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The variation of labile organic matter content following the application of industrial compost in maize production

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Summary: This study examined the influence of compost application on alterations in soil organic matter levels and the content of labile organic matter fractions in soil during maize sowing. Due to the lack of organic fertilizers, industrial compost is being investigated as an alternative. The research aims to identify relevant soil quality and fertility indicators and their effects on agricultural production. Short-term compost application as an organic fertilizer may increase the content of labile organic matter fractions in the soil, especially in less fertile plots. The results indicate a significant influence of compost application on soil quality, confirming its role as a nutrient source and enhancer of soil physical, chemical, and biological properties. This highlights its potential for preserving soil quality and supporting agricultural production.
Key words: HWOC, maize, organic fertilizer, soil organic matter

Introduction

The process of soil formation and development is an ongoing phenomenon driven by pedogenetic factors (relief, climate, geology, human activity, fauna and vegetation) which require an extended period of time for its maturation (Milošev & Šeremešić, 2010). In recent decades, soil has been subjected to intensified anthropogenic influences, the extent and intensity of which can significantly alter the direction and manifestation of other contributing factors (Vojnov et al., 2020a). Therefore, the selection of management practices has primarily focused on increasing crop yields, with less emphasis on soil properties. Consequently, recent research has been directed toward technologies that aim to preserve soil quality while maintaining stable yields. Also, some findings demonstrated that high soil organic matter content could be associated with higher yields (Vojnov, 2020b; Kovačević, 2022). The lack of organic fertilizers, primarily manure, coupled with the use of heavy machinery and synthetic fertilizers, has led to the deterioration of soil's physical, chemical, and biological properties (Vojnov et al., 2020c).

With inadequate soil treatment so far, there is a need to test and implement alternative organic fertilizers that serve both economic and ecological purposes (Vojnov et al., 2019). This would provide sufficient carbon (C) rich material to prevent the negative trend in soil quality. In current literature, the term "organic carbon" is increasingly used instead of humus or organic matter, mainly due to the ease and precision in defining carbon content. Organic C constitutes a substantial portion of soil humus (averaging 58%), though in calcareous soils, inorganic carbon derived from calcium carbonate may also be present. Presently, there is a noticeable intensification of agricultural production on a global scale, leading to a decline in soil organic carbon content, which has been halved (Blum, 2008; Zang, 2016; Crespo, 2021). Soil organic matter is considered to be minimal, comprising only a few percent; despite this, it has a great influence on the dynamics and properties of the soil, facilitated by rapid transformations and activities. According to Jarak & Čolo (2007), humus accounts for around 30-50% of soil organic matter. In order to better understand its dynamics in the soil organic matter can be divided into three fractions based on stability: labile, stable, and inert (Strosser, 2010).

Labile organic matter, also referred to as active, fresh, or assimilative, represents the fresh, nutritious part of humus. It is younger in origin and serves as an indicator of soil's productive capacity, highly influenced by agrotechnical practices (Bremer et al., 1995). Fresh organic matter is considered biologically active and dynamic. Stable organic matter (persistent humus) acts as a nutrient reservoir of nutrients with profound effects on soil's physical properties. The labile fraction consists of less stable, simple compounds, and decomposed plant residues (Golchin et al., 1994). It is the most dynamic reservoir of soil organic carbon and is the first to exhibit changes (Janzen et al., 1992). Notably, labile organic carbon comprises various components such as live microorganisms, carbohydrates, polysaccharides, proteins, organic acids, amino acids, remains of flora and fauna, their degradation products, waxes, fatty acids, and other non-specific humic compounds (Zou et al., 2005). This fraction serves as a source of nourishment for microorganisms (Ćirić, 2014).

Research on labile organic matter content (Sparling et al., 1998; Chen et al., 2009; Martinez–Mena et al., 2012) has been extensively conducted in various soil types and land-use scenarios during the past. Obtained results suggest that the content of labile organic matter (carbon soluble in hot water) HWOC constitutes approximately 1-4% of the total organic carbon. Previous findings indicate that HWOC, a component of soil's labile fraction, is linked to microbiological activity and comprises a blend of carbohydrates and proteins (Leinweber et al., 1995).

