

Different Tillage Systems and their Influence on Crops Yield Formation and Post-Harvest Residues

Različiti sustavi obrade tla i njihov utjecaj na formiranje prinosa usjeva i posliježetvene ostatke

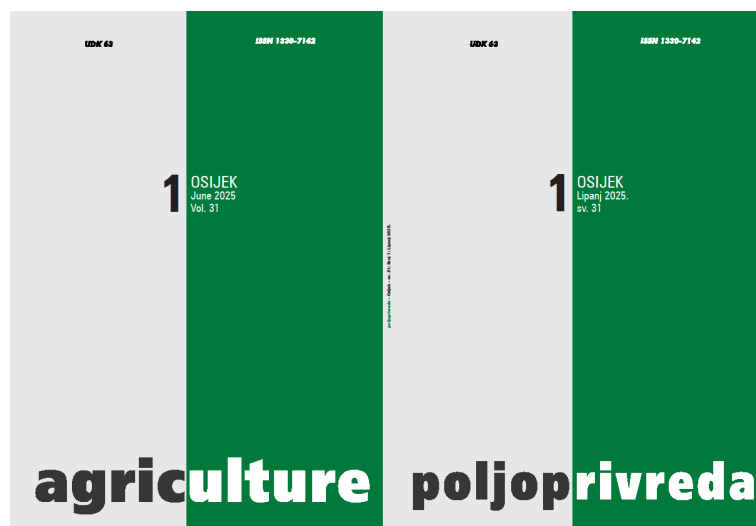
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Poljoprivreda / Agriculture

ISSN: 1848-8080 (Online)

ISSN: 1330-7142 (Print)

<https://doi.org/10.18047/poljo.31.1.2>



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DIFFERENT TILLAGE SYSTEMS AND THEIR INFLUENCE ON THE CROP-YIELD FORMATION AND THE POSTHARVEST RESIDUES

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Original scientific paper

Izvorni znanstveni rad

SUMMARY

*Tillage system is an eco-friendly farming method that can improve the soil health and increase the crop yields even under unfavorable climatic conditions. These benefits, however, will likely vary, based on the farming practice used, tillage, and crop types, which the current study seeks to address. During this triennial research, a crop rotation was as follows: soybeans (*Glycine max* L.), maize (*Zea mays* L.), and winter wheat (*Triticum aestivum* L.). This study aimed to determine the effects of different tillage approaches (conventional tillage [CT], disk harrowing [DH], chiseling [CH], and subsoiling [SS]) on a crop residue and a crop yield as the indicators. The applied tillage systems resulted in the statistically significant differences in some yield components. The highest yields, the highest harvest index, and the highest biological yield in the soybean and maize cultivation were achieved with the SS and CH tillage systems, followed by the DH and CT tillage. The conservation (CH and SS), reduced (DH), and conventional (CT) tillage systems resulted in the statistically significant differences in the number of postharvest residues remaining on the soil surface.*

Keywords: reduced and conservation tillage, cereal yields, postharvest residues

INTRODUCTION

In agricultural production, natural resources such as arable land are limited. Moreover, they interact directly with the climate—that is, with the current climate changes that affect the sustainability and uniformity of yields in agricultural production. Agricultural producers of central Europe, and thus of Croatia as well, still prefer traditional and conventional tillage methods to make the soil prepared for sowing. The different tillage systems and land-management practices have a potential of mitigating the unfavorable climatic conditions confronting the agricultural systems while concomitantly increasing the crop yields (Jug et al., 2005). The farmers, as the primary users of soil in the food-production process, are faced with the greatest challenge of soil degradation, which is provoked by the anthropogenic as well as the non-anthropogenic change drivers, including the impacts on climate variability and change. Soil structure and its overall health play an essential role in a crop-production process. For example, the soil structure in the area of root development can negatively affect evaporation, infiltration, water permeability of the soil, aeration, and crust formation, paving the way for erosion (Bašić et al.,

2004; Belić et al., 2014; Bluett et al., 2019; Bogunović et al. 2018). As early as in the 1970s, research began to indicate that a deep plowing was not the best solution to the soil preparation and cultivation (Jug et al., 2017). Conventional tillage is a great consumer of fossil fuels, with a simultaneously large negative impact on the tractor-wheel slippage, anthropogenic soil compaction, and soil degradation in general (Benković et al., 2021). Based on these findings, the last two decades have witnessed an intensive use of different tillage approaches depending on the crops grown, agroclimatic conditions, and soil characteristics of the cultivated area. In recent years, the quantities of the main components which determine soil fertility have unfortunately decreased. It is manifested by a reduction of organic matter, humus content, basic micro- and macroelements, structure failure, bulk den-

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sity, and water-capillarity management (Medvedev et al., 2018; Skrylnyk et al., 2018). Enriching the soil with an organic matter that favorably affects the structure increases its ability to absorb and retain moisture. So, the postharvest residues can become one of the agrotechnical measures that favorably affect the high yields and the excellent crop quality. In the absence of manure in the field, Gamayunova et al. (2024) determined that the postharvest residues can significantly affect the yield and quality of sorghum. In a world of technological advancement, agricultural technology is a vital tool for the improvement of the quantity of food production, and the adoption of an appropriate agricultural technology has an important impact on agricultural sustainability (Kovačev et al., 2013).

