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Analysis of weed biomass and winter cover crops prior to soybean sowing in sustainable production systems

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SUMMARY

This study investigates the role of winter cover crops in controlling weeds within low-input and organic farming systems prior to soybean sowing. Weeds are a persistent challenge in crop production, especially in organic production systems, requiring effective management strategies to ensure high yields, productivity and environmental sustainability. Traditionally, herbicides were commonly used, but growing concerns over their environmental impact have shifted the focus toward sustainable agricultural practices. This research explores the use of winter cover crops, such as rye and pea-oat mixtures, to reduce weed biomass in fields under low-input and organic farming conditions. Trials were conducted over three years in Serbia (2019-2022) demonstrate that cover crops significantly reduce weed biomass, with rye proving to be a strong competitor. The study highlights the potential of cover crops as an effective ecological strategy for weed management prior soybean sowing, offering benefits such as reduced herbicide use, conservation tillage, improved soil health, erosion prevention, and better long-term crop yields.

Keywords: cover crops, weeds, low input production, organic production, soybean.

INTRODUCTION

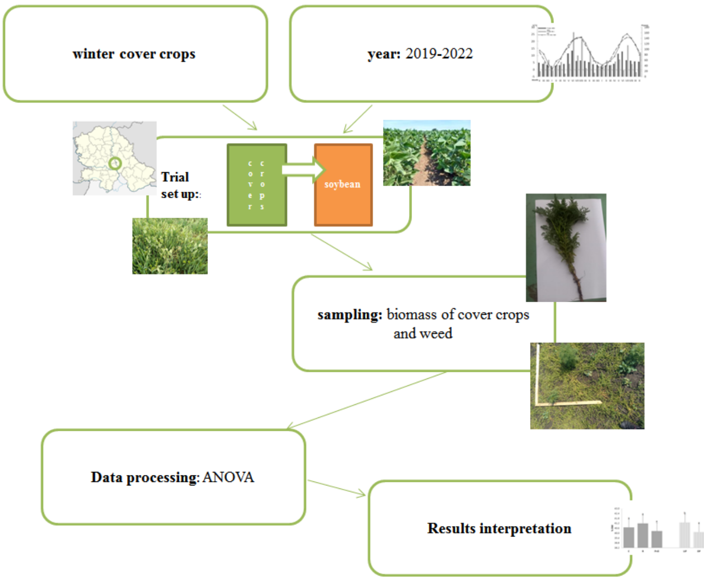
Weeds are a constant subject of monitoring worldwide, because of their connection and co-existence with cultivated plants (Vilà et al., 2021; Horvat et al., 2023; Grün et al., 2024). Since the very beginning of agricultural practice, significant efforts have been made to protect crops and achieve the highest possible yield. However, due to various external influences, ongoing changesin the agro-ecosystem, and the interactions between plants and weeds, it has become necessary to adapt cultivation technology and practices to ensure production which aligns with the requirements of organic or low-input production. The previous century was a period of intensive "modern" agricultural production, characterized by the use of excessive inputs, i.e. the use of pesticides in the fight against various pathogens and weeds, which is a characteristic of conventional agricultural production (Chauhan et al., 2017). Such production systems that rely on excessive pesticide use have led to serious problems and pollution of the environment, especially soil and water. As a result, we are faced with serious challenges in maintaining stable and high yields, taking care of the product quality and health safety, and simultaneously preserving the environment. Recently, the weed management strategies have become more complex due to the absence of available active ingredients for chemical weed control, the desire for a sustainable approach to production, climate change, and resource conservation.