Efforts to preserve or increase soil organic matter/carbon pools in arable soils involve various measures. Recently, much effort has been put into understanding the role and importance of the labile form of organic matter. In addition to that, there is a research gap in understanding relationship of various SOC pools and conservation tillage, manure application, crop residue incorporation, mineral fertilizers, and, in some cases, crop rotation (Manojlović et al., 2008). In recent years, the absence of manure in the production conditions of the Republic of Serbia can be partially compensated for by the use of green manure (Vojnov et al., 2022) and compost. It enriches soil through the microbiological decomposition of diverse organic materials (plant and animal waste) (Mirecki et al., 2011). The positive impact of compost lies in its role as a nutrient source for plants and its capacity to enhance soil's physical, chemical, and biological characteristics. Compost application varies but is commonly within the range of 0.5-6 kg m^2 (Mirecki et al., 2016). Approximately 40-60% of plant nutrients are released from compost during the first year, with the rest is released over the subsequent two years. Thus, compost proves highly valuable for soil quality, particularly for soils with poor production capabilities. Utilizing modern technologies, composting can be conducted under controlled conditions, requiring appropriate machinery and equipment for industrial production. Two main methods of composting exist: open and closed systems. A closed system involves the use of expensive equipment and gives lower output, due to space limitation, compared to an open system, which is why it is used less frequently (Zimmer et al., 2017). However, the closed system shortens the composting process significantly compared to the open system. Composting larger quantities of waste necessitates facilities and technologies that provide improved conditions for biological decomposition and the production of higher-quality compost (Thompson, 2001). Authors Zimmer et al. (2017) outlined a three-phase composting process, involving shredding and milling in the first phase, humification of organic matter, homogenization, and mixing in the second phase, and sieving in the final phase. In this research is used compost made in closed system. This research aimed to determine the impact of compost application at different rates on changes in the level of organic matter and the content of labile organic matter in the soil, in maize production.

Material and Method

The research was conducted in a trial field at the Institute of Field and Vegetable Crops in Novi Sad, located in Rimski šančevi (N 45.324621°, E 19.848819°). The trial was established on soil classified as a Calcic Chernozem (Clayic, Aric, Pahic) (according to WRB, 2022) formed on loess. Preliminary soil tests were carried out in 2017 to select the site and determine the initial soil conditions (Table 1).

Table 1. Basic soil chemical properties on testing site (initial state)

pH		$CaCO_3$ %	Humus %	Total N %	AL-P_2O_5 mg/100g	AL-K_2O mg/100g
in KCl	in H_2O					
7.38	8.03	2.03	2.47	0.184	8.8	23.0

According to the agrochemical analysis of the initial state (Table 1), the soil solution had a slightly alkaline reaction. In terms of humus content and total nitrogen, the examined site was moderately supplied. The soil's content of available phosphorus was in the low supply class (8.8 mg P_2O_5/100 g soil), while potassium was in the optimal supply class (23 mg K_2O/100 g soil).

The Rimski Šančevi site, located in southern Bačka, is characterized by a moderately continental climate. Figure 1 presents the multi-year monthly averages of precipitation and mean daily temperatures for the period from 1987 to 2017, as well as the production year 2019. Unlike multiyear averages, the production year 2019 indicates that the mean monthly temperatures during 2019 were slightly higher compared to the average mean temperatures during the previous multi-year observations. The average annual precipitation in Vojvodina ranges around 550-600 mm/m^2, characterized by an uneven distribution of rainfall. In the production year 2019, significantly higher amounts of precipitation than the average were recorded in May and June, while below average multi-year rainfall was observed in September and October.

For the calculation of the Carbon Management Index (CMI), samples were taken from the nearby virgin soil (not under agricultural use) simultaneously with those from the agricultural soil. The natural vegetation on this soil consisted of communities of the ruderal association *Convolvulo-Agropyretum repentis* Felf. 1943 from the alliance *Convolvulo-Agropyrion repentis* Görs 1966, the order *Agropyretalia repentis* Oberd., Müll. et Görs 1967, and the class *Agropyretea repentis* Oberd., Müll. et Görs 1967. These communities typically thrive in habitats significantly influenced by anthropogenic activities, especially in open anthropogenic areas adjacent to fields (Kojić et al., 1998; Dancza, 2009).