As a succession tool, basic plowing has become increasingly less important, as the new tillage systems, which have been proven to be economically viable while eliminating the disadvantages and unfavorable characteristics of a deep tillage by plowing, are used extensively. A research on the reduced-tillage systems concluded that a reduced tillage with a lower number of passes and a shallower tillage depth was a good option for an ecological soil conservation (less compaction), economic prosperity (lower production costs), and reduced organizational effort (fewer field operations; Stipešević et al. 1997; Jug et al. 2010, 2015). Conservation tillage is a tillage approach in which the plant residues are deliberately left on the surface or are integrated into the near-surface soil layer. In this tillage system, 30% or more of the soil surface should be covered with the plant residues to prevent or reduce erosion and maintain soil moisture (Jug et al., 2015). Without a proper application, conservation tillage can also lead to an increased weed population, decrease in crop yield (which can be connected with the lower soil temperatures), and a higher bulk density. Therefore, there is a need for a comprehension of all plant production factors, i.e., the existing and applicable agrotechnical measures used nowadays that influence soil quality, the optimal state of the ecosystem, and the responses of the crops grown (Liebman and Gallandt, 1997). An intensive crop production is directly connected with an impact on the anthropogenic load and soil fertility. Product quantity does not always compensate for the removal of soil nutrients by applying a sufficient amount of organic fertilizers (Veremeyenko and Semenko, 2019).

The yields of crops such as soybeans, maize, and wheat are primarily influenced by climatic factors, but their adverse effects can be significantly mitigated by the application of appropriate techniques. An alternative to conventional tillage is conservation tillage, and it could become an essential tool for the implementation of a sustainable agricultural production. Conservation tillage is particularly important in the areas with a semiarid climate, in which the evaporation of surface water exceeds the amount of precipitation during most months of the year. The research results speak about a success of conservation agriculture, which has yet to be accepted by the farmers (Lyon et al., 2004). The farmers across differ-

ent agroecological regions are encouraged to adopt different tillage approaches, especially conservation tillage, which can reduce soil compaction and erosion, nutrient loss, tractor consumption, and the working hours spent (Benković et al., 2021) while positively increasing carbon storage and microbiological activity (Peigne et al., 2007). Conservation tillage is ideal for the use in arid areas or regions with prolonged dry periods, contributes to nitrogen conservation (Omonode et al., 2006; Sainju et al., 2006), and improves the yields (Tolimir et al., 2001). The influence of water and a high risk of soil erosion can be reduced by applying conservation tillage (Bašić et al., 2000; Husnjak and Bogunović, 2002; Kisić et al., 2005), but the yield losses are likely in the first years of application (Ray and Rai, 2018). Also, covering the soil with the previous culture's straw-crushed residues can prevent soil erosion, increase soil fertility, and also make the soil moisture higher, with positive cultivation effects on maize, as demonstrated in research in northeastern China (Liu et al., 2022). The incorporation of straw as a postharvest residue is the most economical way to enrich the agricultural soil with organic matter. In the years subsequent to the decomposition, these incorporated postharvest residues are a helpful organic fertilizer, which improves the soil structure and water capillarity and increases the crop yield. Numerous studies prove that the use of postharvest residues increases organic matter and humus content and exerts an influence on the reduction of soil compaction (Ovcharuk, 2020).

This research is aimed to identify the alternative technologies in the tillage systems and compare them with a conventional tillage. The most favorable tillage system for a particular soil can be established by determining its influence on the postharvest residues and the yield components in the end. A comparison of conventional with the reduced and conservation tillage systems will make it possible to find an optimal agrotechnical solution and recommendation for a high yield under the specific agroecological conditions of the investigated area.

MATERIALS AND METHODS

Soybeans (*Glycine max* L.) was monitored in the first research year in 2017, maize (*Zea mays* L.) in the second year (2018), and winter wheat (*Triticum aestivum* L.) in the third research year (2018–19). The experiment was set up in an agricultural area in the village of Donja Vrba in Brod-Posavina County, Croatia. A mechanical soil analysis was conducted in accordance with the HRN ISO 11464 (2004) standard applying the sieving method and the sedimentation method in accordance with the ISO 11277 standard (2009). It revealed that the organic layer had an extremely high dust content (fine + coarse powder = 82.5%). The experiment was conducted on the pseudogley soil. For conducting a chemical analysis of the soil, the bulk samples were collected from the arable pedogenetic horizon from the depth of 30 cm using a probe. The calculation of fertilization recommendation was based on the chemical analysis of the soil

and the application of nutrients for each crop studied in the rotation. The soil's chemical properties were as follows: 12.74 mg K₂O/100 g soil (AL method), 7.7 mg P₂O₅/100 g soil (AL method), humus 2.54%, pH (KCl) 4.62, pH (H₂O) 5.43.

Setting Up the Experiment

The results represent a part of a wider research performed at the same study sites. A portion of these results from the doctoral dissertation Benković et al., (2023) on the same crops and the same period is already published. The experiment was a completely randomized block design with four repetitions. The main factor of the study was a "tillage system," and "crop" was a subfactor. The dimensions of a basic trial plot for every tillage system was 10 m x 90 m (900 m²). The total size of the plot for four tillage systems and with all four repetitions was 14,400 m².

Soil preparation for the soybean sowing and setup of the main research experiment factor (four different tillage systems) began in the autumn of 2016 and was conducted evenly in 2017 and 2018. The depth of the investigated tillage systems were as follows: conventional tillage—plowing (CT) at 35 cm, reduced tillage—disk harrowing (DH) at 15 cm, conservation tillage systems—chiseling (CH) at 30 cm, and subsoiling (SS) at 50 cm. Additional tillage and a pre-sowing preparation was performed using a rotary harrow at a depth of 7 cm and was uniform in all the tillage systems investigated.

