SOIL TILLAGE SYSTEMS IN THE FUNCTION OF ECOLOGICAL SUSTAINABILITY

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Sustavi obrade tla u funkciji ekološke stabilnosti

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SUMMARY

Stationary field experiment pertaining to the winter wheat in Croatia was performed during the three seasons. This study's intention was to examine and diagnose the effect of tillage systems (TSs) on soil chemical properties (soil acidity, phosphorus [P], potassium [K], and organic matter content). The TSs were as follows: CT — ploughing up to 30 cm depth, DT — disking up to 8-12 cm depth, LT — loosening up to 35 cm depth, and NT — no-tillage. The experimental design was a randomised block design in four repetitions, in which the basic TSs plot amounted to 540 m^2. Soil sampling for 0-30 cm soil layer was performed prior to setting up the experiment and subsequent to the three seasons with a total of 320 soil samples. Chemical analysis was performed according to standard pedological procedures. Economic indicators were calculated using economic equations and standards, whereas statistical analysis was performed with SAS 9.3 and Microsoft Excel 2016. Generated results indicate that the expressed accumulation of phosphorus and potassium appeared with a distinct vertical stratification in the systems with shallower tillage or no-tillage. At the same time, these TSs ensured the soil organic matter and soil fertility preservation. A conservable agricultural production of reduced soil tillage systems has its efficiency and vigor while providing soil degradation.

Keywords: soil chemical properties, tillage systems, phosphorus, potassium, organic matter

INTRODUCTION

Modern agriculture has been recently provoked to commit its operation recapitulation and modification due to the alternations in soil, water, and the environment caused by the weather patterns and climate implications/aberrations (Stocker et al., 2014; Rasmussen et al., 2018). Similarly, ecological, economical, and biological arguments influence the agricultural sector to comply with the demands of modified climate conditions, such as temperature extremes, droughts, water problems, desertification, high radiation, etc. Cammarano et al., 2019; Song et al., 2019). An agrosystem, or a production system, can be boosted, not only by the regulation of agrotechnical operations, its suitable intensity, and frequency but also should assess the capacity of soil to maintain and preserve water and nutrients. That is dictated by the content of the organic matter in the soil and its appropriate structure and microbiological vivification (Schlesinger and Amundson, 2018). Nowadays, it is usually essential to supply the scarcity of soil organic matter by the implementation of crop residues and straw, organic carbon-rich residues, or intercrop biomass into it (Coonan et al., 2019). In an agrotechnical chain, soil tillage is an operation, that can be modified and become a tool to elevate or mitigate agroecological stresses (Cooper et al., 2019). In general, elected soil tillage and tillage tools implicate the efficiency and performance of crop production. Climatic requirements and limitations, soil physical, chemical, and biological properties, disposable tillage mechanization, financial configuration, etc. are the elements that highly influen-

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ce and identify an adequate tillage selection (Karimi et al., 2018; Servadio et al., 2016). However, tillage anteriority will not be accomplished with a possible loss of soil productivity. Soil productivity is the constitution of attributes that represents soil potency for agricultural crop production, defined by soil fertility, i.e. plant nutrient activity, whereas tillage implicates the changes in nutrient content and distribution. There is a vast body of literature reporting on the influence of tillage on nutrients, e.g., Dorneless et al. (2015) point out that the available phosphorus and potassium were significantly influenced by the tillage systems, whereby they recorded the highest values in the 0-5 cm layer with regard to the reduced tillage. Also, the pH value, as they marked, was highest in the surface layer at NT, when compared to conventional tillage. Probably due to soil disturbance reduction, the same tendency pertains to the organic matter, where the highest values are registered in the NT and RT procedures. Similar results were obtained in the research conducted by Zukaitis and Liaudanskiene (2020). Issaka et al. (2019) highlight the fact that NT is the most appropriate and advisable tillage system for upgrading soil nutrients and reducing nitrogen and phosphorus dissipation. Lewis et al. (2011) claimed that the use of NT systems during the organic transition can increase soil quality without compromising yield and profitability. Other findings criticize reduced systems, especially NT, for tillage absence and nutrient stratification in the upper soil layer as a result of surface spreading (Smith et al., 2017). Also, Daryanto et al. (2017) alerts that N in NO_3^- form could be leached due to macropore continuity in an NT. The authors suggest a cover cropping, catch crops, and injectors for fertilizers to reduce the leaching and raise N use capability. In terms of N leaching, Struck et al. (2019) state that tillage intensity had no clear effect on the drainage N-losses. The aim of this study was to analyse the effect of a tillage system on its chemical properties, including pH, potassium (K), phosphorous (P), and the organic matter content in autumnal wheat cultivation.