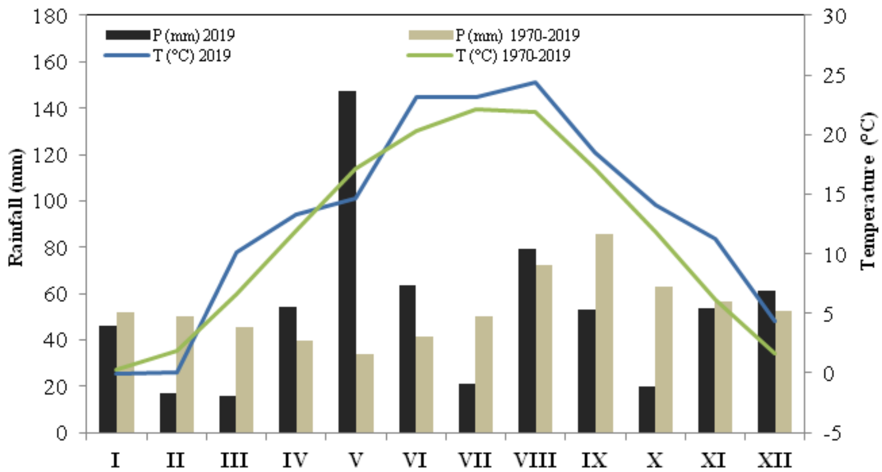


Figure 1. Multi-year monthly averages of precipitation and mean monthly temperatures for the period from 1970 to 2019 and for the production year 2019

The selection of material (compost) with its chemical composition listed in Table 2. was also conducted. Compost was applied in increasing doses, comprising 5 treatments and a control, with four replications. The control plots were arranged in a Latin square design. The area of each plot was 9 × 20 m, equivalent to 180 m^2 (Figure 2). The applied doses are presented in Table 3. The maize hybrid selected for sowing in the trial was NS 3022. Sowing was carried out on 15^{th}, April 2019, with a planting density of approximately 68,000 plants per hectare. Throughout the vegetation period, regular agrotechnical measures, including herbicide application and inter-row cultivation, were applied for crop management. Maize harvesting took place in the second half of September using a specialized Wintersteiger trial harvester. At the end of the growing season, i.e., after harvest, soil samples were collected using an Edelman-type soil probe by the Eijkelkamp manufacturer at depths of 0-20 cm and 20-40 cm, under disturbed conditions. Four individual samples were taken from one experimental plot in order to make one composite sample.

Table 2. Chemical content of applied compost (fresh matter)

Description of the analysis	Values
Total nitrogen N %	2.40
Total phosphorus P_2O_5 %	1.85
Total potassium K_2O %	2.59
Total carbon C %	26.47
Organic carbon C %	25.18
C/N ratio	11.03
Ash %	35.97
Organic matter %	50.21
pH value	7.95
Moisture %	13.82

