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Cover crops in a sustainable cultivation system and their influence on the content of organic matter in the soil

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Abstract

Cover crops are very important, especially from the aspect of sustainability of agricultural production. This biological measure maintains or increases the level of organic matter in the soil, improves the physical properties of the soil, accumulates nitrogen in legumes, improves microbiological activity in the soil, suppresses weeds and increases soil fertility. In the research, 4 plant species were included as cover crops: common vetch, winter forage peas, winter oats and winter forage kale. The experiment was carried out on the experimental field of the Maize Institute "Zemun Polje" during two growing seasons on low-carbon chernozem. Autumn soil preparation (deep plowing and fine pre-sowing preparation) was carried out immediately before the sowing of cover crops in early November. Original seeds from the Institute for forage crops of the Institute for Agriculture and Vegetables from Novi Sad were used for sowing. In the spring before mowing, the biomass of cover crops was measured, then mowing and plowing, after which half of the plot was treated with microbiological fertilizer, which helped in the mineralization of plant residues, which would further influence the increase of soil fertility. The aim of the work is to examine different types of cover crops, which by plowing the biomass produced contribute to the increase of organic matter in the soil, prevent leaching of nutrients and have an impact on the general fertility of the soil. The highest above-ground biomass was measured in fodder kale (54040 t ha^{-1}) in the second year of the study, which had more favorable meteorological conditions. After winter oats, the content of organic matter increased the most and averaged 4.467% and 4.090%, which was statistically significantly higher compared to other cover crops.

Key words: *cover crops, sustainable cultivation system, organic matter, soil fertility.*

Introduction

The key reason for growing cover crops in a sustainable and organic agricultural production system is to increase soil fertility, reduce the occurrence of weeds, pests and diseases, as well as increase biological diversity (biodiversity) in the agroecosystem (Poeplau and Don,2015; Sturm et al., 2018; Dolijanović et al., 2020). Soil is a natural resource that represents the basic base for the production of organic matter by growing different plant species. One of the most significant forms of soil degradation is the loss of organic matter, and in recent years this process has been very intense (Jakšić et al., 2023; Rajičić et al., 2024). Application of large amounts of mineral fertilizers and pesticides, which are considered environmental pollutants, as well as poor management of plant residues, insufficient application of organic fertilizers, affects soil degradation and negatively affects soil fertility (Rajičić et al., 2020; Stojiljković et al., 2021, Rajičić et. al., 2025). In intensively cultivated land, organic matter decomposes faster, which reduces its fertility and usability, and it is also more exposed to compaction and erosion. Cover crops have an important role in protecting the soil from erosion and creating a sufficient amount of organic mass that develops during the growing season and ensures the retention of nutrients absorbed from the soil. By introducing the remains of cover crops into the soil, organic matter is introduced that encourages the work of microorganisms. If there is not enough nitrogen in the introduced organic mass, the microorganisms will use the existing N from the soil, which is why leguminous plants are often grown as cover crops. In the last few years, there has been an increasing number of researches related to the interactions of plants and certain groups of microorganisms with the aim of ecologically and economically profitable production (Cvijanović et al., 2012). For this purpose, symbiotic and associative groups of microorganisms are used in the system of growing leguminous and non-leguminous plant species. Fast-growing cover crops (grasses and cabbages) bind the soil, reduce the formation of bumps and protect it from erosion (Sarrantonio, 2007). They can be grown whenever the soil remains bare throughout the year. Small vetch, grown alone or in a mixture with cereals can reduce erosion, enrich the soil with nitrogen and organic matter (Clark, 2007). The intercropping of legumes with cereals offers scope for developing energy-efficient and sustainable agriculture (Jakšić et. al, 2024). The improvement of soil properties by growing cover crops is reflected in the reduction of soil volume by 3.5% and the reduction of the C:N ratio, especially in the deeper layers, up to 40 cm (Haruna and Nkongolo, 2015).

