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Weed species diversity and community composition in organic potato field

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Abstract

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Weeds are the component of biological diversity in the agricultural systems (agrobiodiversity) and one of the greatest limiting factors to efficient organic crop production.

The goal of the experiment is to define the influence of organic agricultural practices on the dynamics of weed infestation, weed species diversity and community composition in organic potato field included in three-field crop rotation.

The results show that all analyzed weed parameters are characterized by high dynamics during potato grown seasons. The biological development of weeds in the cover crop before incorporation to the potato field was strongly limited. According to the data obtained, cover crop for green manure and mechanical soil tillage in the organic potato field were effective practices for controlling the weed infestation. The effect of organic practices on the weed community parameters were assessed by ecological indexes (Shannon index (H′), Shannon-Wiener evenness index (J′), index of dominance (Simpson dominance index**,** D) and similarity indexes (Sørensen similarity index, SSI). Results show that the studied three-field crop rotation included winter wheat, green bean, peas and rye mixture as cover crops and potato is a strategic scheme for achieving good weed control at the end of the rotation. The comparison of similarity of weed communities in a potato field between 2012 and 2013 using Sørensen indices shows that the similarity was higher on the base of the qualitative index (35.3%) than of the quantitative ones (20.8%).

Keywords: organic potato; green manure; weed community; ecological indexes

Introduction

The weeds are one of the greatest limiting factors to the efficient organic crop production. The sustainable weed management requires applying of agricultural practices, which not only influence the weed density and community but also keep their positive impact on the ecology. The published results show that the organic fields are usually characterized by high weed density and biomass compared to the conventional ones (Rasmussen et al., 2006; Feledyn-Szewczyk, 2012; Armengot et al., 2013) because the organic practices have lower weed control effects than that of the herbicides.

The crop rotation is a fundamental part of the organic farming systems. The diversification of species in the farming systems is one of the strategies for regulation of the weed density and community structure but the effect depends on many biotic and abiotic factors (Barbieri et al., 2017).

The aim of present study is to analyze the influence of different organic practices on the weed species diversity and community composition in an organic potato field, which is included in a biological crop rotation.

Material and Methods

The study was conducted at the Suhodol Experimental Station (near Sofia) of the Institute of Soil Science, Agro-Technology and Plant Protection "N. Pushkarov". The potato field was a part of three-field crop rotation: 1) winter wheat (*Thriticum aestivum* L.); 2) green bean (*Phaseolus vulgare* L.) with organic manure, 3) cover crop (mixture of *Secale sereale* + *Peasum sativum*) for green manure – potato (*Solanum tuberosum* L.). The cover-crops mixture was sown in autumn and incorporated as a green manure in spring before potato planting. All crops have been grown according to the organic standards since 2004. In this paper data for 2012–2013 are presented. The weed infestation of crop area was determined by weigh-counting method on 1 m^2 area (3 samples) in each 4 replications. The assessment of weed infestation included weed species composition as well as the number of weeds and their green and dry matter. The weed species composition was measured in cover crop mixture before incorporation into the potato field and three times during the potato vegetation period. Different ecological indexes (Shannon' index of biodiversity (H′), evenness (J′), Simpson dominance index were applied for weed community assessment. Sørensen similarity indexes (qualitative and quantitative) were used for comparison of the weed community's similarity in the potato field between 2012 and 2013.

Weed biodiversity within the communities was estimated and compared based on: species richness (S) – number of species in the community; Shannon-Wiener diversity index (H′): $H' = -\Sigma p_i (\mathrm{Ln}\, p_i)$, where Ln-natural logarithm and p_i –relative abundance of the *i*-th species in the community, Shannon-Wiener evenness index (Pelou's index, J′): J′= H′/LnS, Simpson dominance index: $D = \Sigma\, p_i^2$.

The qualitative, accordance to weed species, and quantitative similarities between weed communities compared using the Sørensen similarity indexes: 1) Sørensen qualitative index: $SSI_1 = [2C(A + B)^{-1}]*100$, where C – the number of the common to each community species and A + B – the sum of total number of species in each community; and 2) Sørensen quantitative index: $SSI_2 = [2jN(Na + Nb)^{-1}]*100$, where jN – the sum of lower of the two abundances of each species in the community; Na – all number of individuals in population A; and Nb – all number of individuals in population B. All indexes were described by Magurran (Magurran, 2004).

