa and 40 dicotyledonous and 5 monocotyledonous taxa. In the second period of the study, conducted in 2014–2015, 41 taxa were counted (30 annuals and biennials and 11 perennial taxa; 36 dicotyledonous and 5 monocotyledonous taxa).

Good rye complex (5) in the first period of the study (1991–1995) was most heavily infested with *Chenopodium album*, *Echinochloa crus-galli* and *Stellaria media*, and additionally with *Galinsoga parviflora*, *Setaria pumila*, *Galium aparine*, *Galeopsis tetrahit*, *Polygonum persicaria*, *Fallopia convolvulus* and *Spergula arvensis* (Table 7). Among annuals and biennials taxa the highest infestation was caused by *Equisetum arvense*, *Convolvulus arvensis* and *Elymus repens*. In the second period of the study there was an increase

Table 7

A statement of the degree of phytosociological constancy (S), cover index (*D*) and the degree of an infestation (*Z*) of potato cultivation on defective wheat complex (3)

No.	Species	Years of study					
		1991–1995			2014–2015		
		S	*D*	*Z*	S	*D*	*Z*
1	2	3	4	5	6	7	8
Annuals and biennials							
1.	Stellaria media (L.) Vill.	IV	443	2	I	5	5
2.	*Chenopodium album* L.	V	610	1	V	1522	1
3.	*Echinochloa crus-galli* (L.) P. Beauv.	IV	841	1	III	1105	1
4.	*Galinsoga parviflora* Cav.	III	550	2	III	722	2
5.	*Setaria pumila* (Poir.) Roem. & Schutt.	III	400	3	III	554	2
6.	*Galium aparine* L.	III	63	5	I	10	5
7.	*Galeopsis tetrahit* L.	III	207	4	–	–	–
8.	*Polygonum persicaria* L.	III	34	5	II	86	5
9.	*Fallopia convolvulus* (L.) H. Löve	IV	152	3	I	6	5
10.	*Spergula arvensis* L.	III	451	3	–	–	–
11.	*Matricaria maritima* L. *subsp. inodora* (L.) Dostal	II	40	5	IV	1148	1
12.	*Veronica persica* Poir.	II	49	5	I	5	5
13.	*Papaver rhoeas* L.	I	33	5	I	2	5
14.	*Sinapis arvensis* L.	I	2	5	II	8	5
15.	*Atriplex patula* L.	II	14	5	III	512	2
16.	*Amaranthus retroflexus* L.	–	–	–	I	60	5
17.	*Lamium purpureum* L.	I	10	5	I	62	5
18.	*Thlaspi arvense* L.	I	20	5	II	31	5
19.	*Avena fatua* L.	I	3	5	–	–	–
20.	*Anagalis arvensis* L.	I	4	5	I	3	5
21.	*Viola arvensis* Murray	I	5	5	I	4	5
22.	*Vicia hirsuta* (L.) S.F. Gray	I	3	5	I	2	5
23.	*Vicia tetrasperma* (L.) Schreb.	I	3	5	I	2	5
24.	*Vicia angustifolia* L.	I	2	5	I	1	5
25.	*Apera spicaventi* (L.) P.B.	I	1	5	–	–	–
26.	*Geranium pussilum* Burm. f. ex L	I	2	5	I	1	5
27.	*Centaurea cyanus* L.	I	1	5	I	1	5
28.	*Anthemis arvensis* L.	I	2	5	I	2	5
29.	*Veronica arvensis* L.	I	4	5	I	3	5
30.	*Sonchus asper* (L.) Hill.	I	2	5	I	1	5
31.	*Sonchus oleraceus* L.	I	1	5	I	1	5
32.	*Capsella bursa-pastoris* (L.) Medik.	I	2	5	I	1	5
33.	*Myosotis arvensis* (L.) Hill	–	–	–	–	–	–
34.	*Polygonum aviculare* L.	I	2	5	I	2	5
35.	*Galinsoga cilliata* (Raf.) S. F. Blake	I	2	5	I	1	5
36.	*Thlapsi arvense* L.	I	1	5	I	1	5
37.	*Erodium cicutarium* (L.) L'H.	I	2	5	I	2	5
38.	*Poa annua* L.	I	2	5	I	1	5
39.	*Senecio vulgaris* L.	I	1	5	I	2	5
40.	*Scleranthus annus* L.	I	1	5	I	1	5
41.	*Setaria viridis* (L.)P. Beauv.	I	2	5	I	2	5
42.	*Melandrium album* (Mill.) Garcke	I	1	5	I	1	5
43.	*Conyza canadensis* (L.) Cronquist	I	1	5	I	1	5