Cover crops reduce nitrogen losses from agricultural systems by reducing leaching of nitrates and volatilization of ammonia and nitrogen oxides into the atmosphere. The decomposition of organic matter improves the physical properties of the soil – structure, water-air regime and buffer capacity (Restovich et al., 2012). These are the so-called "prolonged effects of growing cover crops" that enable better growth and development of subsequent crops (Oljača and Dolijanović, 2013). The most common crops for green fertilization are mainly plant species from the Fabaceae family (peas, lupins, beans, lentils, clovers and alfalfa), which with the help of nitrogen fixation often provide enough N for their needs, and a significant amount remains in the soil and will be used the next crop (Blanco-Canqui et al., 2015; Cutti et al., 2016). Drought-tolerant crops that require minimal investment are preferred when selecting species.

For example, in areas where erosion is possible, the solutions are grasses, and where there is a need to improve potential fertility or reduce weediness of the soil, the best solution is leguminous species, which produce a large amount of organic matter in a relatively short period of time. Thanks to their deep roots, these species can absorb nutrients from hard-to-reach forms and deeper soil layers and move them into the plowed layer. Also, they are capable of fixing atmospheric nitrogen. Legumes as cover crops can often provide sufficient nitrogen needed for main crop production. Thiessen-Martens et al., (2005) called this feature of cover crops "fertilizer replacement value". For the maize crop, which is a high consumer of nitrogen, legumes are a good choice because they grow quickly in the fall, protect the soil during the winter, and start growing early in the spring by accumulating a large amount of nitrogen-containing organic matter (Jabran et al., 2018). Organic matter greatly affects a whole series of very important physical and chemical properties of the soil: structure, water capacity, ion sorption, content of biogenic elements (N, P, S) and others. In addition to the content of organic matter and humus, important factors of soil quality are salinity, pH. number of microorganisms and soil contamination (Dolijanović and Oljača, 2006). Soil quality should be managed to ensure optimal conditions for crop growth, development, flowering and fertilization. Nemecek et al., (2008) point out that growing peas as a cover crop reduces soil acidification by an average of 18% if peas are included in the rotation.

Numerous studies confirm that leguminous cover crops improve soil quality and thus provide more favorable conditions for the growth, development and yield of main crops (Amossé et al., 2013; Hubbard et al., 2013; Tiemann et al., 2015; Somenahally et al., 2018; Elsalahy et al., 2019; Kocira et al., 2020). Cover plant species with different habitus characteristics can use light more efficiently and thus reduce its availability on the soil surface, which will lead to reduced weed emergence. The unique patterns of growth and development of the root system and the ability to adopt and activate nutrients in the soil by cover plant species in mixtures can affect more efficient use of nutrients, which directly affects the reduction of resources for weeds (Tribouillois et al., 2015). On the occasion of World Soil Day on December 5. in Novi Sad, in 2019. a scientific meeting "Ecological importance of organic matter in soil" was held in Matica srpska. Some of the solutions offered by the participants of this meeting refer to the application of different models of reduced tillage, sowing of cover crops, green fertilization, organic agriculture, improvement of irrigation, creation of varieties and hybrids tolerant to changed growing conditions due to climate change and the like. One of the conclusions is that organic matter is also recognized as a powerful weapon in the fight against climate change due to its ability to absorb large amounts of carbon, which is found in the gases responsible for creating the greenhouse effect. The consequences of climate change on soils with a high content of organic matter can be mitigated. The aim of the work is to examine the influence of the type of cover crops, after mowing and plowing of the above-ground biomass, on increasing the content of organic matter in the soil, reducing leaching of nutrients and their contribution to the general fertility of the soil.

