Bulgarian Journal of Agricultural Science, 18 (No 4) 2012, 608-615
Agricultural Academy

DIVERSITY OF WEED FLORA IN WHEAT DEPENDING ON CROP ROTATION AND FERTILISATION

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Abstract

NIKOLICH, L., D. MILOSEV, S. SEREMESICH, I. DALOVICH and V. VUGA-JANJATOV, 2012. Diversity of weed flora in wheat depending on crop rotation and fertilisation. *Bulg. J. Agric. Sci.,* 18: 608-615

The paper analyses weed flora in wheat depending on crop rotation and fertilisation in a twenty-year period. In both studied periods (1990 and 2010) the total of 49 weed species were determined on different variants of crop rotation, while 20 weed species were found in both studies. In the first research period, in 1990, there were 16 differential species, which were not found in 2010, while in the second research, after 20 years, there were 13 new weed species, which had not been previously determined. In the second research period, the floristic diversity was significantly reduced, and in certain variants of crop rotation (three-year rotation, unfertilised three-year rotation and twelve-year rotation) the number of species was reduced two times. In both studied periods, the dominant species were weed-ruderal plants, with the significant share of segetal plants, while the most common life forms were therophytes from the T_4 group. Apart from the positive effects of crop rotation and fertilisation on reducing weediness, the paper also focuses on the presence of species important for biodiversity conservation, such as *Fumaria officinalis* L. from the category of endangered species, as well as seven other species from the category of vulnerable species - *Centaurea cyanus* L.*, Consolida regalis* S.F.Gray*, Papaver rhoeas* L.*, Viola arvensis* Murr., *Lathyrus tuberosus* L.*, Ranunculus arvensis* L. and *Lamium amplexicaule* L., which are most likely to survive among crops.

Key words: diversity, weed, flora, wheat, crop rotation, fertilization

Introduction

Biodiversity is a common term, which comprises all the biological resources of the planet Earth, including genetic, species and eco-system diversity. Biodiversity is changing over time, and in today's civilization and technological conditions, its conservation becomes of primary concern. Fundamental studies, which deal with direct verification and systematisation of the overall biodiversity, are the basis for biological diversity conservation in general. Anthropogenic impact on changes in biodiversity bears numerous risks, and little direct benefits (Stevanovic and Vasic (eds.), 1995).

Therefore, the research focusing on studying and conservation of biodiversity of agro-ecosystems is of great importance, as this kind of research is under the direct anthropogenic influence, and there is an action plan devised at the European level (The 2001 Biodiversity Action Plan for Agriculture /COM/2001/0162).

Within agro-ecosystems, there is a special place for a particular group of plants – weeds, which contribute to the floristic diversity, and whose survival is, on one hand, increasingly endangered (Hulina, 2005), while on the other hand, from the agronomic point of view, they grow among crops causing numerous negative effects which are reflected on the yield and quality of products

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(Kojic and Janjic, 1994; Konstantinovic, 1999; Janjic and Kojic, 2003).

In the process of weed reduction in agro-ecosystems, the most significant measures are agro-technical measures and application of chemical substances. Crop production systems based on a high level of mechanisation (deep tillage, large doses of mineral fertilisers) and chemical substances are not sustainable in the long term as they have negative impact on environment and biodiversity (Barberi et al., 1997). Therefore, proper crop rotation is of special significance in the production technology (Stojkovic et al., 1975; Molnar, 1999; Milošev, 2000; Seremesic, 2005). Crop rotation and fertilisation, being important agro-technical measures, have considerable impact on relations within agrobiocenosis, and consequently on the diversity of weed synusia (Suarez et al., 2001; Derksen et al., 2002; Moss et al., 2004; Teasdale et al., 2004; Anderson, 2005; Kovacevic et al., 2007). It should be noted that there is also indirect impact of crop rotation on the floristic composition, which is reflected in the intensity, time and methods of soil preparation. Lately, the system that has been also increasingly favoured is organic agriculture, which contributes to conservation of biological diversity (Znaor, 1996; Diver, 2001; Barberi, 2002; Kristiansen, 2003, Nikolic et al. 2011).