The transition from conventional cultivation systems to sustainable production requires substantial technological adjustments (Kovačević i Momirović, 2008). This very goal has given rise to various combinations of „new - old" technologies and their forms, referred to bydifferent terms such as ecological agriculture, sustainable agriculture, organic agriculture, low-input agriculture, etc. All of them rely on new scientific research achievements in various fields. Therefore, regardless of the production system, the goal is the same: to reduce investments and the use of pesticides while ensuring high-quality, health-safe products in acceptable quantities. Thus, Böcker et al. (2019) state that positive effects on natural resource protectioncan be achieved by reducing herbicide use and implementing an integrated preventive approach to preserving soil quality, ultimately favoring the entire living world. This aligns with the statements of Milošev and Šeremešić (2008), who explain that low-input production implies reducing the use of external inputs and instead relying on on-farm resources cush as manure, cover crops, and green manure. Ljubelj (2008) also emphasizes that this agricultural system relies heavily on the minimal use of pesticides and modified agrotechnical measures aimed at improving land resources. It is known that weed control is one of the limiting factors in organic production systems as well as in low-input methods of production. Therefore, Kovačević and Momirović (2008) point out that the control of weeds, diseases, and pests in these two systems is a particularly sensitive part of the production technology, because they almost completely exclude chemical means of weed control. For this reason, much attention has been given to specific measures, such as crop rotation, intercorpping and cover crops, which show good potential when integrated into sustainable systems. Those practices contribute to multifunctionality, diversification, and input reduction, leading to a more effective weed management while also supporting sustainability and biodiversity preservation (Teasdale, 1996; Kovačević and Momirović, 2000; Janošević, 2021). Given that cover crops can serve farmers in many ways and have a broad impact on the agroecosystem (Brust et al., 2014; Baraibar et al., 2021) their introduction can increase the resilience of sustainable farming systems (Rivière et al., 2022). Also, the efficient use of resources can reduce the amount of mineral fertilizers, reduce the risks of environmental pollution and greenhouse gas emissions caused by agriculture, which can affect the mitigation of global climate change.

Intercropping potentially affects both above- and below-ground biodiversity, which will improve the services of a given agro-ecosystem (Yang et al., 2021). The application of cover crops, before sowing the next crop, is one of the well-known agricultural practices and is currently very current around the world (Romdhane et al., 2019). Thus, the introduction of cover crops has become a desirable practice for sustainable agriculture, as it contributes to soil fertility and improves the performance of the following crop in rotation (Teasdale, 1996). Cover crops have a beneficial effect on improving soil structure, soil physical properties, better microbiological activity and diversity of microorganisms in the soil, on increasing the amount of organic C and N. Additionally, they enhance the accessibility of P, K, Ca, Fe and Mg, which is essential in the process of preserving soil as an important natural resource (Koudahe et al., 2022). Sowing of cover crops also shows good results when it comes to reducing weed abundance, where the choice and combination of cover crop species plays a major role (Schappert et al., 2019; Janošević, 2021). There remains much room for research into the most optimal selection of cover crops, which will have a long-term positive effect on the reduction of weed biomass, on the yield and quality of the next crop, on soil conservation, as well as on the overall well-being of the agro-ecosystem in different ecological conditions, and in accordance with the requirements for minimal investments. In support of this, this paper presents an analysis of the biomass of weeds and winter cover crops (pure crops of rye and mixture of peas and oats), grown in the period of soil preparation for soybean sowing. The aim is to determine the optimal conditions that would lead to the reduction of weed biomass under minimal investment conditions (low-input production of LIP) and without the use of herbicides.

MATERIAL AND METHODS

The trials were conducted from 2019 to 2022 under low-input (LIP) and certified organic production (OP) in Serbia, at Rimski Šančevi (low-input) and Čurug (organic). Cool-season cover crops (CCs) were sown after the winter wheat harvest in July: LIP on October 27th, 2019; October 15th, 2020; October 10th, 2021; and OP on October 25th, 2019; October 2nd, 2020; October 20th, 2021. The trials used a block system with random plots in three replications. The total area under trial was 30 × 90 m across both production systems (30 × 30 m per cover crop, and the control (without sowing of winter cover crops). Weather conditions varied across years. The autumn of 2019 was warm and dry, reducing soil moisture and hindering sowing. However, November rainfall improved production conditions. The winter of 2019/2020 was one of the warmest in fifty years, with little snow and adequate moisture. Autumn 2020 was similarly warm, with heavy rainfall in October supporting cover crop sowing. Finally, the dry period from January to March 2022 affected moisture levels in the soil. Biomass sampling measured the fresh and dry mass of weeds and cover crops in 2020, 2021, and 2022 (Scheme 1). In 2022, measurements were taken from rye (R), a pea-oat mixture (P+O), and control plots. Weed biomass was terminated mechanically and was not incorporated into soil in contrast to winter cover crops, which were mulched and incorporated. Weed species were identified according to Josifović (1970-1986). The collected data were analyzed in accordance with the experimental design. The data were statistically processed by StatSoft Inc. (Tulsa, USA) using the analysis of variance (ANOVA) statistical method, followed by mean separation according to Tukey's HSD test ($P < 0.001$).