cont. table 7

1	2	3	4	5	6	7	8
	Perenials						
44.	*Elymus repens* (L.) Gould	III	52	5	V	1506	1
45.	*Equisetum arvense* L.	IV	530	1	III	634	2
46.	*Convolvulus arvensis* L.	IV	331	2	II	205	4
47.	*Cirsium arvense* (L.) Scop.	II	125	4	I	102	5
48.	*Plantago maior* L.	I	2	5	I	2	5
49.	*Plantago lanceolata* L.	I	1	5	I	1	5
50.	*Taraxacum officinale* F.H. Wigg.	I	2	5	I	1	5
51.	*Rumex acetosella* L.	I	1	5	I	1	5
52.	*Trifolium repens* L.	I	1	5	I	1	5
53.	*Lotus corniculatus* L.	I	1	5	I	1	5
54.	*Trifolium arvense* L.	I	1	5	I	1	5
55.	*Artemisia campestris* L.	–	–	–	–	–	–

in the occurrence of *Galinsoga parviflora*, *Setaria pumila*, *Matricaria maritima* ssp. *indora* and *Atriplex patula* (all 1st degree of infestation), but *Galeopsis tertrahit*, *Spergula arvensis*, *Avena fatua* and *Apera spica-venti* were not present. Among perennial taxa there was a sharp increase in infestation with *Elymus repens*. Overall on soil suitability complex 5 (good rye) there were 52 weed taxa in 1991–1995, including 41 annuals and biennials and 11 perennial, and 47 dicotyledonous and 5 monocotyledonous. In the second period of the study, conducted in 2014–2015, 49 taxa were counted (38 annuals and biennials and 11 perennial; 46 dicotyledonous and 3 monocotyledonous). In general, irrespective of the soil complex, when the research was resumed after 20 years in selected municipalities of the Zamość region, certain taxa were no longer observed, such as *Papaver rhoeas* and *Avena fatua.* Moreover, the occurrence of *Galeopsis tetrahit*, *Veronica persica*, *Thlaspi arvense*, *Avena fatua*, *Centaurea cyanus*, *Sonchus oleraceus*, *Capsella bursa-pastoris*, *Sinapis arvensis*, *Spergula arvensis*, *Fallopia convolvulus* and *Polygonum persicaria* was very limited, and on poorer soil complexes *Galium aparine* and *Stellaria media* as well. On the other hand, an increase was noted in infestation of the potato crops by *Chenopodium album*, *Echinochloa crus-galli*, *Setaria pumila*, *Matricaria maritima* ssp. *indora*, *Atriplex patula* and *Lamium purpreum*. In addition, among perennial taxa the potato crops are currently infested to the greatest degree by *Elymus repens* and *Equisetum arvense*. As most of these species are nitrophilous, it seems that modern fertilization techniques involving higher levels of mineral fertilizers cause changes in infestation of potato crops, both indirectly (the forecrop) and directly.

Discussion

One of the most important factors affecting crop yield is weed infestation, and therefore the method of weed control is a significant element of cultivation techniques. In the case of potato, infestation at the start of the growing period (primary infestation) and at the end of this period (secondary infestation) is particularly harmful (RĘBARZ and BORÓWCZAK 2009). Secondary infestation developing when weed control procedures are no longer being applied poses a particular threat (SKRZYCZYŃSKA and SKRAJNA 2000). This results in accumulation of diasporas of weeds in the soil, which in subsequent crops are highly problematic for farmers and lead to increased costs associated with soil cultivation in neglected fields in subsequent growing seasons (MAŁECKA and BLECHARCZYK 2000, ZIEMIŃSKA-SMYK and TRĄBA 2004, KLIKOCKA 2010, WRZESIŃSKA et al. 2016).