The aim of this paper is a detailed analysis of changes in diversity, categorisation according to sites and biological spectrum of weed flora in wheat grown in different variants of crop rotation and fertilisation in the period of 20 years. The obtained results can be used as a good basis for monitoring, control, as well as conservation of biological diversity of weed flora in wheat grown with the application of crop rotation and fertilisation.

Materials and Methods

Floristic studies of wheat weed under the conditions of crop rotation and fertilisation were carried out during the vegetation periods of 1990 and 2010 on a long-term experimental field "*Plodoredi*" (established in 1946/47, 1950/51 and 1969/70) of the Institute of Field and Vegetable Crops, Novi Sad, at the location of Rimski Sancevi. The weed flora was studied on the following variants of the experiment: unfertilised two-year and three-year rotation (E2 and E3), established in 1946/47, two-year and three-year rotation with application of mineral fertilisers (I2 and I3), established in 1969/70, twelve-year rotation with application of mineral fertilisers (I12), established in 1950/51, and monoculture of wheat with applied mineral fertilisers (IMO), established in 1969/70. On the fertilised variants of crop rotation, nitrogen mineral fertilisers were applied each year in the amount of 100 kg ha^{-1} (50 kg ha^{-1} in autumn + 50 kg ha^{-1} as dressing). Due to the high level of phosphorus and potassium in soil, these two elements have not been applied since 1986. The trials were set up on chernozem soil type, which belongs to automorph soil types, class A-C (humus accumulative soil, the subtype is chernozem on loess and loesslike sediments, the carbonate chernozem variety, medium deep) (Škorić, 1986). Determination and nomenclature of weed species were carried out according to Josifović (ed.), (1970-1986) and Tutin et al. (eds.) (1964-1980), and life forms according to Ujvárosi (1973), while the categorisation based on sites was performed according to Kojic et al. (1972). The method used for the analysis of organic matter content in soil samples is Tyrin's titrimetric method, in which a soil sample is oxidised with 0.2M potassium dichromate with sulphuric acid and heated to the boiling point for 5 minutes DM 8/1-3-017. pH-value in suspension (10g: 25cm^3) of soil with potassium chloride (potential acidity) was determined potentiometrically by pH-meter, while the content of $CaCO_3$ was determined volumetrically, by Scheibler's calcimeter; ISO 10693:1995. Determination of readily available phosphorus (extraction with ammonium lactate) was performed by AL method; spectrophotometric determination; Determination of readily available potassium (extraction with ammonium lactate) was performed by AL method; flame photometric determination (Ubavić and Bogdanovic, 2006).

Results and Discussion

Comparison of agrochemical properties of the soil was conducted in order to examine how weed flora is dependent on the changes occurring in the arable layer of the soil. During the research period, there was a slight increase of the level of organic matter in the soil, although this was not a general trend, but was associated only with certain farming systems. The obtained results are not in accordance with the research conducted by Seremešić et al. (2010), who determined the decline of organic matter content in the soil in the period 1970-2010. More significant increase of organic matter content was achieved in treatments in which there is both qualitatively and quantitatively higher intake of plant residues (I3), while the differences are more pronounced depending on fertilisation than on crop rotation. The highest content of organic matter was determined for monoculture of wheat (IMO) (Table 1).

The pH value of the soil is slightly lower in the fertilised variants than in the unfertilised ones (Molnar et al., 1997). There is a general trend of increasing pH value by 0.12, which can be associated with bringing up $CaCO_3$ from the deeper layers of the soil to the surface through the basic tillage, but also by application of physiologically acid mineral fertilisers. The content of readily available phosphorus is reduced, but is still within the range of high provision, which is the consequence of regular fertilisation with manure and mineral fertilisers. The smallest changes of readily available phosphorus were determined in the arable layer of unfertilised plots, where the natural reserves of this macroelement are practically depleted, which is reflected in the yield of wheat and floristic composition of weeds.

The content of potassium in soil tends to slightly decrease, but this still does not disturb the normal supply of plants with potassium, as there are considerable reserves of this element in the soil. The obtained results are consistent with previous studies on the same trial conducted by Belic et al. (1986), but contrary to the trend of the general increase of K on the arable land due to application of mineral fertilisers (Vasin and Sekulic, 2005). The content of $CaCO_3$ shows great absolute variations depending on farming systems (even up to 40%). Its content increased in the surface layer of the soil, which is also associated with pH values of the arable layer, as pH values indirectly increase due to deepening of the arable layer. Molnar et al. (1997) and Milosev (2000) present similar findings in the studies.