Scheme 1. Dynamics of trial activities.

RESULTS AND DISCUSSION

Based on the results of the analysis of variance (ANOVA), it was determined that all factors (cover crop (A) and production system (B)) and their interactions show high statistical significance for the parameter of fresh and dry mass of the winter cover crop and weed biomass (control plot) – Table 1. This indicates that each of the factors, namely cover crop (A), production system (B), and year (Y), significantly influenced the amount of produces winter cover crop biomass.

Table 1. ANOVA for fresh and dry biomass (t ha^{-1}).

Factor	Fresh biomass	Dry biomass
Cover crop (A)	0.000000***	0.000000***
Production system (B)	0.000000***	0.000000***
Year (Y)	0.000764**	0.000000***
A x B	0.005383**	0.001319**
A x Y	0.000000***	0.000000***
B x Y	0.004949**	0.000015***
A x B x Y	0.000000***	0.000031***

** $p \leq 0.01$, *** $p \leq 0.001$

The lowest average fresh mass was determined in 2022 in the P+O treatment (9.6 t ha^{-1}), and the highest in R in 2020 (14.5 t ha^{-1}) under low-input production. In organic production, the lowest produced fresh biomass was on treatment P+O (11.4 t ha^{-1}) in 2020 and the highest on R (18.8 t ha^{-1}) in 2021 (Table 2, Figure 1, 2). These results indicate the variability of biomass depending on the year and the selected cover crop. Biomass values depended on the number of weed species present at the Rimski Šančevi (LIP) site, and were recorded at the highest levels in organic production. Dry mass of cover crops (t ha^{-1}) was measured across all treatments during the three experimental years, and the values ranged from 1.9 to 3.1 t ha^{-1} in low input systems. This was in contrast to organic production, where the lowest dry mass was 1.8 t ha^{-1} in R in 2022, while the highest was 4.2 t ha^{-1} in P+O in 2021 (Table 2; Figure 1, 2).

Table 2. Average biomass of cover crop and weeds (t ha^{-1}) in low-input production (LIP) and organic production (OP).

PS	Biomass	2020			2021			2022		
		C-Weeds	R	P+O	C-Weeds	R	P+O	C-Weeds	R	P+O
LIP	Fresh mass	4.17c	14.50a	10.37b	3.60c	13,67a	9.73b	4.43c	11.97a	9.63b
	Dry mass	1.70c	3.16a	2.45b	1.43c	2.60a	1.94b	1.65c	2.13a	1.92b
OP	Fresh mass	6.57c	18.73a	11.40b	4.23c	18.80a	17.40b	9.17a	10.40a	14.33b
	Dry mass	1.87c	3.85a	2.43b	1.43c	3.98a	4.18b	1.90a	1.80a	2.55b

PS- production system: C-weeds, R- rye; P+O - mixture of peas and oats; different letters showing statistical difference among treatments in the trial according to Tukey's test

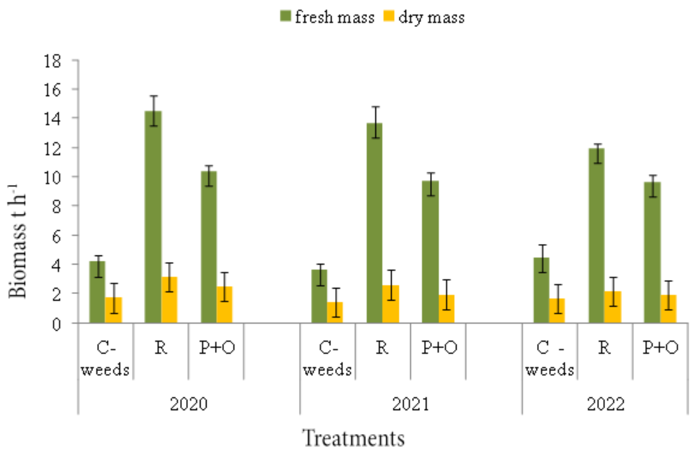


Figure 1. Average values of weeds biomass (C – control) and cover crops (R-rye, P+O – pea and oat) in low-input production (LIP).