In the first year, soybeans (*Glycine max* L.)—namely, the variety *Sinara*—was investigated as an experimental subfactor: in all tillage systems. All

the tillage systems investigated were tilled on 25 November 2016. Prior to soybean sowing, the seeds were inoculated with the soybean inoculant Biofiks-S, for which *Bradyrhizobium japonicum* D344, produced by the Microbiology Department, Faculty of Agriculture in Zagreb, was applied. Sowing was performed on 15 April 2017 using a Kongskilde PROFILINE DR23, which was set to a sowing depth of 3 to 4 cm and a 52 cm row spacing. The set row spacing amounted to 4 to 5 cm. Prior to soybeans, winter wheat was sown.

In the second research year, a maize's (*Zea mays* L.) *Kulak* variety of the Agricultural Institute Osijek (from the middle group of FAO 400) was monitored, in all tillage systems. All tillage systems investigated were tilled on 28 October 2017. Fertilization and top dressing were performed uniformly and according to the recommendation in all observed tillage systems. Maize was sown on 18 April 2018 using a Gaspardo DORADA SP6 pneumatic seed drill, which was set to an 18.6 cm row spacing and 70 cm distance between the rows.

In the third study year, an early winter-wheat (*Triticum aestivum* L.) variety, the variety *Viktoria* produced by Agro Genetics Osijek, was monitored on all tillage systems. All investigated tillage systems were tilled on 24 October 2018 applying the same agricultural techniques and tillage depths as in the previous research years. Winter wheat was sown on 5 November 2018 using a Kongskilde Profiline DR23 seed drill set to a row spacing of 13 cm.

During all three study years, a Massey Ferguson 8480 Dyna-VT tractor (Fig. 1) was used to investigate the tillage system influence.



Figure 1. Tractor Massey Ferguson 8480 Dyna-VT.

Slika 1. Traktor Massey Ferguson 8480 Dyna-VT.

A five-furrow plow produced by Regent Titan was used to perform conventional tillage (CT), whereas reduced tillage (DH) was performed using a RAU Rondo XL 44 disk. Conservation tillage, chiseling (CH), and subsoiling (SS) was performed using a Pegoraro MEGA DRAG 7 subsoiler (Fig. 2), which was set to the different

working depths mentioned above. For additional cultivation, Kongsilde HK 31 rotary harrow was used. The number of passes for all investigated tillage systems and additional cultivation was limited to one pass. The other agrotechnical interventions, (fertilization, protection, and harvesting) was uniform in all three research years.



Figure 2. Subsoiler Pegoraro MEGA DRAG 7.

Slika 2. Podrivač Pegoraro MEGA DRAG 7.

Postharvest Residues

The measurement of soil-surface coverage with the postharvest residues was performed applying a line-transect method adapted to the metric measurement system. The postharvest residues were measured diagonally (at an angle of 45°) to the sowing direction. A 10 m long rope was marked every 10 cm, and the presence of the postharvest residues longer than 2 cm was determined precisely at the points where the rope was marked. According to empirical research (Lafren et al., 1981; Shelton et al., 1995; Laamrani et al., 2007), the counted residues at one hundred measurement points provided a percentage of coverage by the postharvest residues for each of the tillage systems investigated.

This method was applied to count the postharvest residues of winter wheat (a precursor to soybeans in the first year of research) on 20 April 2017, soybeans on 20 April 2018, and maize on 18 November 2018 on all applied processing systems in four replicates.

Statistical Analysis

Statistica (version 13.5.0.17, TIBCO Software Inc., 2018) was used for statistical processing of the collected data. Fisher's test for the detection of significant differences and comparison of the mean values resulted in the least significant differences (LSD) for a significance $p < 0.05$.

RESULTS AND DISCUSSION

The mean annual temperature for the 1963–2023 multiannual period (Table 1) was 11.2 °C, while the amount of precipitation in the study region was 769.9 mm (Table 2). In the research period, a higher amount of precipitation than the multiyear average was recorded in the years 2017 and 2019, while there was less precipitation in 2018. Average temperatures were 1.2 °C higher during the three years of research than the 60-year average. By a comparison of the average temperatures in the research period and the multiannual averages (Fig. 1), it is evident that the temperature at the time of the research was slightly higher in all twelve months. Monthly precipitations (Fig. 2) during the investigation period was higher in the hibernal and in the vernal months, while it was lower than the multiannual average in the summer and autumn. A positive impact on a high yield at all research tillage systems was probably also due to the 23.7 mm higher precipitation in the research years than a multiannual average. Such a favorable distribution and amount of precipitation is not characteristic of a research longer than 10 years, wherefore the importance of a correct selection of a soil-tillage system and the conservation of winter precipitation can be better understood (Kisić et al., 2010).

Table 1. A comparison of monthly temperature (°C) deviation in the research period (2017–2019) with a multiannual (1963–2023) average