Results

The first assessment of weed infestation in 2012 and 2013 was done in a grass-leguminous mixture field before incorporation as a green manure into the potato field. The weed infestation level in 2012 was not very high – the weed density reached 33 plants/m^2 with green biomass of 16.56 g/m^2. We have to note that at this moment the grass-leguminous mixture has accumulated a high amount of fresh biomass, which suppressed the weeds. The data of weed density are presented in Table 1, and fresh and dry weed biomass – on Figure 1.

The weed infestation in control plot (bare fallow) increased considerably (192.6 pl./m^2 and biomass of 112.5 g/m^2) in comparison to the field of cover crops. These results highlight the role of the cover crops for green manure for controlling the weed density. The observed results in early spring of 2013 were similar – the weed density was 36.5 pl./m^2 with 28.65 g/m^2 fresh biomass. The weed community structure in 2012 was dominated by annual weeds. The weed spaces were presented mainly by weeds with spring and winter-spring biological life cycle. *Veronica hederifolia* L. was the prevalent weed species. The population density of perennial weeds in the cover crops phytocoenosis was not very high (6 plants/m^2). The perennial weeds were dominated by *Euphorbia* sp. L. which was the main weed species in this group, but the weed plants were not well developed and the fresh weed biomass was only 2 g/m^2. The small abundance level of perennial weeds could be explained by the crop rotation design, where the potato planted after the other row crops (green bean), which technology was also based on the inter-row mechanical cultivations. In addition, the soil tillage operations for the seed bed preparation of the cover crops destroyed the emerged weeds in late autumn. During spring, weed plants were suppressed by the dense stand of the cover crops and they did not accumulate high amount of biomass. In the next experimental year (2013), the weed community in the cover crops was characterized by higher proportion of perennial weeds than in previous measurement. *Convolvulus arvensis* L. was totally predominant in the community of perennial weeds (70%). The weed density was not an adequate parameter to characterize completely the infestation. At this moment low fresh weed biomass was measured – only 18.44 g/m^2.

The potato was planted immediately after the cover crops incorporation. The next weed sampling was done before the first inter-row mechanical cultivation of the potato in June. According to the received data, the weed community composition changed as a result of soil tillage before the potato planting, which eliminated the weeds of the early and spring-winter group have observed in the cover crop phytocoenosis. In this time of vegetation, the species of the late spring biological group dominated in the weed community. The total numbers of annual and perennial weeds were 72 pl/m^2 with higher fresh biomass compared to the previous assessment. The meteorological conditions were more suitable and stimulated the crop and weeds development. The weed community was dominated by *Hibiscus trionum* L. with 34 pl/m^2 and proportion

Table 1. Weed species density (plants/m²) during the potato vegetation

Weed species	2012				2013		
	Weed sampling						
	1-st 22.04.	2-nd 20.06.	3-rd 6.07.	4-th 12.08	1-st 28.04	2-nd 18.06.	3-rd 14.08
Lamium amplexicaule L.	1.5	–	–	–	–	–	–
Veronica hederifolia L.	13.0	–	–	–	–	–	–
Anthemis arvensis L.	6.5	1.0	–	–	–	–	1.0
Ranunculus arvensis L.	5.0	–	–	–	1.0	–	–
Setaria viridis L.	–	27.5	2.5	15.7		5.3	4.0
Amaranthus retroflexus L.	–	–	–	2.6	–	–	
Anagallis arvensis L.	1.0	–	–	–	–	–	–
Polygonum aviculare L.	–	–	–	–	2.5	–	–
Taraxacum oficinale L.	1.0	–	–	–	–	–	–
Portulaca oleracea L.	–	–	–	–	–	2.3	2.0
Echinochloa crus-galli L.	–	–	1.0	0.7	–	1.7	1.5
Plantago major L.	–	–	–	–	–	1.0	4.0
Mentha arvensis L.	1.0	–	–	–	–	–	–
Cirsium arvense L.	–	8.5	8.5	2.3	3.0	2.0	3.0
Convolvulus arvensis L.	–	–	5.0	4.0	25.5	1.3	–
Lithospermum arvense L.	–	–	–	–	–	–	1.5
Hibiscus trionum L.	–	–	13	17.3	–	3.7	–
Euphorbia sp.	4.0	–	–	–	1.5	–	–
Sonchus arvensis L.	–	–	–	–	–	2.7	1.0
Chenopodium album L.	–	1.0	–	1.0	–	–	–
Xanthium strumarium L.	–	–	–	–	3.0	–	–
Hibiscus trionum L.	–	34.0	–	–	–	–	1.5
Mentha arvensis L.	–	–	1.5	1.0	–	–	–
Total weeds	33.0	72.0	31.5	44.6	36.5	20.0	19.5
The statistical significance using one-way ANOVA	$GD_{5\%} = 16.2$; $GD_{1\%} = 18.0$; $GD_{0.1\%} = 24.8$				$GD_{5\%} = 7.2$; $GD_{1\%} = 12.4$; $GD_{0.1\%} = 16.8$		