The comparison of wheat yield was conducted for both analysed years as well as the average yield for the period 1970-2010 (Figure 1).

The analysis of the achieved yield of wheat points to a significant difference between fertilised and un-

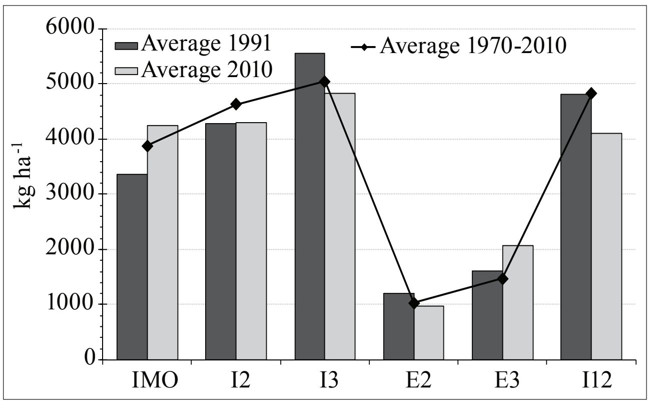


Fig. 1. Average yield of winter wheat at different cropping system 1970-2010, 1991 and 2010

Table 1
Comparative review of agro-chemical properties of the studied farming systems

	Humus, %			pH (KCl)			Al-P_2O_5 mg 100g $^{-1}$			Al-K_2O, mg 100g $^{-1}$			$CaCO_3$, %		
	1991	2010	diff	1991	2010	diff	1991	2010	diff	1991	2010	diff	1991	2010	diff
IMO	Feb-87	Feb-88	-0.01	Jul-38	Jul-56	-0.18	53.40	29.21	24.19	46.20	31.94	14.26	Jan-28	3-Jul	-1.79
I2	Feb-61	Feb-60	0.01	Jul-33	Jul-29	0.04	64.30	44.71	19.59	45.00	31.41	13.59	Jan-49	Jan-36	0.13
I3	Feb-41	Feb-69	-0.28	Jul-47	Jul-56	-0.09	105.30	94.08	Nov-22	47.40	41.34	6-Jun	May-55	Mar-24	Feb-31
E2	2-Sep	Jan-98	0.11	Jul-50	Jul-65	-0.15	Jul-20	5.00	Feb-20	15.40	14.97	0.43	May-96	Oct-25	-4.29
E3	Feb-30	Feb-33	-0.03	Jul-41	Jul-60	-0.19	Aug-30	Apr-40	Mar-90	16.80	17.72	-0.92	Feb-98	May-50	-2.52
I12	Feb-53	Feb-65	-0.12	Jul-44	Jul-57	-0.13	56.40	32.20	24.20	45.00	39.50	May-50	Feb-55	Jan-38	Jan-17
	Feb-47	Feb-52	-0.05	Jul-42	Jul-54	-0.12	49.15	34.93	14.22	35.97	29.48	Jun-49	Mar-30	Apr-13	-0.83

fertilised experiment variants. The highest yield was achieved on the fertilised three-year rotation, followed in most of the years by fertilised two-year and twelve-year rotation. Nitrogen fertilization was found to be the most important agronomy practice for the formation of higher grain yield (Ivanova and Tsenov, 2010). When comparing the fertilized rotations, monoculture had the lowest yield. However, despite the unfavourable crop rotation, it was shown that monoculture could achieve the yield between 3000 and 4000 kg ha^{-1}. In addition to that, winter wheat grain yield responded to preceding crop and residual N in soil profile. Dogan and Bilgili (2010) in rain-fed Mediterranean conditions also found positive influence of previous crop and N fertilization on grain yield. The lowest yield was obtained on unfertilised rotations with 1000 kg ha^{-1} on unfertilised two-year rotation and 1500 kg ha^{-1} on unfertilised three-year rotation. After analysing the yields from several years it was found that, there is certain stability in yields at a certain level and relatively small annual variations (Milosev, 2000; Milosev et al., 2010; Seremesic, 2011). At the same time, the real potential of wheat yield was not fulfilled, most frequently due to unfavourable crop rotation (I2 and E2) or absence of fertilisation (E2 and E3).