MATERIALS AND METHODS

Research site description

A 3-year study field trial was conducted in a winter wheat-soybean cropping system at a research station in Osijek-Baranja County, Croatia (45° 37′ N, 18° 42 E, 83 m elevation). The soil, according to the FAO IUSS Working Group WRB (2015), was a silt loam (Gleysols; Van Velthuizen and Verelst, 2009) that belongs to a group of acidic soils, with a medium organic matter content, low phosphorus, and medium potassium content (OG, 20/18, 115/18, 98/19, 47/19) (Table 1). Prior to the experiment, winter wheat-maize-sunflower-sugar beet have been cultivated for 20 years using the recommended fertilizer rates and conventional tillage (ploughing) with a crop straw return, and the average wheat yield was 8.57 t ha^{-1}.

Table 1. Soil chemical and physical properties

Tablica 1. Kemijske i fizikalne značajke tla

Horizon / *Horizont*	Soil mechanics, % particles φ mm / *Mehanička svojstva tla, % čestice φ mm*			Soil texture / *Tekstura tla*	Microaggregate stability / *Stabilnost mikroagregata*	
	2-0.05	0.05-0.002	< 0.002		Ss, %	Mark
P 0-36 cm	11.51	63.92	24.57	Silty loam	84.65	Stabile
	Bulk density, g cm^{-3}	Packing density, g cm^{-3}	Porosity, %	Soil moisture, %	Air capacity, %	Water capacity, %
	1.74	1.96	33.59	28.72	2.22	31.37

Experimental design and operations

The investigation comprised the following tillage systems (TSs): 3-year ploughing up to 30 cm (CT), 3-year disking up to 12 cm (DT), a 3-year subsoiling up to 35 cm (LT), and a 3-year no-tillage (NT). Basic tillage plot was 30 m * 18 m (540 m^2), with 120 rows of wheat spaced 0.15 m. A randomized complete block design was used in four repetitions (16 plots), and the winter wheat cultivar Srpanjka was sown. Machinery performance and soil operations used in different TSs are shown in Table 2. In each vegetation season, 175 kg ha^{-1} P_2O_5 (288 kg ha^{-1} monoammonium phosphate) and 90 kg ha^{-1} K_2O (150 kg ha^{-1} potassium chloride) were used on the basic tillage plot as primary fertilization. Nitrogen (150 kg ha^{-1}) was applied during prime fertilization (35 kg ha^{-1} from monoammonium phosphate) and 45 kg ha^{-1} (urea) and in a tillering (40 kg ha^{-1}) and jointing (30 kg ha^{-1}) phase as the calcium ammonium nitrate on each plot.

Table 2. Detailed overview of operations for winter wheat

Tablica 2. Detaljan prikaz agrotehničkih operacija za pšenicu

TSs	Operations
CT	NPK fertilization, ploughing, seedbed preparation, sowing, weeds, pests, and disease protection, 2x side dressings, harvesting
DT	NPK fertilization, disking, seedbed preparation, sowing, weeds, pests, and disease protection, 2x side dressings, harvesting
LT	NPK fertilization, loosening, seedbed preparation, sowing, weeds, pests, and disease protection, 2x side dressings, harvesting
NT	NPK fertilization, sowing, weeds, pests, and disease protection, 2x side dressings, harvesting