Materials and Methods

The study of the effect of growing cover crops on the content of organic matter in the soil was carried out at the experimental field of the Maize Institute "Zemun Polje" in Zemun Polje, Serbia (44°52'N 20°20'E), at an altitude of 110 m, during a two-year period. The experiment was set up according to the split-plot system in four replications. The cover crops consisted of four types of plants, two legumes: P1-common vetch, *Vicia sativa* L. (fam. Fabaceae), P2-winter forage pea, *Pisum sativum* L. (fam. Fabaceae) and two non-leguminous species: P3-winter oats, *Avena sativa* L. (fam. Poaceae) and P4-winter forage kale, *Brassica oleracea* (L.) *convar. acephala* (fam. Brassicaceae). Cover crops were sown manually at the beginning of November, using original seeds from the Institute for Fodder Plants of the Institute of Crop and Vegetable Agriculture from Novi Sad. In both years, the main crop was winter wheat. Before sowing, soil samples were taken for agrochemical analyses: the first at a depth of 0-20 cm and the second at a depth of 20-40 cm, then in the spring after mowing the cover crops, and before sowing the main crop and in the summer after harvesting the main crop (sweet corn). Fertilization of cover crops was carried out together with basic tillage. The entire amount of P and K was introduced in the fall with MKP fertilizer (0:52:34), and the required amount of nitrogen was introduced in the spring, together with the sowing of the main crop in the form of individual Urea fertilizer. Immediately before mowing, the biomass of the cultivated cover crops was measured, and the mowing and plowing of the cover crops was done in the spring so that the crops were as lush as possible. Immediately after ploughing, a liquid microbiological fertilizer (mobilizer of nutrient elements) containing strains of proteolytic and cellulolytic bacteria in the amount of 10 l ha^{-1} was applied to the soil on half of the elementary plot which helped the mineralization of the introduced plant residues and whose application had a favorable effect on the increased fertility.

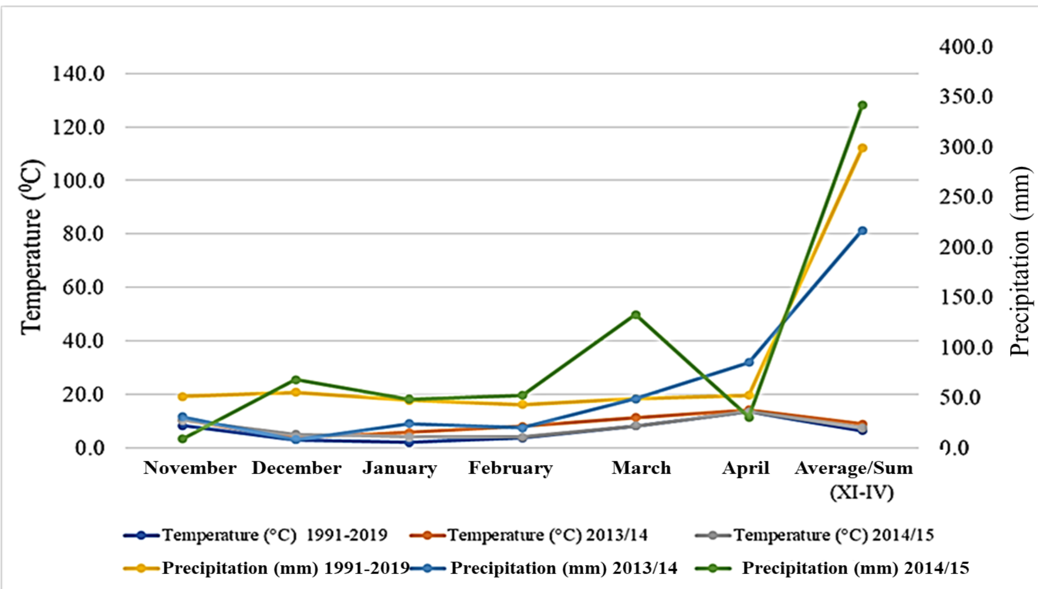
Accessible nitrogen was determined according to the method of Scharpf and Wehrmann (1975), accessible phosphorus according to the method of Olsen et al., (1954) and accessible potassium from the same solution (alkaline $NaHCO_3$) with an ion-selective electrode. The K content was also determined by ICP-OS (EPA Method 200.7. Martin et al., 1994), and the extraction of elements with Mehlich-extraction solution, according to the SRIEG 18 procedure (1983). The content of organic matter was determined according to the method of Magdoff (1996).