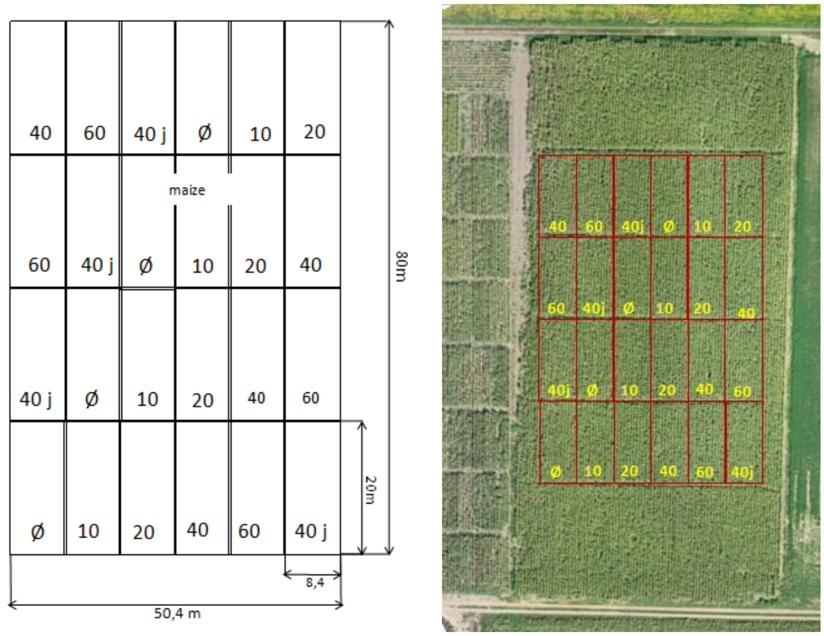


Figure 2. A design of the experimental field (left) and a drone shot during the growing season (right)

Table 3. Distribution of doses of compost applied in the experiment

Treatment	Amount of compost t ha^{-1}	Time of application
Ø	0	-
10	1.2	autumn 2017 and autumn 2018
20	2.4	autumn 2017 and autumn 2018
40	4.8	autumn 2017 and autumn 2018
60	7.1	autumn 2017 and autumn 2018
40j*	14.4	only in the autumn 2017

*j – annual application of higher dose

The determination of humus in soil samples was carried out using the titration method by Tjurin (1937), based on the wet combustion of organic matter. The labile fraction of organic matter (OM) soluble in warm water (HWOC) was determined in soil samples using a modified procedure as described by Ghani et al. (2003). In this method, 10 g of air-dried soil, sieved through a 2 mm sieve, was placed in 50 ml vials. To the soil sample, 40 ml of distilled water was added. The vials with the samples were placed on a horizontal shaker at 30 rpm for 30 minutes. After shaking, the samples were placed in a steam bath at 80°C for 16 hours. The next step involved centrifugation using an MCE centrifuge (Measuring & Scientific Equipment LTD., London) at 3000 rpm for 20 minutes. Upon completion of centrifugation, the substrate was filtered through a 0.45 µm ME 25/21 CT filter. The determination of labile OM content in the examined soil samples was performed using the titration method by Tjurin (1937). Carbon Management Index (*CMI*) was obtained according to the mathematical procedures used by Blair et al. (1995) and Viera et al. (2007), which are described below:

$$CMI = CPI \times LI \times 100$$

where CPI is the carbon pool index and LI is the lability index.

The CPI and the LI are calculated as follows:

$$CPI = \frac{C\ pool\ in\ treatment}{C\ \ pool\ in\ reference}$$

$$LI = \frac{L\ in\ treatment}{L\ in\ reference}$$

where L refers to the C lability, calculated as:

$$L = \frac{content\ of\ labile\ C}{content\ of\ non-labile\ C}$$

The data obtained from the research were processed using the method of analysis of variance (ANOVA) at the level of significance ($p < 0.001$) and ($p < 0.05$). Statistical data processing was performed in the program Statistica 13.0

Results and Discussion

Based on the analysis of the variation in the labile organic matter content (Table 4), the factor A (compost fertilization) exhibited the most substantial and highly significant influence according to the F-test. Factor B (sampling depth) did not show significant effects, indicating no statistically significant differences. The analysis of the collected data reveals that there are also no statistically significant interactions between these two factors, A and B.

Table 4**.** Analysis of variance of labile organic matter

Term	Degrees of Freedom	Sum of Squares	%	Mean of Squares	F	Probability
Effect A	5	523709.5000	78.3	104741.8984	3.460**	0.0000
Effect B	1	3285.3333	0.5	328.3333	0.987	0.6735
Effect AB	5	11261.1670	1.7	2252.2334	0.676	0.6461
Blocks	3	20511.0000	3.1	6837.0000	2.054	0.1179
Error	33	109868.5000	16.4	3329. 3484		
Total	47	668635.5000				

Used marks: A- impact of compost fertilization, B-depth; ** high significant impact ($P < 0.01$)

In Figure 3, it can be observed that the highest content of the labile organic matter fraction occurred in treatment 40, corresponding to the application of 4.8 t ha^{-1} of compost over a 2-year period (517 µg g^{-1}). The lowest HWOC level was recorded in treatment 40j, where 14.4 t ha^{-1} of compost was applied for only one year (in the autumn 2017). When comparing different depths, minor differences can be noticed. Vojnov et al. (2020) noted in their research that early-sown crops and the interaction between intercropping (as a form of organic fertilizer application) and fertilization, specifically the use of mineral fertilizers, particularly nitrogen, have a significant impact on the labile organic matter levels. The highest HWOC value was measured in the maize crop, reaching 658 µg g^{-1} in the surface layer, indicating a higher content of the labile organic matter fraction compared to the application of compost alone. It appears that the higher level of compost application did not increase significantly HWOC probably due to inability of soil to protect the labile C from mineralization and enhancing the microbial activities (Whalen et al., 2014).