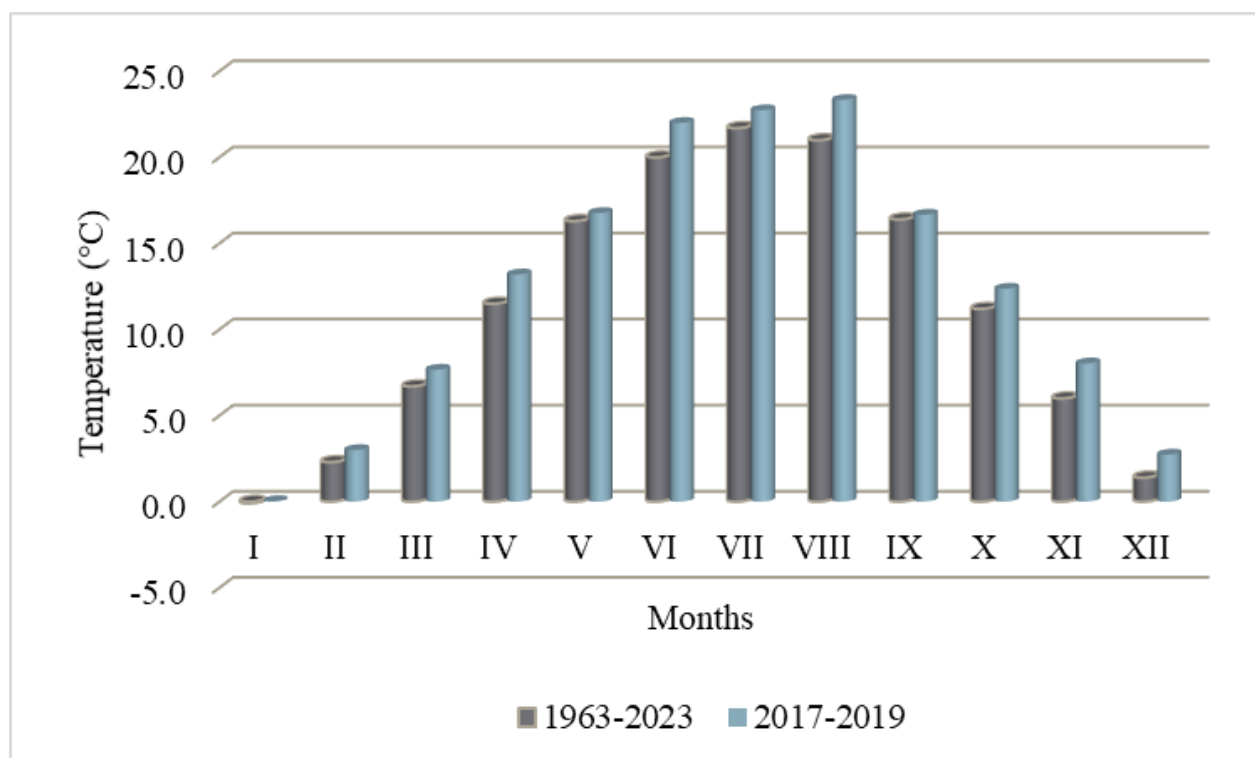
Tablica 1. Usporedba odstupanja mjesečnih temperatura (°C) razdoblja istraživanja (2017. – 2019.) u odnosu na višegodišnji prosjek (1963. – 2023.)

Period	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
Average, 1963–2023	-0.1	2.3	6.7	11.5	16.3	20.0	21.7	21.0	16.4	11.2	6.0	1.4	11.2
2017	-4.7	1.9	2.8	-0.2	0.7	2.2	2.2	2.9	-0.4	-0.2	0.3	1.9	0.8
2018	4.6	-1.7	-1.9	4.4	3.0	0.8	0.2	1.9	0.4	2.4	1.4	-0.2	1.3
2019	0.5	1.9	2.0	0.9	-2.3	3.0	0.7	2.2	0.8	1.3	4.4	2.3	1.3
Average, 2017–19	0.0	3.0	7.7	13.2	16.8	22.0	22.7	23.3	16.7	12.4	8.0	2.7	12.4

Table 2. A comparison of precipitation (mm) deviation in the research period (2017–2019) with a multiannual (1963–2023) average

Tablica 2. Usporedba odstupanja količine oborina (mm) u razdoblju istraživanja (2017. – 2019.) u odnosu na višegodišnji prosjek (1963. – 2023.)

Period	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
Average, 1963–2023	50.8	44.4	47.8	59.5	75.9	84.0	78.8	67.9	71.3	62.8	66.5	60.2	769.9
2017	-8.9	27.9	4.6	11.9	98.7	-37.3	-33.0	-48.1	42.9	23.9	-18.5	14.7	78.8
2018	9.4	47.4	38.4	-41.8	28.9	35.8	44.1	-42.1	-41.8	-52.2	-36.0	-20.2	-30
2019	1.8	-12.4	-21.0	27.4	73.0	37.0	-28.9	-28.2	-4.0	-30.2	12.6	-4.8	22.3
Average, 2017–19	51.6	65.4	55.1	58.7	142.8	95.8	72.9	28.4	70.3	43.3	52.5	56.8	793.6

**Figure 1. A comparison of monthly temperature means (°C)—a multiannual average (1963–2023) vs. a research period (2017–2019).**

Grafikon 1. Usporedba mjesečnih srednjih vrijednosti temperature (°C) — višegodišnji prosjek (1963. – 2023.) u odnosu na razdoblje istraživanja (2017. – 2019.).