Table 1. Basic agrochemical properties of the soil in the experimental field

Depth (cm)	N (kg ha^{-1})	NH4 (kg ha $^{-1}$)	NO3 (kgha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	Moisture (%)	P2O5 ppm (mg kg^{-1})	K2O (ppm)	pH H2O	pH nKCl
0-20	44.37	1.82	42.55	25.96	280.42	10.72	29.73	150.75	7.05	7.04
20-40	21.66	0.70	20.96	33.19	298.47	11.16	38.01	160.45		

The weakly carbonate chernozem of northeastern Srem is characterized by a humus-accumulative (Ah) horizon 0-50 cm deep, dark to dark-black in color and its textural composition is powdery-clay loam. The clay content is about 32%, powder 15% and sand 53%. This type of soil has favorable water-physical properties. The content of $CaCO_3$ in the humus accumulative layer, which does not exceed 5%, caused this low carbonate soil to have a neutral to slightly alkaline reaction of the soil solution. The content of organic C is also the highest on the surface and amounts to 1.95%.

The soil is optimally supplied with total nitrogen, the C:N ratio is quite good (average 9.39) which means that ammonia is extracted from the cells of microorganisms and can be used by plants as an assimilative. The soil is moderately provided with easily accessible phosphorus, and very provided with easily accessible potassium, which should be taken into account when determining the amount of fertilizers for fertilizing this land. In the layer 0-20 cm deep the content of organic matter is on average 3.3% and the total $CaCO_3$ is 9.7%. Based on data from autumn in the first year of research (Table 1) the chemical reaction of the soil is neutral (Ah horizon) to weakly alkaline, and with increasing depth it is increasingly basic (pH in water 7.05 and pH in KCl 7.04). The total N content is 44.37 kg ha^{-1} in the 0-20 layer and 21.66 in the 20-40 cm layer. The soil contains 29.73 and 38.01 mg of available P per 100 g of soil and 150.75 and 160.45 mg of K per 100 g of soil, respectively.



Graph 1. Meteorological conditions in the investigated locality (source RHMZS)

From the meteorological conditions mean monthly air temperatures, amounts and distribution of precipitation were considered as limiting factors of plant production. When it comes to precipitation the most important thing is its distribution during the year especially during the vegetation period of plants. In addition to supplying plants with water, precipitation enables the uptake of nutrients and minerals as well as their transport from the roots through the tree to the leaves. For this research. meteorological conditions were analyzed for the multi-year period from 1991-2019. year which were obtained from the RHMZ of Serbia as well as the meteorological conditions for the research period. Higher air temperatures in the winter and spring months during the test in the first year of the year were accompanied by a small amount of precipitation, lower than the multi-year average (341.4 and 217.2 mm). It is particularly important to highlight the small amount of precipitation in December and February, which caused a lower yield of above-ground biomass of cover crops in the first year of testing, while the second year was significantly more favorable for the growth and development of plants in terms of average air temperature (7.5 °C) and the amount and distribution of rainfall during the entire vegetation period of cover crops.

The results presented in this paper are part of a three-year research with the theme of a sustainable system of cultivation of the main crop (sweet corn) the production of which was carried out after the plowing of cover crops and those parameters were not taken into account in the analysis of the given data. The obtained results of this study were statistically processed by analysis of variance and tested by the LSD test (*Least Significant Difference Test*) in the program IBM SPSS Statistics, version 26.0. and are presented tabularly and graphically.

Results and discussion

The results shown in Table 2 show that the average yield of biomass at the investigated location was 32130 kg ha^{-1}, which represents a significant potential in improving the content of organic matter in the soil. The largest amount was measured in the second year (41780 kg ha^{-1}), and significantly lower in the first year research (22480 kg ha^{-1}). The highest biomass yield was achieved by winter fodder kale (P4), especially in the second year of the trial (54040 t ha^{-1}), which is to be expected because it is known that the optimal biomass yield of winter fodder kale is between 65-70 t ha-^{1} and in years with rainy early spring, biomass can exceed 80 t ha^{-1}. By plowing above-ground biomass during the appearance of flower buds of winter fodder kale, it is possible to introduce up to 150 kg ha^{-1} of pure N into the soil, which has the potential for multi-year and gradual release, which enables the continuous supply of the following crops in the crop rotation with this essential element for growth and development of each plant.