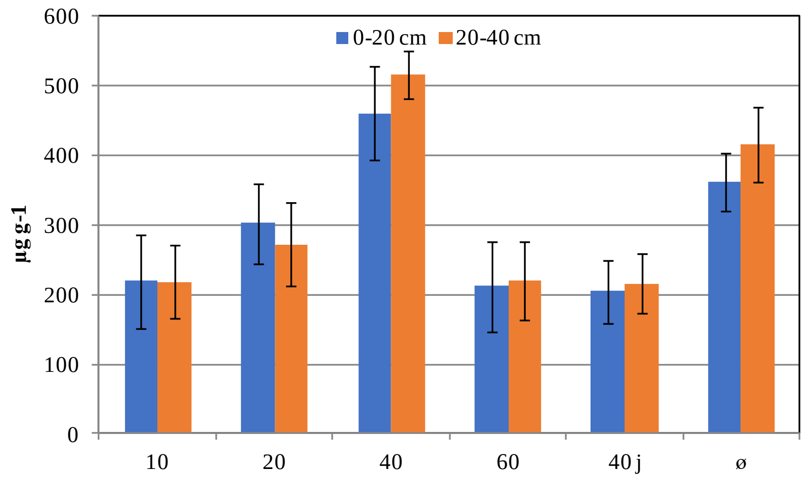


Figure 3. The content of the labile fraction of organic matter soluble in hot water after the compost application at different doses under maize production

Figure 4 displays a higher humus content in the surface soil layer at 0-20 cm. This is consistent with the findings of Šeremešić et al. (2016), who reported that the highest humus levels are typically found in the 0-10 cm layer, although the exact levels are subject to variation depending on the treatment applied. In Figure 5, the highest humus content in the 0-20 cm soil depth is observed after treatment 10 (application of 1.1 t ha^{-1} of compost over 2 years), while the lowest content at the same depth is seen in treatment 40, which involves the application of 4.8 t ha^{-1} of compost over 2 years. When considering the 20-40 cm depth, the highest humus content was determined in treatment 20 (2.4 t ha^{-1} of compost over 2 years), while the lowest content was observed in the treatment 40J.

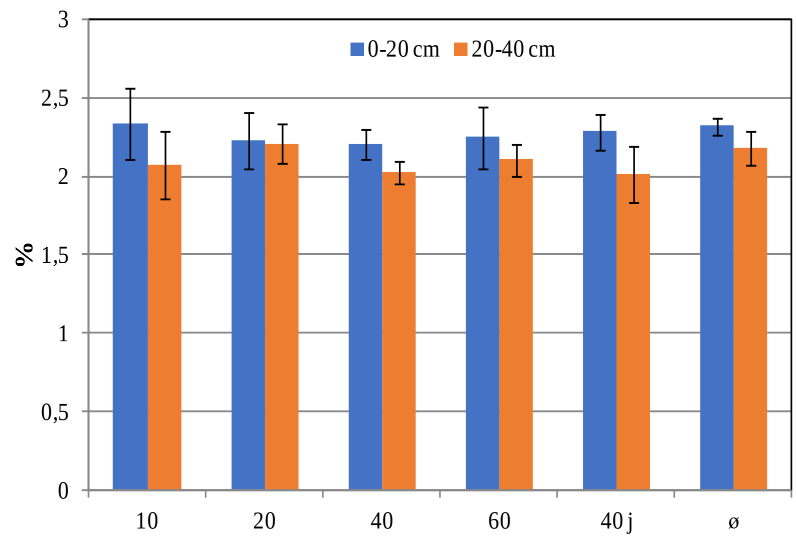


Figure 4. The content of humus after the compost application at different doses under maize production