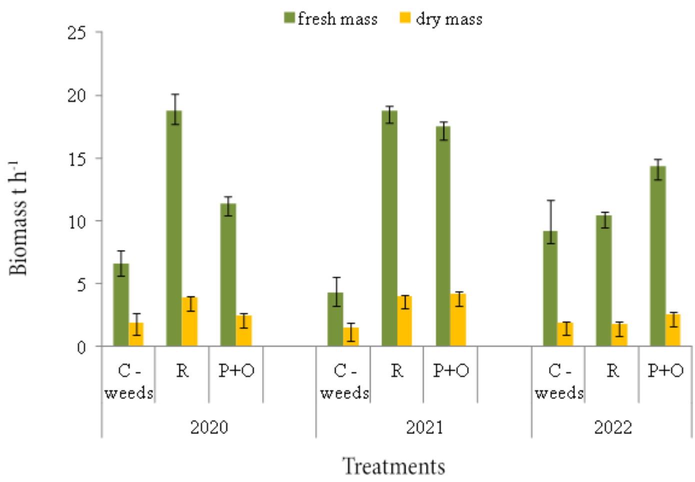


Figure 2. Average values of weeds biomass (C – control) and cover crops (R-rye, P+O – pea and oat) in organic production (OP).

In 2022, alongside measurementsof fresh and dry biomass (Table 3, Figure 3), the following weed species were determined in both production systems: *Stellaria media* (L.) Vill., *Sinapis arvensis* L., *Descurainia sophia* (L.) Webb., *Capsella bursa-pastoris* (L.) Medik. and *Taraxacum officinale* Web. Results shown in Table 3 and Figure 4 indicate that the share of weed biomass in cover crops in 2022 was extremely low. Thus, the lowest share of weed biomass of 2.80% (0.06 t ha^{-1}) was recorded in the R cover crop in both production systems, while the highest share of weeds was recorded in the organic P+O mixture cover crop, where it accounted for only 7.80% (0.20 t ha^{-1}).

Table 3. Average values of fresh and dry biomass (t ha^{-1}) in production systems in 2022.

Parameter	LIP					OP				
	R	Weeds/R	P+O	Weed/ P+O	C-Weeds	R	Weeds/R	P+O	Weeds/ P+O	C-Weeds
Fresh mass	11.97	0.15	9.63	0.47	4.43	10.4	0.2	14.33	0.82	9.17
Dry mass	2.13	0.06	1.92	0.15	1.65	1.8	0.06	2.55	0.20	1.90

R- rye; P+O - mixture of pea and oat; C-weeds

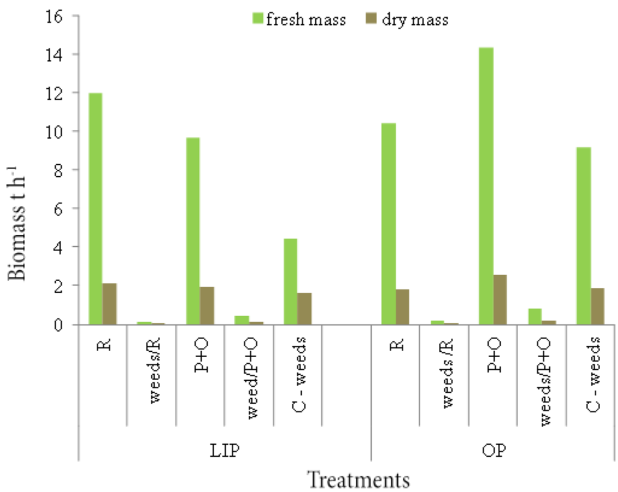


Figure 3. The share of weed biomass in the biomass of different cover crops in 2022 (R- rye; P+O - mixture of pea and oat; C-weeds).