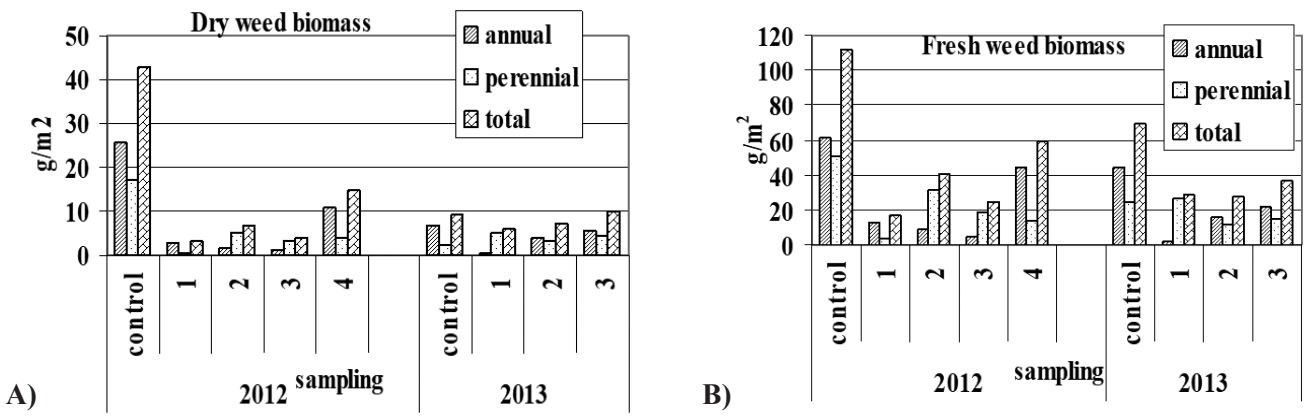

Fig. 1. Fresh (*A*) and dry weed biomass (*B*) during the potato growing season (1, 2, 3, 4 – weed samplings)

of 50% from weeds abundance. Opposite to the high density at the beginning of the vegetation, the weed species formed very small amount of green biomass (3.51 g/m^2) without any practical influence. The species *Setaria viridis* L., which is mono-cotyledonous weed, had higher density than the other species presented in the community. The group of perennial weeds was presented in a small proportion and included only *Cirsium arvense* L. with 8.5 pl/m^2.

The observation shows that the arable weed vegetation was a very dynamical system. Weed flora changed over the growing season. It responds to the agronomic factors associated with crop cultivation and, at the same time, with the climatic conditions. During the potato vegetation period the new germinated weeds were destroyed by timely applied mechanical cultivations and in the tuber formations stage the number of weed plants was lower than in the previous sampling. It is well known that soil tillage operations considerably influence the weed germination, weed seeds bank in soil and also their distribution within the soil profile. In the third weed sampling before the other soil cultivation in July the weed density was twice lower compared to the first measurements and the differences are statistically significant ((GD = 0.01%). The number of weeds was 32 individuals per 1 m^2 with of 24 g/m^2 green biomass and very small dry biomass of 4 g/m^2. This means that the weeds formed insufficient weed biomass which could not influence the plant growth.

Both annual and perennial weeds were presented in the community composition by equal proportion (52% and 48%). The weeds were mainly of the late-spring biological group. The *Hibiscus trionum* L. species was dominant with share of 40% but the weed density was 60% lower compared to previous measurement. *Setaria viridis* L. and *Echinochloa crus-galli* L. were practically eliminated to the non significant number of 1–2 individuals per 1 m^2. The weed infestation with perennial weeds also was decreased substantially. The perennial weeds were represented mainly by *Mentha arvensis* L., *Cirsium arvense* L., *Convolvulus arvensis* L., which reached 79% of the total weed biomass in the samples. The control of the weed density with species of this group usually is more difficult for biological management because are several mechanical and cultural operations are to be applied. These figures emphasize on the effectiveness of two mechanical cultivations applied during the potato vegetation period for substantial decreasing of the weed density. The effective weed control during the previous crop in the crop rotation also had important role for this result.