By examining the weed flora on the long-term field trial "*Plodoredi*" the 49 weed species from 44 genera, classified in 23 families were determined. The most numerous representatives were from the family *Asteraceae* with 6 species and *Lamiaceae*, *Fabaceae* and *Poaceae* with 4 species each. Other families were represented with only two or one species (Table 2).

In the total floristic composition in both studied periods (1990 and 2010), there were 20 weed species in common on all the studied variants of crop rotation. In the first research period (1990), there were 16 differential species which were not found in 2010. However, in the second research period (2010) 13 new weed species had not been determined in the previous period (Table 2).

With regard to floristic diversity, significant differences can be determined between certain variants of crop rotation and fertilisation, as well as between the studied periods. Greater diversity of weeds was determined in 1990 for all the experiment variants. The prominent variants in the 1990 experiment in terms of the number of species are unfertilised two-year rotation (24 weed species), twelve-year rotation (22 species), unfertilised three-year rotation (21 species) and two-year rotation (19 species). After twenty years, there was a considerable reduction in the number of weed species in all the studied variants of the experiment, and in certain variants the number of species decreased almost by half (Figure 2). The highest wheat yield was determined on the fertilised variants (three-year, two-year and twelve-year rotation), which points to the increased competitive ability of wheat in relation to weed when sufficient amount of nitrogen is provided. Thus, growing crops with different crop rotations and fertilisation resulted in reduction of floristic diversity, which is also confirmed by the literature data (Moss et al., 2004; Randy, 2005; Nikolic et al., 2008).

In the total number of species in both studied periods, the dominant species are weed-ruderal species (29; 59.18%), followed by segetal species or weed in a narrower sense with 18 species (36.73%), one (2.04%) is ruderal and one (2.04%) is weed of meadows and pastures. In the first research (1990), out of 36 species, the dominant ones were also from the category of weed-ruderal species (23 species; 63.89%), 11 species (30.56%) were segetal, one (2.78%) was from the category of ruderal and one (2.78%) was meadow and pasture weed. After twenty years, it was found that the number of weed-ruderal plants was reduced (18 species; 54.55%), while the share of the segetal species was increased (14 species; 42.42%). There was only one (3.03%) ruderal species (Table 2).

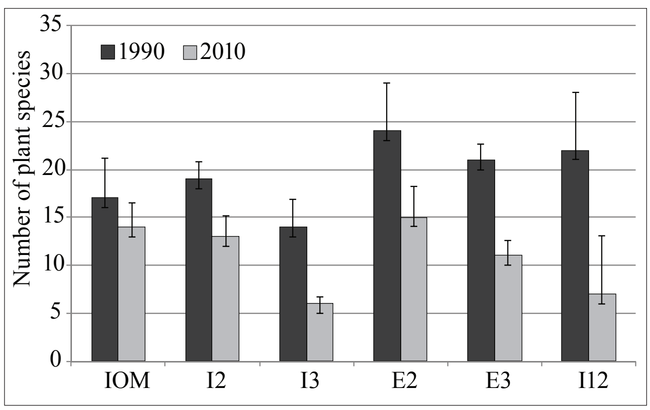


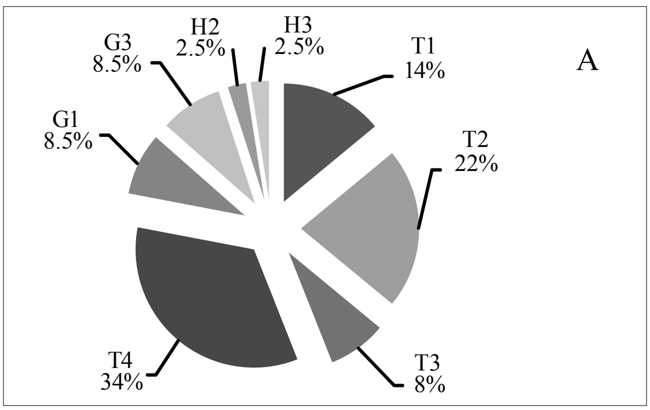
Fig. 2. The number of plant spacies at different cropping systems in 1990 and 2010