Soil sampling and analysis

Prior to the investigation commencement, the soil samples were collected subsequent to the barley harvest, from all TSs in four repetitions at a 0-30 cm depth using a professional pedological probe (SP50, Dendrotik). Soil sampling was carried out as the baseline/initial status of soil chemical properties. Samples were collected from ten points (whereby each point had five samples that were mixed to create a composite sample) per each plot. The same procedure was applied subsequent to the wheat harvest according to the GPS coordinates following the three years of the field trial, and the total number of soil samples was 320. Heterogeneous soil samples were sieved through a 7 mm sieve and crop and root remains, and gravels were disposed, while the samples were air-dried in the shadow. Soil chemical and pedological analyses were performed according to the standard procedures, as follows: soil pH (HOH and KCl) was determined according to the ISO standard (ISO 10390), the available P and K content (AL-P_2O_5 and K_2O, mg kg^{-1}) was determined according to Egner et al., (1960), and humus (%) was examined pursuant to the ISO standard (14235).

Data analysis

The data were subjected to an analysis of variance (ANOVA) using the Principal Component Analysis (PCA) and the general linear model procedures of a statistical analysis system (*SAS 9.3* software package, (SAS Institute Inc., NC, USA). Correlation analysis was carried out by the MS Excel 2016 tool pack.

RESULTS AND DISCUSSION

Winter wheat trial was conducted on acidic soil with low available P content, medium K, and medium humus content (Table 3).

Table 3. Initial chemical properties of the P soil arable horizon at the start of investigation

Tablica 3. Inicijalne kemijske značajke P horizonta na početku istraživanja

Horizon / *Horizont*	Depth (cm) / *Dubina (cm)*	pH		AL-P_2O_5	AL-K_2O	Humus (%)
		HOH	KCl	mg kg^{-1}		
P	0-30	5.61	4.52	86.0	242.3	2.13

Such soils belong to a group of soils with a lesser actual fertility, which classifies them into the soils very suitable for research related to the efficiency of different soil tillage concerning the productivity of crop production. The impact of diverse TSs on wheat grain yield was published (Stošić et al., 2017), and according to the aforementioned authors, a significant difference in yield was determined on the NT when compared to other TSs, with an average yield of 6.94 t ha^{-1} wheat grain. According to a PCA analysis of all variables, the greatest TS influence was determined in the available P and K content, while the soil acidity ratios, as well as those of humus, were less influenced by the TS (Fig. 1).

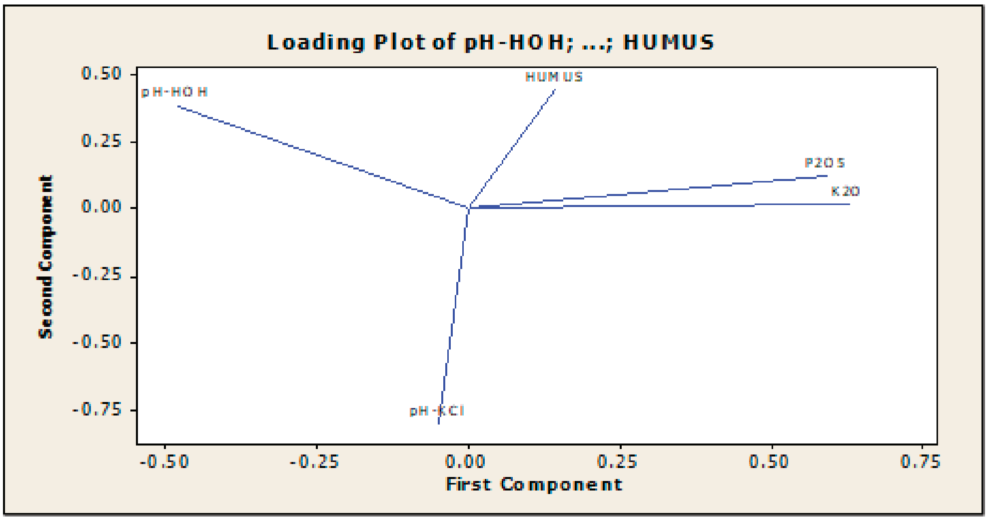

Figure 1. Principal Component Analysis of all variables

Grafikon 1. PCA za sve parametre

ANOVA confirmed the determined relationship, and a significant difference was primarily detected in the phosphorus and potassium content. The NT system had a statistically significantly higher content of available P and K compared to all other TSs. Soil acidity (pH KCl) was also influenced by the TS, with only differences between CT and NT. No significant differences were detected in humus content between the different TSs (Table 4).