Unmanageable weed population in an agro-ecosystem can be replaced with a manageable cover crop (Teasdale, 1996). Because of their quick emergence, canopy formation, and root growth, cover crops have the ability to suppress weeds (Rueda-Ayala et al., 2015). The sowing of cover crops can reduce the pressure of weed species in organic production. In organic and low-input production systems, cover crops are becoming increasingly relevant as an ecological strategy for weed control (Restuccia et al., 2020). According to Baraibar et al. (2018) and Osipitan et al. (2019), grasses and grass-based combinations are often more weed-suppressive than legumes and brassicas, although weed biomass in cover crops varies by species. This is confirmed in our study, when it comes to the cover crop R, which proved to be a strong competitor. Due to its optimal stand density, there was no dominance of weed species in the rye cover crop. Sowing of a mixture of pea and oat (P+O) as a winter crop brings multiple benefits, including reducing the presence of weed species (Simić et al., 2018). In our study, the winter cover crop P+O was moderately competitive against weed species, while the highest number of weed species was recorded in the control plot (C – without sowing a winter cover crop). This is in line with the study of Smith et al. (2020), who reported that mixtures were never more weed suppressive than the cover crop grown as a monoculture (pure crop). Our study confirms this for rye as a winter cover crop.

CONCLUSION

Herbicide application is a regular practice for weed management, but its environmental impacts have led to the exploration of integrated weed management and more eco-friendly strategies, such as incorporating cover crops into existing crop rotations. In our research, winter cover crops, such as rye (a pure crop) and pea-oat (a mixture), have emerged as effective tools in sustainable farming systems for controlling weeds prior to soybean sowing. Produced biomass showed considerable variability across years and treatments, ranging from 9.6 to 14.5 t ha^{-1} in low-input and 11.4 to 18.8 t ha^{-1} in organic systems for fresh mass, and from 1.9 to 3.1 t ha^{-1} in low-input and 1.8 to 4.2 t ha^{-1} in organic systems for dry mass. In 2022, a total of six weed species were determined in both production systems. Our results clearly show that the share of weed biomass in cover crops in 2022 was extremely low. The results of this study highlighted the success of rye in suppressing weed growth in low-input and organic farming systems, especially in organic production, where herbicides are not allowed and weed control relies solely on mechanical measures. Overall, cover crops offer a promising solution for achieving more sustainable and resilient agricultural practices while minimizing environmental degradation.

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Biomasa korova i ozimih pokrovnih useva u održivim sistemima proizvodnje soje

REZIME

U ovim istraživanja ispitivana je uloga ozimih pokrivnih useva u kontroli korova u *low input* i organskoj proizvodnji pre setve soje. Korovi predstavljaju kontinuirani izazov u biljnoj, posebno u organskoj proizvodnji, koji zahtevaju efikasne strategije upravljanja kako bi se osigurali visoki prinosi, stabilna proizvodnja i ekološka održivost. Tradicionalno, upotreba herbicida se podrazumevala, međutim postoji opravdana zabrinutost zbog njihovog uticaja na životnu sredinu, što je pomerilo fokus ka održivim poljoprivrednim praksama. U ovim istraživanjima ispitivana je mogućnost upotrebe ozimih pokrovnih useva, kao što su raž i mešavina graška i ovsa, u cilju smanjenja biomase korova u *low input* i organskim proizvodnim sistemima. Ogledi su postavljeni tokom tri vegetacione sezone (2019-2022) u Srbiji. Dobijeni rezultati pokazuju da pokrovni usevi značajno smanjuju biomasu korova, a raž se pokazala kao jak konkurent. Takođe, ovo istraživanje ističe potencijal pokrovnih useva kao efikasne ekološke strategije za upravljanje korovima pre setve soje, nudeći prednosti kao što su smanjena upotreba herbicida, konzervacijska obrada zemljišta, poboljšano zdravlje zemljišta, prevencija erozije i bolji dugoročni prinosi useva.

Ključne reči: pokrovni usevi, korovi, poljoprivreda, proizvodnja sa niskim ulaganjima, organska proizvodnja, soja.