The lowest average biomass yield was achieved by growing winter oats, especially in the first year of testing 19675 kg ha^{-1} which is almost half less than the average green biomass yields of oats at the level of Serbia, which amount to about 30 t ha^{-1} (https://www.stat.gov.rs/). Considering the potential of winter peas and common vetch, i.e. the varieties grown in the trial, whose biomass is 40-60 and 30-50 tons per hectare, in this test the yields can be assessed as low (31955 and 29500 kg ha^{-1}). Oljača and Dolijanović, (2013) state that green fertilization enriches the soil with about 35-40 t ha^{-1} of organic matter.

Table 2. Above-ground biomass of cover crops (kg ha^{-1}) in the examined period

Year (A) / Cover crops (B)	I	II	Average
P1	18310	45600	**31955**
P2	20760	38240	**29500**
P3	19675	29240	**24458**
P4	31175	54040	**42608**
Average	**22480**	**41780**	**32130**
Factors	A	B	AB
LSD p<0.05	6494.30	9184.30	15907.80
LSD p<0.01	8906.50	12595.70	21816.30

Legend: P1-common velch; P2-winter fodder peas; P3-winter oats; P4-winter fodder kale

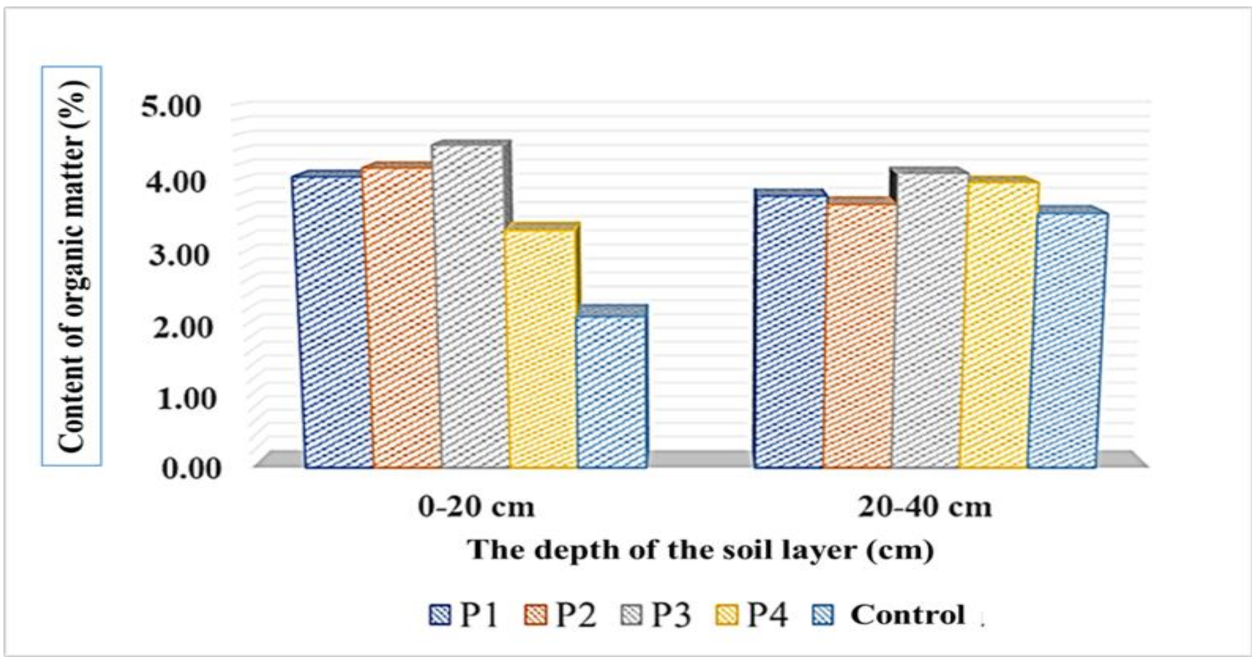
Species used as cover crops should produce high biomass, which is important for even coverage of the soil surface. Their C:N ratio should be balanced and should not decompose quickly thus protecting the soil, even in the early stages of growth and development of the main crops (Wallace et al., 2017). Soil not covered by vegetation is more susceptible to weeding and erosion, while a high C:N ratio leads to N losses from the system, reducing its availability to cultivated plants (Rizzardi and Silva, 2006). The content of organic matter on cover crop variants was measured in both years of testing in the spring (Table 3) ten days after plowing the biomass of the cover crops, and before sowing the main crop despite the fact that it is known that the content of organic matter does not change quickly and cannot can be fixed, and not improved in a short period of time. The initial content of organic matter from autumn in the first year of research (3.3%), when the research began is considered. Statistical analysis revealed that the content of organic matter changed under the influence of factors, both individually and in interaction regardless of the fact that winter wheat was the predominant cover crop every season. The average content of organic matter in the examined period was 3.624 and 3.812 % in the first and second soil layers. The difference in the content of organic matter by years of testing is the result of varying meteorological conditions and the amount of plowed biomass of cover crops.