Table 4. Soil chemical properties of the P soil arable horizon at the end of the investigation

Tablica 4. Kemijske značajke P horizonta na kraju istraživanja

TSs	Depth, cm	pH (HOH)	pH (KCl)	AL-P_2O_5 mg kg^{-1}	AL-K_2O mg kg^{-1}	Humus, %
CT	0-30	5.40 **A**	4.29 **A**	71.4 **B**	243.5 **B**	1.62 **A**
DT		5.28 **B**	4.19 **AB**	82.9 **B**	248.8 **B**	1.58 **A**
LT		5.30 **AB**	4.20 **AB**	79.1 **B**	245.4 **B**	1.65 **A**
NT		5.28 **B**	4.14 **B**	104.2 **A**	280.0 **A**	1.66 **A**
*P <0.05		0.1072	0.1224	14.348	26.962	0.1319

The means followed by different letters are significantly different ($p<0.05$) / *Razlike između vrijednosti koje sadrže istu slovnu oznaku nisu statistički značajne ($p<0.05$)*

In general, according to the TSs, available P content was higher on NT if compared to all the other TSs by 26 % and potassium by 13 %, respectively. Furthermore, for a soil available P and K content, a positive correlation was detected between the NT and DT $r = 0.78$ (phosphorus content) and $r = 0.87$ (potassium content) (Figs. 2 and 3).

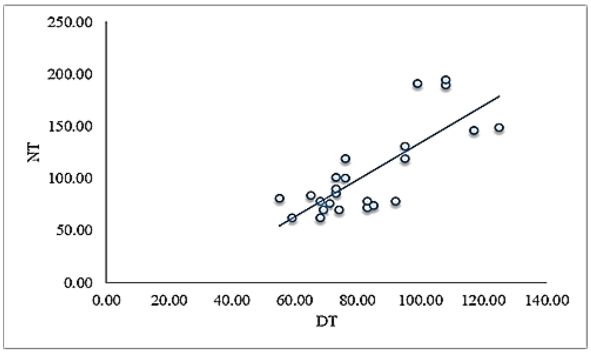

Figure 2. Correlation between the NT and DT for available soil P content (mg P_2O_5 kg^{-1})

Grafikon 2. Korelacija između NT-a i DT-a za pristupačan sadržaj fosfora (mg P_2O_5 kg^{-1})

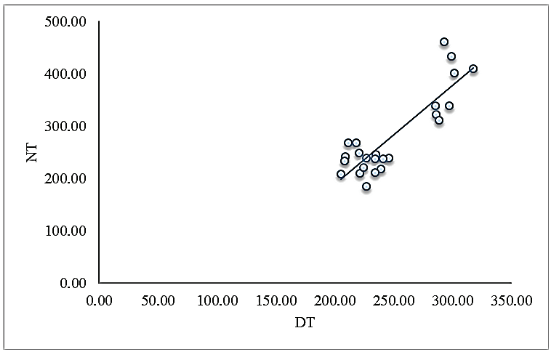

Figure 3. Correlation between the NT and DT for available soil K content (mg K_2O kg^{-1})

Grafikon 3. Korelacija između NT-a i DT-a za pristupačan sadržaj kalija (mg K_2O kg^{-1})

Soil chemical properties are a very important and limiting factor that directly and indirectly affects the level of plant production and crop yield (Yan and Hou, 2018.). According to the Technological Instructions for interpreting the results of soil fertility testing of the Republic of Croatia, the analysed soil belongs to a group of acidic soils with a medium organic-matter content, low available P, and medium K content (OG, 20/18, 115/18, 98/19, 47/19).