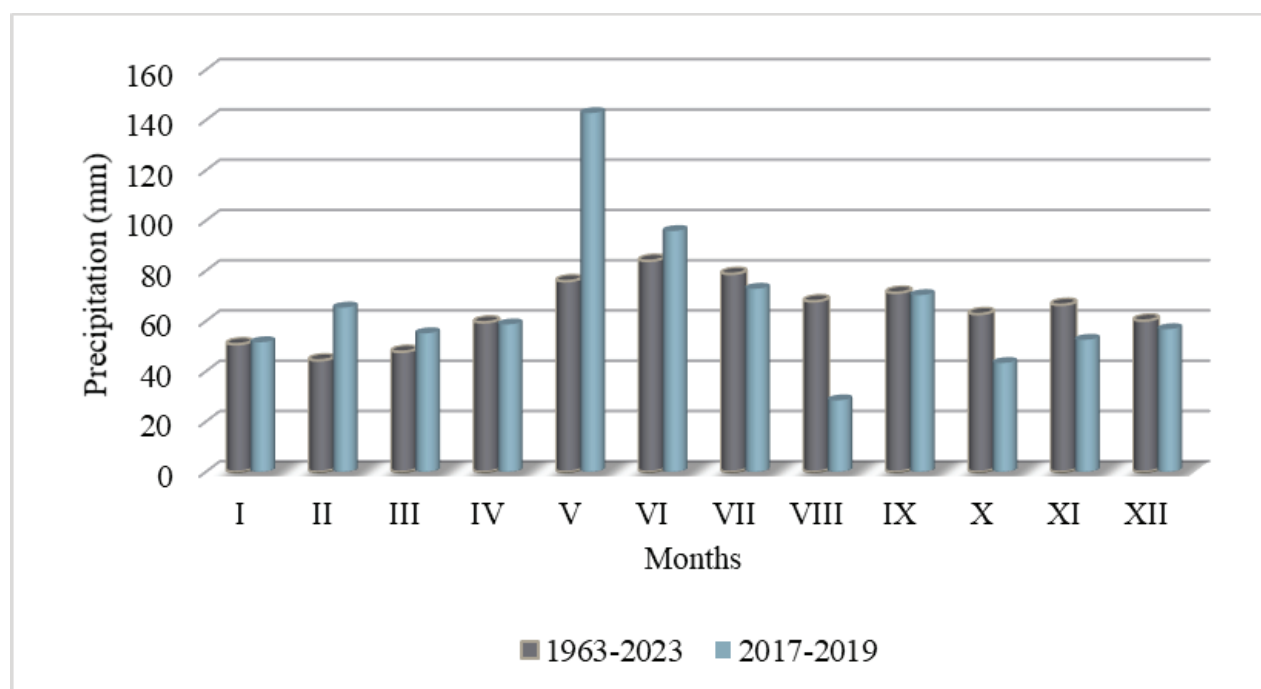
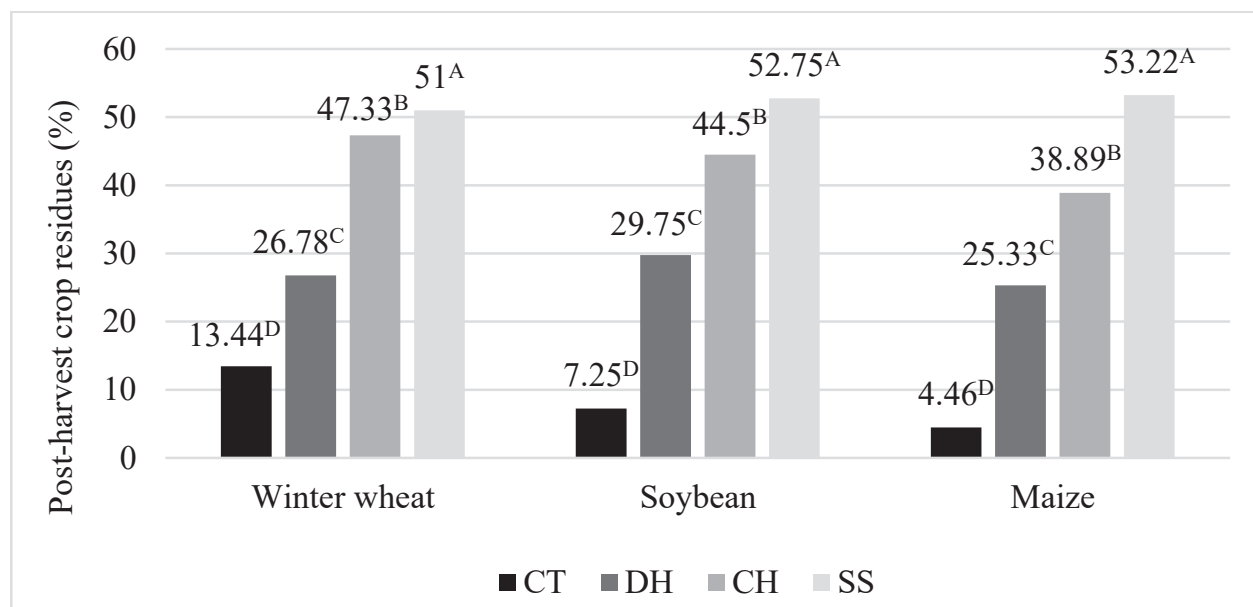


Figure 2. A comparison of monthly precipitation means (mm)—a multiannual average (1963–2023) vs. a research period (2017–2019).

Grafikon 2. Usporedba mjesečnih srednjih vrijednosti oborina (mm) — višegodišnji prosjek (1963. – 2023.) u odnosu na razdoblje istraživanja (2017. – 2019.).

The applied tillage systems and their influence on the amount of postharvest residues is presented in Figure 5. The results of an applied tillage system

concerning the agricultural yield, biological yield, and a harvest index of the observed crops are also presented in Tables 3, 4, and 5.



The capital letters (A–D) indicate the significant differences ($p < 0.05$) between the tillage systems in every crop season.

Figure 3. Tillage system influence on the amount of postharvest residues

Grafikon 5. Utjecaj sustava obrade tla na količinu posliježetvenih ostataka.

A cover with the postharvest residues in the first year of the study, with the winter-wheat residues, was statistically significantly influenced by tillage ($F = 314.25$). The average soil cover with the postharvest

residues stood at 34.64%. The highest coverage was measured in the SS treatment (51.00%) and the lowest one in the CT treatment (13.44%). The soil cover with the postharvest residues was 13.33% lower in the CT treat-

ment than in the DH one, 33.89% lower than in the CH one, and 37.56% lower than in the SS one. The differences in a soil cover with the postharvest residues between the DH and CH (20.56%) and the DH and SS (24.22%) were statistically significant, as was a difference in a soil cover with the postharvest residues between the the CH and the SS treatment (3.67%).