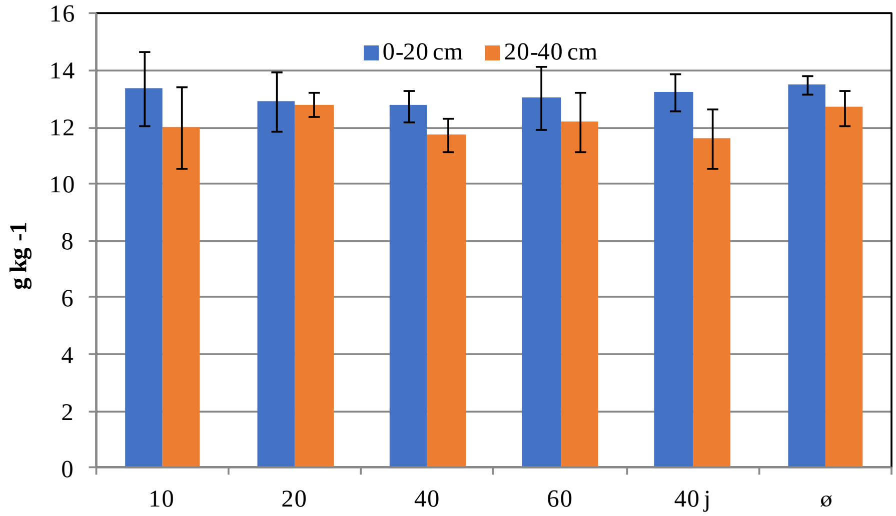
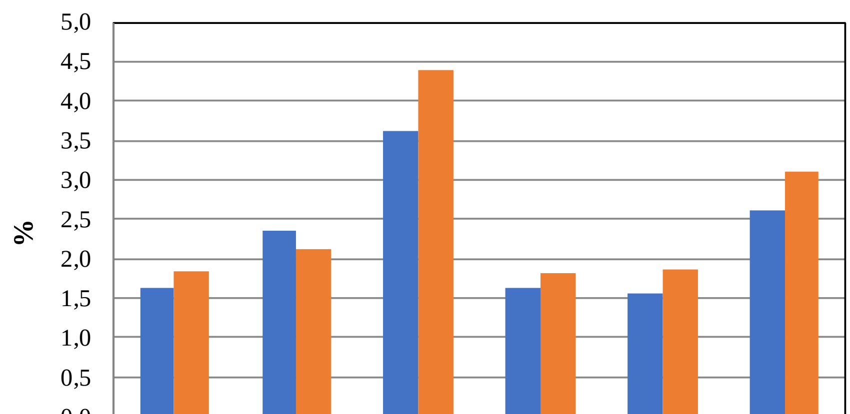


Figure 5. The content of soil organic carbon after the compost application at different doses under maize production

The organic carbon content in the soil is higher in the surface layers of the soil (0-20 cm), with the highest levels observed in treatment 10 (1.2 t ha^{-1} of compost over 2 years), and the lowest in treatment 20 (2.4 t ha^{-1} of compost over 2 years). In the deeper soil layer at a depth of 20-40 cm, it is notable that the organic carbon content is highest in treatment 20, while the lowest level is found in treatment 40J (Figure 5).



	10	20	40	60	40 j	ø
0-20 cm	0.2	0.2	0.4	0.2	0.2	0.3
20-40 cm	0.2	0.2	0.4	0.2	0.2	0.3

Figure 6. Share of labile organic matter in total OM

The analysis of the labile organic matter content in the total organic matter (OM) reveals that its highest proportion is observed when treatment 40 is applied, while the lowest is found in treatment 40j (14.4 t ha^{-1} for only one year) and on the control plot. When considering both depths, the obtained values for the labile fraction of OM in the total OM content align with the research conducted by Šeremešić et al. (2020).