In the next experimental year (2013) the weed density accounted during the potato flowering and tuber formation was not very high too, despite of the heavy rains in June and July (131.6 mm and 59.7 mm) and the fact that after the first cultivation new weeds was provoked to germinate. The annual and perennial weeds were identified with total weeds number of 20 individuals per 1 m^2, green biomass of 27.41 g/m^2 and dry weight of 7 g/m^2. The proportions of both weed groups in the weed community were 65% to 35%. The annual weeds were identified by different mono- and dicotyledonous weeds, presented by a few numbers in diapason of 1 to 5 individuals per 1 m^2. The weed community consisted mainly of *Setaria viridis* L., *Hibiscus trionum* L., *Echinochloa crus-galli* L., and *Portulaca oleracea* L.

In general, the potato field at harvesting was characterized by a significantly lower number of weed species than at the beginning. In 2012, late-spring annual weeds *Setaria viridis* L., *Hibiscus trionum* L. and *Amaranthus retroflexus* L., dominated. In the weed community, few numbers of *Echinochloa crus-galli* L. and *Chenopodium album* L. species were also identified. They accounted 84% of the total weeds abundance. The weeds of these biological groups typically occurred in the area of the spring-summer crops and usually germinate after the last mechanical tillage operation. At harvesting, when part of the potato biomass was dead and good conditions for secondary infestations were created, new weeds germinated. This was the reason for establishing an increased number of annual weeds in the last vegetation stage of the potato, about twice higher, compared to their number at the beginning of vegetation. Weed density remained at a low level. The density of the perennial weeds substantially decreased as a results of mechanical soil tillage operations during the summer period when the weed roots and belowground stems were cut off and buried in the soil or exposed to the climatic factors. The successful control on perennial weeds *Mentha arvensis* L.*, Cirsium arvense* L. and *Convolvulus arvensis* L. was measured.

The observed tendency at potato harvesting in 2013 was similar accounted 45.3% lower weed numbers than the beginning of potato vegetation. It is obvious that timely soil tillage operations during potato vegetation are very effective for weed control against to both annual and perennial weeds.

The summarized results show that the weed density values change substantially during the period of investigation. The coefficient of variation (CV) was higher than 30% which indicated that the weed communities were strong in heterogeneity and the infestation level depended on many factors and their interactions.

The results indicated that the weed species richness in the potato field varied substantially during the study period – from 5 to 10 species. The greatest weed richness (10 species) was counted in the cover-crops field in 2012 which was higher than the measured species in 2013 (6 species).

In the study of the weed community structure in a potato field it was found that the weed species composition was sig-

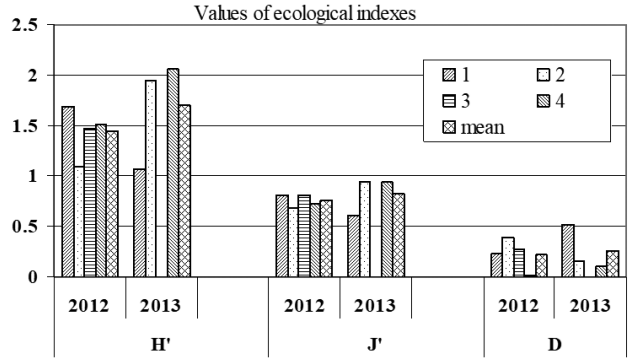

Fig. 2. Values of ecological indexes for assessment of the weed community structure during the potato grown season (1, 2, 3 and 4 are the weed sampling)

nificantly affected by the agronomy management. The measured weed species in an organically managed potato field were from 5 to 9 species. The weed flora changed over the grown season under the influence of the cover crop for green manure and the mechanical soil cultivation in the potato field.

Figure 2 demonstrates the reflected by the Shannon-Wiener index of diversity (H′), evenness (J′) and Simpson index of domination (D) weed flora diversity.

Shannon-Wiener index of diversity (H′), from the beginning of growing season up to harvesting of potato, increased from 1.09 to 1.50 in 2012 and from 1.95 to 2.06 in 2013 showing increased biodiversity, irrespective of the intensive soil tillage. The weed species diversity was unsatisfactory which indicated for a low level of complexity of the weed communities. The evenness (J′) is the measure of abundance heterogeneity among the species in a community. According to the average values of species evenness (J′ = 0.75-0.82), the weed communities were relatively even. The values of the Simpson index (D) in the potato harvesting indicated no one weed species dominated in this community. On the contrary, the highest value of this index was observed for the flora community in the cover crop in 2013 because of the dominance of one species *Convolvulus arvensis* L. The comparison of similarity of weed communities in the potato field between 2012 and 2013 by using Sørensen indices show that the similarity was higher on the base of the qualitative index (35.3%) compared to the quantitative ones (20.8%).