One of the soil's chemical factors that directly implicates the availability of plant nutrients or the elements of plant nutrition is soil acidity (Neina, 2019). In these studies, the alterations in soil pH (H_2O and KCl) were monitored in a 0-30 cm deep arable layer. The results presented in Table 3. Showed a change related to the influence of soil tillage on the changes in soil chemical properties if compared to the initial state. In all tillage systems, there was a decrease in soil pH and in organic matter content. Similar reports about the organic matter were submitted by Araujo et al. (2016), although Šimanský et al. (2016) and Kibet et al. (2016) had reported contrary results that reduced tillage preserved a significantly greater amount of organic matter in the topsoil layer when compared to CT. Ghimire et al. (2017) stated that soil pH was higher in DT than in CT systems in soil layers of 0-10 and 10-20 cm, respectively. Obour and Holman (2017) also underline a significant decrease in soil pH in the topsoil layer in NT when compared to CT. Additionally, Margenot et al. (2017) registered a decrease in soil pH under a reduced tillage. Meanwhile, the tillage generates soil mixing and a disposition of subsoil that has a proportionally higher pH and Ca^{2+} and Mg^{2+} concentrations that can contribute to the modification of soil pH changes on the CT or in the tilled systems, especially on CT or in some reduced systems.

Furthermore, there was a decrease in the available P and K content on all systems except NT, where an increase in the content of these elements was recorded. The content of phosphorus and potassium in arable soil is an extremely important component of plant nutrition (Weil and Brady, 2017), especially in the systems of reduced tillage or no-tillage, as in these systems the nutrients remain on the surface. A more detailed analysis of changes in the phosphorus content demonstrates that the increase occurred only in some TSs, especially in those systems in which there was a lesser soil mixing and inversion. In reduced TSs, however, in which the subsoil was not affected by tillage (such as DT), a partial LT and an integral NT, and P accumulation occurred. Such changes in the P content were effectuated due to a shallow application of mineral fertilizers, i.e. due to a shallow mixture of fertilizers with the soil surface layer on some variants (such as DT), or due to the application of mineral fertilizer on the soil surface, as is the case of the NT variant. These results are in accordance with the findings of Alam et al. (2018), who detected a significant phosphorus stratification in the topsoil layer (0-6 cm). Despite this stratification, however, and in spite of increased plant available water and root mass density, it did not affect the yield. Nevertheless, phosphorus stratification is not always registered in the NT, as reported by Jones et al. (2007). They found that after 30 years of converting NT to CT, or CT to NT, no vertical stratification of phosphorus, or of a classical model of phosphorus accumulation, was confirmed. Abdi et al. (2014) stated that NT changed the distribution of phosphorus classes through a soil profile, escalating the soluble phosphorus (i.e. the inorganic form) loss by runoff and organic phosphorus leaching. All of these changes lead to the minimization of total (i.e. inorganic and organic) phosphorus bioavailability in deeper soil horizons. Furthermore, in this study, potassium content and vertical dynamics were also influenced by soil tillage and were very similar to that of phosphorus, whereby a significant accumulation of potassium content in the topsoil layer was observed, especially in the DT and NT systems. Yet, possible problems in plant nutrition do occur, as in the no-tilled systems or in the systems with a shallow mixing of the surface layer surface and an uneven accumulation of nutrients. Neugschwandtner et al. (2014) observed that no-tillage accumulated more potassium in the topsoil layer (0-10 cm) than the tilled systems. Confirmation was also reported by Tan et al. (2015), noticing that a significantly higher content of available potassium was recorded in the 0-10 cm layer. It is indisputable that an increase in potassium content (as well as in that of phosphorus) is to be expected in the topsoil layer (0-10 cm) of systems with shallow tillage, especially in those with a no-tillage approach, which was further confirmed by Munson (1985), emphasizing a necessity of elevating phosphorus and potassium content prior to the establishment of a reduced tillage system. By virtue of a soil-inversion reduction in a no-tillage system and by increasing potassium/ or phosphorus content in the 0-10 cm layer, the soil available potassium/or phosphorus level in the deeper layers decreased (Meng et al., 2019). As in the non-tilled systems or in the systems with shallow mixing topsoil, the fact that the nutrients are located on the surface can lead to the physical isolation of the available nutrients (i.e., phosphorus and potassium) and the root system (Noack et al. 2014; Robbins and Voss, 1991), although Asenso et al. (2018) note that a zero tillage potentiate a more available NPK. In order to prevent and conserve the chemical, biological, and hydrological aspects of viable soil, the organic matter content is a remarkably relevant soil component (Rusu et al., 2013). With regard to the changes in the organic matter content, it should be noted that the period observed in these studies was too short to better monitor the significant changes with respect to this indicator, so only a decrease in organic matter content was detected in all systems if compared to the initial state (Table 3). Some studies show that reduced tillage aspires to increase soil matter, mostly due to crop rotation (Bogužas et al., 2015; Khaitov and Allanov, 2014). However, to maintain and preserve organic matter content, Goryanin et al. (2019) quote a necessity to import 6.7-8.0 t ha^{-1} of organic manure per year to compensate a balance of the organic matter deficit. According to numerous authors, organic matter and certain nutrients (NPK) accumulate on the soil surface of a no-tillage system during the initial years for a long period of time, and cannot be utilized by the plants. It is thus necessary to apply larger quantities of mineral fertilizers in basic fertilization because the tillage accelerates the organic matter oxidation and the mobilization of nutrients incorporated therein. This is not the case, however, in the no-tillage system due to the deposition of harvest residues on the soil surface.