A postharvest soybean-residue cover (averaged 33.56%) was statistically significantly influenced by tillage ($F = 427.68$). The highest coverage was measured in the SS treatment (52.75%) and the lowest one in the CT treatment (7.25%), as illustrated in Table 1. All the differences in a crop-residue cover between the tillage treatments were statistically significant, corresponding to different combinations, as follows: the DH and CT amounted to 22.5%, the CH and CT amounted to 37.25%, the SS and CT amounted to 45.50%, the CH and DH amounted to 14.75%, the SS and DH amounted to 23%, and the SS and CH amounted to 8.25%.

The average postharvest maize-residue cover amounted to 30.47%. The analysis of variance revealed a statistically significant influence of tillage ($F = 1120$) on a soil cover with the postharvest residues. The highest coverage was detected in the SS tillage treatment (53.22%) and the lowest one at 4.45% for CT (Fig. 1). A soil cover with the postharvest residues was 48.77% higher in the SS treatment than in the CT one, 27.89%

higher than in the DH, and 14.33% higher than in the CH. The soil cover with the postharvest residues was 34.43% higher in the CH treatment than in the CT and 13.55% higher than in the DH. The difference between the DH and CT was 20.88%.

In all three study years, most postharvest residues were detected in the SS treatment (51%, 52.75%, and 53.22%). A lower amount of postharvest residues on the surface was obtained by applying the CH conservation tillage with 47.33%, 44.5%, and 38.89% in the last year of the trial. In the case of the DH cultivation system, 26.78%, 29.75%, and 25.33% of the postharvest residues were recorded in the years studied, while only 13.45%, 7.25%, and 4.46% of the postharvest residues stayed on the surface in the CT treatment. These results of the postharvest residue values were similar to the findings of two studies (Jug et al., 2017; Hunter et al., 2021). A higher amount of postharvest residues could have a positive effect on the evaporation of soil moisture but may present disadvantages when sowing. An increased amount of postharvest residues could affect the instability of the seed-drill guidance during sowing, leading to insufficient seed distribution on the surface and at depth—that is, to a lower density of the build-up and a possible yield reduction (Šumanovac et al., 2004), which was not the case in the current study.

Table 3. The influence of a tillage system on the agricultural and biological yield and the harvest index of soybeans

Tablica 3. Utjecaj sustava obrade tla na poljoprivredni i biološki prinose te žetveni indeks soje

Tillage system / Sustav obrade	Soybeans (<i>Glycine max</i> L.)		
	Agricultural yield / Poljoprivredni prinosi (t ha ⁻¹)	Biological yield / Biološki prinosi (t ha ⁻¹)	Harvest index / Žetveni indeks (%)
CT	4.48 ^A	14.47 ^A	30.98 ^B
DH	3.89 ^B	12.72 ^B	30.48 ^B
CH	4.68 ^A	14.15 ^A	33.02 ^A
SS	4.76 ^A	14.42 ^A	33.02 ^A
F	* ($F = 7.96$)	* ($F = 3.53$)	* ($F = 15.65$)

F = F-test for tillage, * = significant difference, n. s. = no significant difference. The different capital letters (A, B, and C) within the same column indicate significant differences ($p < 0.05$) among the implemented tillage systems in a crop season.

Tillage significantly affected the agricultural yield of soybeans ($F = 7.96$). The average soybean yield was 4.45 t ha⁻¹. The highest yield was obtained in the SS treatment (4.76 t ha⁻¹) and the lowest one in the DH treatment (3.89 t ha⁻¹). The significant differences in the yield were revealed by the LSD test between the CT and DH (0.59 t ha⁻¹), the CH and DH (0.79 t ha⁻¹), and the SS and DH (0.87 t ha⁻¹), as illustrated in Table 2.

A biological yield of soybeans was significantly influenced by tillage ($F = 3.53$). The average biological yield of soybeans was 13.94 t ha⁻¹. The highest yield of soybeans was determined in the CT treatment (14.47 t ha⁻¹) and the lowest one in the DH treatment (12.72 t ha⁻¹). The statistically significant differences in the yield were revealed by the LSD test between the CT and DH treatments (1.74 t ha⁻¹), the CH and DH (1.42 t ha⁻¹), and

the SS and DH (1.70 t ha⁻¹). The differences in biological yield between the CT and SS, as well as between the CT and CH and between the CH and SS, were not statistically significant.

A harvest index of soybeans, which averaged 31.87%, was statistically significantly influenced by tillage ($F = 15.65$). The highest harvest index for soybeans was observed in the CH variety (33.02%) and the lowest one in the DH variety (30.47%). The LSD test indicated that the harvest index of soybeans in the CT variety was 2.05% lower when compared with the CH and SS varieties. The harvest index of soybeans in the DH-processing treatment was 2.55% lower than in the CH treatment and 2.54% lower than in the SS treatment. A difference in a harvest index between the soybeans in the CT and DH

and between the soybeans in the CH and SS was not statistically validated.

The highest grain yields obtained in the SS and CH crops, a harvest index in the SS and CH crops, and a high biological yield in the SS and CH crops correlated with the research results of Košutić et al. (2005) and Gaweda

et al. (2014), having indicated that the conservation-tillage systems supported soybean production. A grain yield in the SS, CH, and CT tillage systems demonstrated a significant correlation between a biological yield and a harvest index, which was similar to the research results of Ali et al. (2013).