Discussion

The role of weeds in theagroecosystems has been largely debated because of both their potential delivery of ecosystem services and the competition between weeds and crops. Weeds of arable land are a component of the biological diversity in the agricultural ecosystems, and they play a vital role in supporting the diversity within the crop fields and also offer different ecological and agronomical services (Armengot et al., 2013; Jastrzębska et al., 2013). The organic fields are usually characterized by higher levels of weed infestation than the conventional ones, probably because of mechanical weed control and due to the fact that the other cultural methods commonly achieve lower control effect than the herbicides (Feledyn-Szewczyk, 2012; Jastrzębska et al., 2013; Wortman et al., 2010).

Organic farming system is based on the use of environmentally friendly production methods that include crop rotations with a large share of legumes, organic fertilizers, and non-chemical methods of plant protection. The use of cover crops in crop rotations is usually recognized as an important management method in the organic production systems (Robačer et al., 2010). Cover crops can affect weed populations in the short and long terms with different mechanisms. They suppress the weeds by competing for the use of light, nutrients and moisture, by effects of allelopathy and in the organic farming are an alternative to the chemical weed control (Bogužas et al., 2010; Barberi, 2002). The results of the present study indicated that the cover crops suppressed the weeds and the weed infestation level in early spring before incorporation to the soil was twice lower than in the bare fallow field. The mechanical soil tillage for preparing the soil bed for the cover crop sowing also influenced the weed infestation through destroying the germinated weeds in the late autumn.

Mechanical cultivation is a common method of weed managing in the organically managed systems. According to Barberi (2002), direct (physical) weed control can be successful only where preventive and cultural weed management is applied to reduce weed emergence (e.g. through an appropriate choice of crop sequence, tillage, smother/cover crops) and improve the crop competitive ability (e.g. through appropriate choice of the crop genotype, sowing/ planting pattern and fertilization strategy). Potatoes were traditionally regarded as a cleaning crop. We observed that weed density and weed biomass changed over the potato growing season depending on the inter row mechanical cultivation and the other factors. The low number of accounted weeds could be explained also with the crop rotation design where potato was grown after the other spring row crop (green bean).

The studied three-field crop rotation with winter wheat, green bean, peas and rye mixture as cover crops and potato are a strategic scheme for achieving good weed control. This is similar to previous studies that reported that by rotating crops with different planting dates and growing periods, contrasting competitive characteristics and dissimilar management practices, weeds can be under control (Liebman & Davis,

2000). Weed dynamics are disrupted when seasonal crops are arranged in a sequence of two cool season crops followed by two warm season crops (Anderson, 2015) like in the studied crop rotation. In the experiment discussed here, the density of the perennial weeds at the end of the potato vegetation period substantially decreased.

Organic management changed the weed community structure and, as consequence, the agroecosystem functioning. The values of Shannon weed biodiversity index, evenness (J') and richness (S) were influenced by the crop rotation complexity, crop characteristics and kind of organic fertilization (Wortman et al., 2010; Marinov-Serafimov et al., 2016). According to Jastrzębska (2013), the organic farming contributed for higher weed species diversity, observed in root crops, and the values of Shannon-Wiener index was statistically higher in organic systems, including cover crops for green manure (H' =1.70) (Edesi et al., 2012). Nikolić et al. (2013) founded small differences in the weed flora structure between conventionally and organic grown potato crops, most likely due to agrotechnical practices. The comparison between the weed communities by using Sørensen indices manifest that qualitative changes are slower than the quantitative ones (Feledyn-Szewczyk, 2012). Our data also supported this conclusion because the comparison between the similarity of the weed communities in a potato field between 2012 and 2013 by using Sørensen indices show that the similarity was higher on the base of the qualitative index (35.3%) than the quantitative one (20.8%). We agree with the opinion of the researchers who indicated that the weed infestation is the major crop protection problem in the organic farming systems, and the development of weed management strategies requires detailed information on the weed population dynamics.

Conclusions

The arable weed vegetation was a very dynamical system. All analyzed weed parameters (weed density and weed biomass) and weed community structure (species diversity, richness, evenness and dominance) influenced by a cover crop for green manure and mechanical soil cultivation and other factors in a potato field. The studied three-field crop rotation that included winter wheat, green bean, peas and rye mixture as cover crops and potato is a strategic scheme for achieving good weed control at the end of the rotation. The comparison of similarity of weed communities in a potato field between 2012 and 2013 using Sørensen indices shows that the similarity was higher on the base of the qualitative index (35.3%) than of the quantitative ones (20.8%).

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