Table 2
Taxonomic review of weed species and their life forms and category according to site

Family	Genus	Plant species	Life form	Category according to site	1990	2010
Equisetaceae	Eqisetum	*E. arvense* L.	G_1	s	+	
Ranunculaceae	Adonis	*A. aestivalis* L.	T_2	s		+
	Consolida	*C. regalis* S.F. Gray.	T_2	s	+	+
	Ranunculus	*R. arvensis* L.	T_2	s		+
Papaveraceae	Papaver	*P. rhoeas* L.	T_2	s	+	+
Fumariaceae	Fumaria	*F. officinalis L.*	T_3	*s*	+	+
Caryophyllaceae	Stellaria	*S. media* (L.) Vill.	T_1	wr	+	+
Chenopodiaceae	Chenopodium	*C. album* L.	T_4	wr	+	+
		C. hybridum L.	T_4	wr		+
	Atriplex	*A. patula* L.	T_4	wr	+	
Polygonaceae	Bilderdykia	*B. convolvulus* (L.) Dum.	T_4	wr	+	+
	Polygonum	*P. aviculare* L	T_4	wr	+	+
		P. lapathifolium L.	T_4	wr	+	
Violaceae	Viola	*V. arvensis* Murr.	T_{2-3-4}	s	+	+
Brassicaceae	Capsella	*C. bursa-pastoris* (L.) Medik.	T_1	wr	+	+
	Sinapis	*S. arvensis* L.	T_3	s	+	+
Primulaceae	Anagallis	*A. arvensis* L.	T_4	wr	+	+
		A. femina Mill.	T_4	s		+
Euphorbiaceae	Euphorbia	*E. cyparissias* L.	G_3	wr	+	
		E. helioscopia L.	T_4	s		+
Fabaceae	Lathyrus	*L. tuberosus* L.	G_1	s		+
	Medicago	*M. lupulina* L.	T_4	wr		+
	Trifolium	*T. repens* L.	H_2	wr	+	
	Vicia	*V. villosa* Roth.	T_2	s	+	
Oxalidaceae	Oxalis	*O. stricta* L.	G_1	wr		+
Apiaceae	Daucus	*D. carota* L.	T_4	wr	+	
	Turgenia	*T. latifolia* (L.) Hoffm.	T_2	s	+	
Rubiaceae	Galium	*G. aparine* L.	T_2	wr	+	+
Sambucaceae	Sambucus	*S. ebulus* L.	G_1	wr	+	
Convolvulaceae	Convolvulus	*C. arvensis* L.	G_3	wr	+	+
Boraginaceae	Lithospermum	*L. arvense* (L.) Vahl.	T_2	s	+	+
Solanaceae	Datura	*D. stramonium* L.	T_4	wr		+
	Solanum	*S. nigrum* L.	T_4	wr		+
Scrophulariaceae	Veronica	*V. hederifolia* L.	T_1	wr	+	+
	Rhinanthus	*R. major* Ehrh. (R.)	T_3	mw	+	
Lamiaceae	Galeopsis	*G. tetrahit* L.	T_4	wr	+	+
	Lamium	*L. purpureum* L.	T_1	wr	+	
		L. amplexicaule L.	T_1	wr		+
	Stachys	*S. annua* L.	T_4	s		+
Asteraceae	Ambrosia	*A. artemisiifolia* L.	T_4	r	+	+
	Centaurea	*C. cyanus* L.	T_2	s	+	+
	Cirsium	*C. arvense* (L.) Scop.	G_3	wr	+	+
	Erigeron	*E. canadensis* L	T_4	wr	+	
	Sonchus	*S. oleraceus* (L.) Gou.	T_4	wr	+	+
	Taraxacum	*T. officinale* Web.	H_3	wr	+	
Poaceae	Agropyrum	*A. repens* (L.) Beauv.	G_1	wr	+	
	Poa	*P. annua* L.	T_1	wr	+	
	Setaria	*S. viridis* (L.) Beauv.	T_4	s	+	
	Sorghum	*S. halepense* (L.) Pers.	G_1	s		+
Total 23	**44**	**49**			**36**	**33**