Table 3. Content of organic matter (%) in soil

Year (A)	**I**		**II**		**Average**	
Depth (cm) (C)	0-20	20-40	0-20	20-40	0-20	20-40
Cover crops (B)						
P1	3.857	3.860	4.227	3.709	4.042	3.785
P2	3.997	2.922	4.325	4.420	4.161	3.671
P3	4.386	4.208	4.547	3.971	4.467	4.090
P4	3.607	3.366	3.024	4.563	3.315	3.965
Control	3.810	2.671	4.509	4.427	2.135	3.549
Average	**3.931**	**3.405**	**4.126**	**4.218**	**3.624**	**3.812**
Factors	A	B C	AB	AC	BC	ABC
LSD p<0.05	0.04	0.07 0.04	0.13	0.07	0.11	0.27
LSD p<0.01	0.06	0.09 0.05	0.18	0.10	0.16	0.49

Legend: P1-common velch; P2-winter fodder peas; P3-winter oats; P4-winter fodder kale

The largest mass was plowed in second year of examination, and with favorable meteorological conditions, the content of organic matter was the highest in that year. The correct selection of the species grown as a cover crop certainly contributes to this, because the selection of the species implies a preliminary assessment of the agro-ecological conditions of the climate, with a special emphasis on the distribution and amount of precipitation, the occurrence of early autumn and late spring frosts, soil properties (Ugrenović and Ugrinović, 2014). In terms of impact on increasing the content of organic matter in the soil, the best results were achieved by winter oats. After winter oats, the content of organic matter increased the most and averaged 4.467 and 4.090%, which was statistically significantly higher compared to other cover crops. Ugrenović et al., (2024) state in their results that mixtures in cover crops significantly increase microbiological activity in the soil, which contributes to an increase in organic matter.
The increase in the level of organic matter depends on the amount of biomass formed in the cover crop and the C:N ratio in the plant residues, which is affected by the plant species and the time when the cover crop is destroyed (Restovich et al., 2012). Plant residues of cover crops with a low C:N ratio such as Fabaceae decompose faster than those with a high ratio as is often the case with species of the Poaceae family.



Graph 2. Average values of organic matter content (%)

It is considered that the ideal C:N ratio is 10:1, while it is favorable from 10:1 to 20:1, and unfavorable when it is >20:1. After the destruction of the grass cover crop, the plant residues on the soil surface have a high C:N ratio, which causes a very slow decomposition and in the long term affects the increase of the content of organic matter in the soil (Diekow et al., 2005). Plants from the grass family accumulate nutrients, especially N through the roots, and they remain in the soil after harvest, so according to Popović

(2010), over 70 kg of N ha^{-1} can be accumulated in three months, which becomes accessible to plants more slowly.