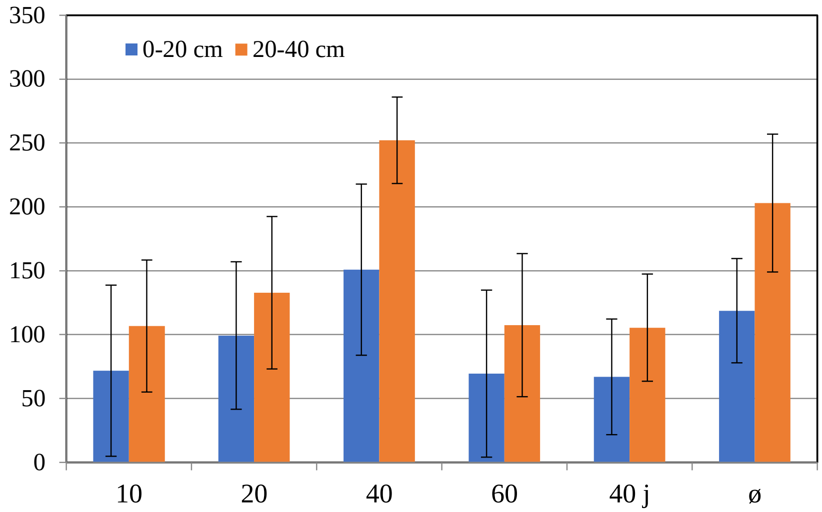


Figure 7. Carbon Management Index (CMI)

According to Chaudhary et al. (2017) the higher values of CMI indicated stable SOC pools in the system than that of other management systems. Based on the calculation of the Carbon Management Index (CMI) (Figure 7), it was determined that the highest accumulation of organic matter (OM) occurred in treatment 40 (4.8 t ha^{-1} of compost over 2 years) at both examined depths. The lowest OM accumulation was recorded in with the lowest application 10 (1.2 t ha^{-1} of compost over 2 years), and 40J (14.4 t ha^{-1} for only one year). The treatment control follows as the next in line regarding the amount of OM accumulation. The obtained results indicate that saturation with C can occur on the Chernozem and that the current practice of application 40 t ha per year can be considered optimal while larger amounts are not necessarily lead to the accumulation of organic matter in the soil, or accumulation takes more time. The highest values of CMI can be associated with the treatments where additional nitrogen was applied with organic manure to assist in mineralisation (Li et al., 2018).

Conclusion

Based on the investigation of the impact of applied compost, the factor of compost fertilization at a rate of 4.8 t ha^{-1} over two years exhibited a highly significant influence on the content of labile organic matter, while the lowest content was observed with the one-year application of 14.4 t ha^{-1} compost. The content of humus and organic carbon varied most significantly depending on the sampling depth, with higher content detected in the upper 0-20 cm layer. The proportion of HWOC in the total organic matter was highest when applying 4.8 t ha^{-1} of compost over two years, while it was lowest in the one-year application of 14.4 t ha^{-1} compost. After two years of research, no correlation was found between the compost application rate and the content of humus and organic carbon. This suggests that the process of soil humus restoration and increase is a lengthy and complex one. Considering that the applied compost, like most organic fertilizers, has a slow-release nature, the full impact of its application is expected after several years, at which point significant differences among treatments might become apparent.

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Promena sadržaja labilne organske materije nakon primene industrijskog komposta u proizvodnji kukuruza

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Sažetak: U ovom istraživanju ispitivao se uticaj primene komposta na promene nivoa organske materije i sadržaja labilne frakcije organske materije u zemljištu pri setvi kukuruza. Usled nedostatka organskog đubriva, kao alternativa se ispituje kompost dobijen na industrijski način. Cilj istraživanja je identifikacija relevantnih pokazatelja kvaliteta i plodnosti zemljišta i efekti na poljoprivrednu proizvodnju. Kratkoročna primena komposta kao organskog đubriva može povećati sadržaj labilne frakcije organske materije u zemljištu, posebno na siromašnijim parcelama. Rezultati ukazuju na značajan uticaj primene komposta na kvalitet zemljišta, potvrđujući njegovu ulogu kao izvora hraniva i poboljšanja fizičkih, hemijskih i bioloških svojstava zemljišta To ukazuje na njegov potencijal za očuvanje kvaliteta zemljišta i podršku poljoprivrednoj proizvodnji.
Ključne reči: HWOC, kukuruz, organska materija, organsko đubrivo