CONCLUSION

As a function of agricultural production's ecological sustainability, tillage systems ensure environmentally friendly agricultural production, which is primarily reflected in the reduced degradation of soil chemical properties. In this study, the NT tillage stood out as the most favourable. Although it guarantees the conservation of soil organic matter, this tillage method does not ensure sufficient wheat yields, so its use in practice is limited. The promising systems of ecological acceptability were LT and DT tillage systems that ensure high yields with a satisfactory ecology, especially in arid conditions. In the long term, the use of different tillage systems ensures ecological sustainability through the reduction of soil degradation and the conservation of organic matter content. Furthermore, the systems with reduced tillage, especially the NT, revealed a phosphorus and potassium accumulation in the topsoil layer (0-15 cm) and pronounced nutrient stratification. Also, on NT, a tendency to decrease soil pH was observed, if compared to CT. As a sequence of actions, the tillage quality must be scheduled and defined in advance, considering and elaborating the potential environmental impacts, a selection of tillage system capabilities, and the recognition of tillage drawbacks and instant improvements.

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SUSTAVI OBRADE TLA
U FUNKCIJI EKOLOŠKE STABILNOSTI

SAŽETAK

Stacionarni poljski pokus za ozimu pšenicu u Hrvatskoj proveden je tijekom triju sezona . Namjera ovoga istraživanja bila je ispitati i dijagnosticirati utjecaj sustava obrade tla (TSs) na kemijska svojstva tla (kiselost tla, sadržaj fosfora, kalija i organske tvari. TSs-i su bili CT — oranje do 30 cm dubine; DT — tanjuranje do 8-12 cm dubine; LT — rahljenje do 35 cm dubine; NT — bez obrade tla. Eksperimentalni dizajn je bio randomizirani blok dizajn u četiri ponavljanja, u kojem je osnovna TSs parcela bila 540 m^2. Uzorkovanje za sloj tla 0-30 cm obavljeno je prije postavljanja pokusa i nakon triju sezona s ukupno 320 uzoraka tla. Kemijska analiza provedena jer prema standardnim pedološkim postupcima. Standardna statistička analiza provedena softverom **SAS 9.3** ***i*** **Microsoft Excel 2016*****. Dobiveni rezultati upućuju da se na sustavima s plićom obradom ili bez obrade javlja izražena akumulacija fosfora i kalija uz izraženu vertikalnu stratifikaciju. Istodobno ovi TSs-i osiguravaju konzervaciju organske tvari tla i očuvanje plodnosti tla. Poljoprivredna proizvodnja uz primjenu reduciranih sustava obrade tla ima svoju učinkovitost i snagu kroz sprječavanje degradacije tla.***

Ključne riječi: kemijske značajke tla, sustavi obrade tla, fosfor, kalij, organska tvar

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