Table 4. The influence of a tillage system on the agricultural and biological yield and the harvest index of maize

Tablica 4. Utjecaj sustava obrade tla na poljoprivredni i biološki prinos te žetveni indeks kukuruza

Tillage system	Maize (<i>Zea mays</i> L.)		
	Agricultural yield (t ha ⁻¹)	Biological yield (t ha ⁻¹)	Harvest index (%)
CT	14,42 ^B	34,01 ^B	42.99 ^A
DH	15,36 ^A	37,3 ^A	41.19 ^B
CH	15,57 ^A	37,4 ^A	41.57 ^{BC}
SS	15,6 ^A	37,29 ^A	42.10 ^C
F	* ($F = 15.82$)	* ($F = 27.32$)	* ($F = 9.3$)

F = F-test for tillage, * = significant difference, n. s. = no significant difference. The different capital letters (A, B, and C) within the same column indicate significant differences ($p < 0.05$) among the implemented tillage systems in a crop season.

The maize's agricultural yield (which averaged 15,24 t ha⁻¹) was under a significant influence of tillage ($F = 15.82$). The highest maize yield (15,6 t ha⁻¹) was recorded under the SS tillage, which ensures a better moisture movement and a lesser soil compaction. The application of perennial CT tillage at the same depth gave the lowest maize yield of 14,42 t ha⁻¹. The statistically significant differences in the maize yield revealed by the LSD test were between the CT and DH (0,94 t ha⁻¹), CT and CH (1,15 t ha⁻¹), and CT and SS (1,18 t ha⁻¹). The yield between the other processing treatments were not significant.

The level of biological yield, which averaged 36,5 t ha⁻¹, was statistically significantly influenced by the treatment ($F = 27.32$). The highest biological yield was measured for maize in the CH treatment (37,4 t ha⁻¹) and the lowest in the CT treatment (34,01 t ha⁻¹). The statistically significant differences in a biological yield were revealed by the LSD test between the CH and CT (3,4 t ha⁻¹), SS and CT (3,28 t ha⁻¹), and DH and CT (3,29 t ha⁻¹). The differences in the level of biological yield between the processing treatments CH, DH, and SS were not statistically significant by.

A harvest-index variation was significantly influenced by tillage ($F = 9.3$). The average harvest-index value was 41.96%. The highest harvest index was achieved in the CT (42.99%) and the lowest in the DH (41.19%). The LSD test showed that the harvest index of maize on CT was statistically significantly higher if compared with the DH (1.81%), CH (1.42%), and SS (0.89%).

The harvest index of maize in the SS was significantly higher than in the DH (0.90%), while other differences were not statistically validated.

The maize-grain yield in the 2018 growing season was at an enviable level. The highest yields were achieved with conservation tillage (SS and CH) and reduced tillage (DH), while the worst ones were achieved with conventional tillage (CT). In his study, Jug et al. (2018) obtained similar results when comparing conservation SS and conventional CT tillage in terms of yield. A deep SS tillage provided the best moisture conservation and the least soil compaction if compared with the other systems applied. This contributed to a stronger root development, better nutrient uptake, and an optimal moisture, ultimately leading to the highest yields. In their studies, Kisić et al. (2002), Rusu (2005), Moret et al. (2006), and Kisić et al. (2010) attained similar results (). In their research, some authors pointed out that a biological yield is related to the availability of water in the soil (Novero et al., 1985; Grant et al., 1989). Water-deficit stress during growth produced cumulative effects that ultimately reduced the biological yield (Kamara et al., 2003). A side-by-side comparison of the applied tillage systems demonstrated that the lowest crop yield was recorded with the DH tillage system and the highest one with the CT tillage system. With a uniform fertilization as recommended and the same weather conditions, maize achieved the best yield index in a conventional CT tillage system. The other systems applied achieved similar but statistically significantly lower yield indices.

Table 5. The influence of a tillage system on the agricultural and biological yield and the harvest index of the winter wheat

Tablica 5. Utjecaj sustava obrade tla na poljoprivredni i biološki prinos i žetveni indeks ozime pšenice

Tillage system	Winter wheat (<i>Triticum aestivum</i> L.)		
	Agricultural yield (t ha ⁻¹)	Biological yield (t ha ⁻¹)	Harvest index (%)
CT	5.62 ^B	14.87 ^C	38.02 ^B
DH	7.00 ^A	16.26 ^B	43.13 ^A
CH	6.95 ^A	16.98 ^B	41.03 ^{AB}
SS	7.01 ^A	17.77 ^A	39.62 ^B
F	* ($F = 74.50$)	* ($F = 20.98$)	* ($F = 6.99$)

F = F-test for tillage, * = significant difference, n. s. = no significant difference. The different capital letters (A, B, and C) within the same column indicate significant differences ($p < 0.05$) among the implemented tillage systems in a crop season.

The average level of wheat's agricultural yield was 6.64 t ha⁻¹. The analysis of variance revealed a statistically significant influence of tillage ($F = 4.21$) on the level of agricultural yield. The SS tillage treatment achieved the highest yield (7.01 t ha⁻¹), while the lowest wheat yield was achieved by the CT tillage (5.62 t ha⁻¹). The statistically significant differences identified through the LSD test in the wheat yield were between the CT treatment and the wheat yield in other tillage treatments. The wheat grain yield in the CT was 1.38 t ha⁻¹ lower than in the DH, 1.33 t ha⁻¹ lower than in the CH, and 1.39 t ha⁻¹ lower than in the SS processing treatment. Other differences in the yield were not statistically significant.