Losses in potato yield due to weed infestation are mainly caused by the dominant taxa. Weeds considered very harmful include *Chenopodium album*, *Stellaria media*, *Galinsoga parviflora* and *Echinochloa crus-galli*. Other species are mentioned as well, such as *Galium aparine*, *Polygonum persicaria*, *Spergula arvensis*, *Convolvulus arvensis* and *Elymus repens* (ZARZECKA 2002, ZARZECKA and GUGAŁA 2005, JASTRZĘBSKI et al. 2015). These observations are confirmed by the present study. Studies dealing with this topic often identify species that are 'dominant' in the weed infestation, usually established arbitrarily by the author on the basis of abundance (BUJAK and FRANT 2006, KRASKA et al. 2006), or less often according to area cover (ŁABZA et al. 2003, GARGAŁA and TRĄBA 2014).

Weed infestation can also be evaluated using ecological indices (WANIC et al. 2005, 2006, 2016, ORZECH et al. 2016). According to ODUM (1982) species or groups of species which have a decisive effect on energy flow and the living environment of all other species are called ecological dominants. The degree of dominance of one, several or many species can be expressed by a suitable dominance index characterizing the importance of each species in the biocoenosis as a whole. The dominance index is the sum of squares of quotients of coefficients for each species (number of individuals, mass, production, etc.) and the sum of the coefficients. In the present study the dominance index was highest on the good wheat complex (0.116 in 1991–1995 and 0.141 in 2014–2015). On the remaining complexes the dominance index was much lower (by 18.5%). In the second period of the study, 2014–2015, the dominance index was higher than in 1991–1995, and was determined by the abundance of *Elymus repens* (0.024), *Chenopodium album* (0.021), *Echionochloa crus-galli* (0.015), *Stellaria media* (0.012) and *Matricaria maritima* subsp. *indora* (0.009). According to ODUM (1982) and SZOSZKIEWICZ et al. (1998), one of the

best ecological indicators is Shannon's total diversity index, which shows how much of the biocoenosis is comprised of species represented in low numbers and having a low coefficient of importance. A large number of species represented in small numbers has a pronounced effect on diversification of the species composition of individual trophic groups and entire biocoenoses. In the experiments Shannon's total diversity index was on average 0.663 and was highest on the good rye complex in the second period of the study (2014–2015) and on the good wheat complex in the first period of the study (1991–1995). A study by KLIKOCKA et al. (2010) showed that differences in soil cultivation methods and the use of catch crops in potato cultivation did not significantly differentiate the dominance index or Shannon's total diversity index.

Chenopodium album is a noxious weed in root crops with massive occurrence all over Poland (SKRZYCZYŃSKA et al. 2002, GARGAŁA and TRĄBA 2014). It may be present in a variety of environments, but is included among nitrophilous species preferring well-fertilized soils (DOBRZAŃSKI et al. 2002). In the area described in this study this species is a constant taxon on three of the soil complexes investigated and at the same time attains very high area cover, which increased considerably after 20 years of observations. Only on the good wheat complex was it noted at the same level as 20 years earlier. *Matricaria maritima* ssp. *indora* and *Echinochloa crus-galli* also occur frequently in fertile habitats and cover a large area. These are nitrophilous species included among expansive weeds not only in Poland, but in other European countries as well (KAPELUSZNY and HALINIARZ 2010, TRICHARD et al. 2013, RZYMOWSKA et al. 2015). This phenomenon was clearly evident in the present study, in which after 20 years a very pronounced increase was observed in the area cover of these species in the potato crops. Potato canopies, particularly near households, are heavily infested with *Galinsoga parviflora.* Its occurrence is linked to higher levels of organic fertilizer, human activity and zoochory (KAPELUSZNY and HALINIARZ 2010, TRZCIŃSKA-TACIK et al. 2010, ŁUGOWSKA and PAWLONKA 2016). It is a thermophilous species with a short growing period, and over the course of a year it can produce 2–3 generations and a vast number of seeds (even 300,000). It is most abundant in fresh, moist, moderately rich, warm soils with neutral pH (WNUK and ZIAJA 2010). *Galinsoga ciliata* was noted much less often and in a lesser degree in the study area.