Legend: T – therophyte, G – geophyte, H – hemicryptophyte, S – segetal weeds, R – ruderal species, WR – weed-ruderal species, MW – meadow weed

The analysis of the total biological spectrum in 1990 on all the variants of the experiment indicates the dominance of therophytes with 78% (28 taxa), the most dominant of which were T_4 therophytes. The life form of geophytes accounted for 1/6, or 17% (6 taxa), which is understandable due to substantial share of weed-ruderal plants compared to segetal ones. Hemicryptophytes were represented by only 5% (2 taxa) (Figure 3A). In the second study period (2010), the only weed life forms that developed were therophytes and geophytes. After twenty years, the dominance of therophytes became even more prominent in the biological spectrum, which is certainly the consequence of strong anthropogenic impact, i.e. instability of weed synusia (Kojic et al., 1988; Kovacevic, 2008). Thus, therophytes accounted for 84.84% (28 species), while the most common among them were again T_4 therophytes (14 species; 42.42%). Geophytes accounted for only 15.15% (5 species) (Figure 3B).



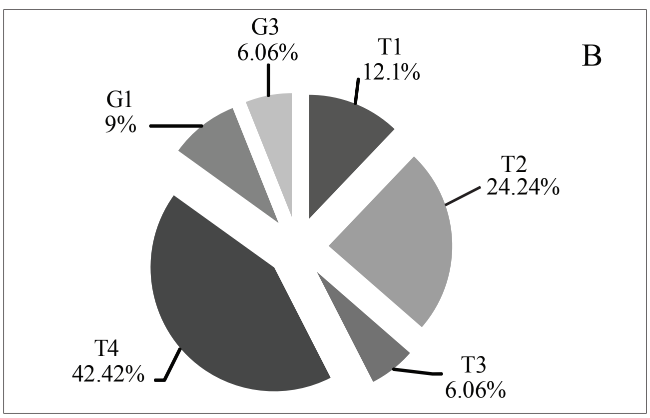


Fig. 3. Biological spectrum of weeds on all variants of cropping systems 1990 (A) and 2010 (B)

Diversity of the weed flora of the studied area is characterised by the presence of plant species that are under the special protection regime in Serbia. Thus, in the first research period there was one legally protected species – *Equisetum arvense* L. (Official Gazette of RS, no. 36/09) and the following 10 species protected by control of collection, use and distribution (Official Gazette of RS, no. 31/05, 22/07): *Taraxacum officinale* Webb., *Equisetum arvense* L. and *Agropyrum repens* (L.) Beauv were determined only in the first study period, while the species determined in both periods were *Centaurea cyanus* L., *Capsela bursa-pastoris* (L.) Medik., *Chenopodium album* L., *Fumaria officinalis* L., *Papaver rhoeas* L., *Polygonum aviculare* L. and *Consolida regalis* S.F. Gray.

Interestingly, among the determined weed species there were also the ones that, according to the world IUCN list (Walter and Giller, 1998), belong to special categories: from the list of endangered species, there was the segetal plant species *Fumaria officinalis* L. in both research periods. From the category of vulnerable species there were 7 species: 4 segetal (*Centaurea cyanus* L., *Consolida regalis* S.F. Gray., *Papaver rhoeas* L. and *Viola arvensis* Murr.) in both research periods, while in 2010 there were three new species from this category, two of which were segetal (*Lathyrus tuberosus* L. and *Ranunculus arvensis* L.) and one weed-ruderal (*Lamium amplexicaule* L.). Hence, during the twenty-year period, there were no endangered or vulnerable species that disappeared from these agroecosystems, but new segetal species from the abovementioned protection categories appeared.

Conclusion

It can be concluded that crop rotation and such agroecosystems are of great importance for preservation of species, which are most likely to survive in their typical environment, i.e. among crops. Weed species which are becoming increasingly endangered today can be protected and preserved in different ways, some of which are introducing organic agriculture, reduced application of herbicides, reduced application of fertilisers, while one of the possible measures is also preservation of these species within botanical gardens (Znaor, 1996; Moss et al., 2004; Hulina, 2005).

Acknowledgements

This study is part of the projects TR - 31016 and TR- 31073 which is supported by the Ministry of Education and Science of the Republic of Serbia.

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Received July, 24, 2011; accepted for printing April, 2, 2012.