The level of wheat's biological yield, which averaged 16.47 t ha⁻¹, was statistically significantly influenced by the tillage treatment ($F = 13.64$). Wheat achieved the highest biological yield in the SS tillage treatment (17.77 t ha⁻¹) and the lowest in the CT tillage treatment (14.87 t ha⁻¹). The statistically significant differences in the wheat's biological yield identified through the LSD test were between the following tillage treatments: the DH and CT (1.38 t ha⁻¹), the CH and CT (2.11 t ha⁻¹), the SS and CT (2.90 t ha⁻¹), the SS and DH (1.51 t ha⁻¹), and the SS and CH (0.79 t ha⁻¹). The harvest index was 40.45% and was statistically significantly influenced by tillage ($F = 6.98$). The highest harvest index was the one for wheat in the DH (43.13%), whereas the lowest one was in the CT (39.62%). The LSD test indicated the significant differences in the harvest index of wheat between the DH and CT (5.12%), the DH and SS (3.52%), and the CH and CT (3.02%).

Regarding the observed tillage systems, the wheat's highest agricultural yield was obtained with the SS, DH, and CH tillage, while it was statistically lower with the CT tillage. Conservation (SS and CH) and reduced (DH) tillage, with a large number of postharvest residues, facilitated a better moisture transport under the 2019 climatic conditions and, consequently, the significantly better results compared with the CT tillage. All of this contributed to a better root development and nutrient uptake, which ultimately led to the highest yields. In their studies, Ahmand et al. (2009) achieved similar results. In their inquiries, some authors indicated that the yield

was more under the influence of weather conditions and soil type (Jug et al., 2018) and precipitation distribution during vegetation (Birkás et al., 2013; Jug et al., 2014) than under the influence of a tillage treatment applied. In the studies conducted by Komljenović et al. (2013) over several years, the authors detected that the yield of the observed crops (maize, winter wheat, and soybeans) was influenced by the weather and only then by the tillage system. The results of his research confirmed that a conventional tillage was not the only solution but that there were other more rational and acceptable solutions to mitigate the climate disasters, which was also demonstrated in this research.

CONCLUSIONS

The remaining amount of the soil-surface postharvest residue was significantly different between the tillage systems used in all three observation years. More postharvest residues were detected in the SS and CH conservation-tillage systems than in a reduced DH and in a conventional CT tillage. The amount of postharvest residues made a positive contribution to the studied conservation-tillage systems in terms of an agricultural and biological yield. The postharvest residues can be proposed as a tool for plant adaptation to a physiological stress in the cultivation of field crops without irrigation.

Together with Croatia, Central Europe's agricultural production still predominantly utilizes conventional tillage. Product competitiveness in the European market creates ever greater demands for a reduction in production costs, simple and cost-effective cultivation, and the preservation of natural soil fertility while simultaneously reducing degradation. The highest grain yields, the highest harvest index, and the highest biological soybean and maize yields were obtained in the SS and CH tillage systems and then in the DH and CT ones. Hence, the results were entirely in line with the theses of some domestic and foreign researchers that the soils treated in accordance with some of conservation tillage systems were suitable for the cultivation of these investigated crops. In this study, the conservation-tillage systems positively affected the observed agricultural crops. Applying an

appropriate tillage system can be the most effective tillage method to achieve the high (optimal) yields while preserving the soil as a resource.

ACKNOWLEDGEMENTS

Funding: University of Slavonski Brod and the Brod-Posavina County (project title *The Influence of an Applied Tillage System and Fertilization on the Arable Crops' Post-Harvest Residues and Yield Components*).

The authors express their special gratitude to the Kurkutović Family Farm for its assistance regarding the conduct of this investigation.

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RAZLIČITI SUSTAVI OBRADE TLA I NJIHOV UTJECAJ NA FORMIRANJE PRINOSA USJEVA I POSLIJEŽETVENE OSTATKE

SAŽETAK

*Sustav obrade tla ekološki je prihvatljiva poljoprivredna metoda koja može poboljšati zdravlje tla i povećati prinose usjeva dapače i u nepovoljnim klimatskim uvjetima. Međutim, te će se prednosti vjerojatno razlikovati ovisno o primijenjenoj poljoprivrednoj praksi, obradi tla i vrstama usjeva, što ovo istraživanje nastoji obraditi. Tijekom ovoga trogodišnjeg istraživanja plodored je bio sljedeći: soja (*Glycine max* L.), kukuruz (*Zea mays* L.) i ozima pšenica (*Triticum aestivum* L.). Cilj ovoga istraživanja bio je utvrditi učinke različitih pristupa obrade tla (konvencionalna obrada [CT], tanjuranje [DH], rahljenje [CH] i podrivanje [SS]) na posliježetvene ostatke i prinos usjeva kao pokazatelje. Primijenjeni sustavi obrade tla rezultirali su statistički značajnim razlikama u nekim komponentama prinosa. Najveći prinosi, najviši žetveni indeks i najviši biološki prinos u uzgoju soje i kukuruza postignuti su sustavima obrade SS i CH, a zatim DH i CT obradom. Konzervacijski (CH i SS), reducirani (DH) i konvencionalni (CT) sustavi obrade tla rezultirali su statistički značajnim razlikama u količini ostataka nakon žetve, koji ostaju na površini tla.*

Ključne riječi: *reducirana obrada tla, konzervacijska obrada tla, prinos žitarica, ostatci nakon žetve*

(Received on April 29, 2025; accepted on May 19, 2025 – Primljeno 29. travnja 2025.; prihvaćeno 19. svibnja 2025.)