On the other hand, the plant remains of butterfly plants are decomposed faster, due to the lower C:N ratio, so they have less effect on increasing the content of organic matter in the soil than grass cover crops (Fageria et al., 2005). Vuyyuru et.al., (2020) state that after plowing sugarcane crop residues, the content of organic matter in the soil and the total C/N ratio increased, which resulted in higher microbiological activity. Cultivation of cover crops and their plowing contributes to the increase of the biomass of microorganisms in the soil, the increase of the biological activity of the soil, the development of saprophytic microflora that prevents the development of numerous diseases of cultivated plants (Motta et al., 2007). The loss of organic matter from the soil can be 20-40% or more, which significantly affects the quality of the soil and water. Soil quality is reduced by limiting microbial activity that is important for healthy and sustainable agriculture (Garten, 2002). It is considered that the content of organic matter, as the best indicator of soil fertility and quality, is most influenced by external factors and poor soil management (Šeremešić, 2015). The amount of green mass that is plowed is 10-20 t ha^{-1} (2-4 t dry matter ha^{-1}), 0.7 - 3.0 t of roots, and about 100 kg N ha^{-1} for legumes (Vukadinović and Vukadinović, 2012).

Conclusion

The results of this research show that growing cover crops is a promising method of sustainable agriculture with the potential to improve soil quality and mitigate the consequences of soil degradation. Based on the two-year results, we can conclude that there was an increase in the content of organic matter in the soil, which was largely influenced by the biomass yield of cover crops. The most significant influence on the biomass yield of cover crops was the meteorological conditions, i.e. the air temperature and the distribution of precipitation during the growing season. In the second year of the research, the highest average biomass of cover crops was measured (41780 kg ha^{-1}), while the lowest was measured in the first year (22480 kg ha^{-1}), which was also meteorologically unfavorable. The variant with a cover crop of winter fodder kale had the highest yield in the second year, and the smallest on the variant with winter oats in the first year. After growing winter oats, the content of organic matter increased the most (depth 0-20 cm - 4.467 and depth 20-40 cm - 4.090%). The short-term benefit can often be lower than the invested funds and work, and the need to grow cover crops should be considered for each specific case, especially considering the long-term benefit (preventing erosion and preserving the agroecosystem, increasing soil fertility).

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Pokrovi usevi u održivom sistemu gajenja i njihov uticaj na sadržaj organske materije u zemljištu

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Apstrakt

Pokrovni usevi su veoma važni posebno sa aspekta održivosti poljoprivredne proizvodnje. Ova biološka mera održava ili povećava nivo organske materije u zemljištu, poboljšava fizička svojstva zemljišta, akumulira azot u mahunarkama, poboljšava mikrobiološku aktivnost u zemljištu, suzbija korov i povećava plodnost zemljišta. U istraživanje su kao pokrovni usevi uključene 4 biljne vrste: obična grahorica, ozimi krmni grašak, ozimi ovas i ozimi krmni kelj. Eksperiment je sproveden na oglednom polju Instituta za kukuruz "Zemun Polje" tokom dve vegetacione sezone na slabo karbonatnom černozemu. Jesenja priprema zemljišta (duboko oranje i fina predsetvena priprema) sprovedena je neposredno pred setvu pokrovnih useva početkom novembra. Za setvu je korišćeno originalno seme Zavoda za krmno bilje Instituta za ratarstvo i povrtarstvo iz Novog Sada. Na proleće, pre košenja i zaoravanja merena je nadzemna biomasa pokrovnih useva, nakon čega je polovina parcele tretirana mikrobiološkim đubrivom, koje je pomoglo u mineralizaciji biljnih ostataka i dodatno uticalo na povećanje plodnosti zemljišta. Cilj rada je ispitivanje različitih vrsta pokrovnih useva, koji zaoravanjem nadzemne biomase doprinose povećanju sadržaja organske materije u zemljištu, sprečavaju ispiranje hranljivih materija i utiču na opštu plodnost zemljišta. Najveća nadzemna biomasa je izmerena kod ozimog krmnog kelja (54040 t ha^{-1}) u drugoj godini istraživanja, koja je imala povoljnije meteorološke uslove. Nakon ozimom ovsa, sadržaj organske materije se najviše povećao i prosečno je iznosio 4.467% i 4.090%, što je bilo statistički značajno više u poređenju sa ostalim pokrovnim usevima.

Ključne reči: *pokrovni usevi, održivi sistem proizvodnje, organska materija, plodnost zemljišta.*

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