Species of the grass family, particularly certain thermophilous monocots, are weeds posing a serious threat in infestation of root crops. An especially expansive taxon is *Echinochloa crus-galli*, one of the most widely distributed weeds in the world (SKRZYPCZAK and ADAMCZEWSKI 2002). In the Zamość region it is a species with massive occurrence on most root crop plantations, and its role has increased considerably in the last 20 years (KLIKOCKA and JUSZCZAK 2010). Another species in this group, *Setaria pumila*, makes up a somewhat

smaller portion of the weed infestation in this area, whereas *Setaria viridis* does not pose a threat to these crops. Among perennial weeds of the grass family the occurrence of *Elymus repens* is notable in the root crops of the area studied. This is a species which is also frequently observed in root crop plantations in other mesoregions of east-central and north-eastern Poland (SKRZYCZYŃSKA et al. 2002, RZYMOWSKA et al. 2015).

Among other perennial species, *Equisetum arvense* and *Convolvulus arvensis* played a major role, which is confirmed in a study on loess soils in the buffer zone of Roztocze National Park (ZIEMIŃSKA-SMYK and TRĄBA 2004). *Convolvulus arvensis* is one of the 15 major weeds in the world and in Poland. Its spread in root crops is due to its high competitiveness and resistance to herbicides. The large quantity of *Equisetum arvense* may indicate localized acidification of the soil (URBANOWICZ 2004). The soils of the area described in this study are largely more or less acidified.

On the basis of the study we can observe a simplification of the floristic composition and vegetation structure in the potato canopies in the Zamość region. Similar observations have been made in other regions of the country (GARGAŁA and TRĄBA 2014). Moreover, an impoverishment of calciphilous flora is observed in the Lublin Voivodeship (HALINIARZ and KAPELUSZNY 2014). This process is the result of the use of chemicals in crops, intensive mineral fertilization (especially with nitrogen), the use of certified seed, mechanization of field work, and a failure to apply proper crop rotation and organic fertilizers (RZYMOWSKA et al. 2015).

In the early 1970s it was already observed that segetal weeds accompanying crops were beginning to vanish. In recent decades many studies have been published on the changes taking place in the flora of fields as a result of intensive agriculture. In the 1990s a list of endangered weed species in Poland was compiled by WARCHOLIŃSKA (1994). It contained 100 species, which constitute a quarter of the weed flora in Poland. In the potato canopies studied in the Zamość region five of the species on this list were identified: *Spergula arvensis*, *Anagalis arvensis*, *Centaurea cyanus*, *Papaver rhoeas* and *Sinapis arvensis*.

Conclusions

1. The intensity of infestation and the floristic richness of the weed communities infesting root crops in the Zamość region were found to depend on habitat conditions. Overall 55 weed species were recorded (43 ephemeral and 12 perennial). The root crops were less infested on good and defective wheat complex soil than on good rye complex soil.

2. There were 45 to 52 species per relevé in the first period of the study (1991–1995) and 41 to 49 in the second period (2014–2015).

3. Nitrophilous species dominated in the potato crops: *Chenopodium album*, *Echinochloa crus-galli*, *Matricaria maritima* ssp. *inodora*, *Stellaria media*, *Galinsoga parviflora*, *Elymus repens* and *Equisetum arvense*.

4. Five taxa from the list of endangered species were noted: *Spergula arvensis*, *Anagalis arvensis*, *Centaurea cyanus*, *Papaver rhoeas* and *Sinapis arvensis*. When the research was resumed after 20 years, *Papaver rhoeas* and *Avena fatua* were not noted in the potato canopies of the Zamość region. However, the proportion of the following species increased in the infestation: *Chenopodium album*, *Echinochloa crus-galli*, *Setaria pumila*, *Matricaria maritima* ssp. *indora*, *Atriplex patula*, *Lamium purpreum*, *Elymus repens* and *Equisetum arvense*.

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