Economic Viability of Winter-Wheat Tillage Systems

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Ekonomska održivost sustava obrade ozime pšenice

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SUMMARY

A multidisciplinary field experiment for winter wheat was conducted in Croatia during three seasons. The intention was to examine the effect of tillage systems (TS) on the economic indicators, that is, on the gross margin (GM), rate of profitability (ROP), cost-effectiveness (E) and productivity (P). The TSs were as follows: CT — plowing up to a 30 cm depth, DT — disking up 8-12 cm, LT — loosening up to 35 cm and NT — no-tillage. The experimental design was a randomized block one in four repetitions, whereby the basic TS plot amounted to 540 m^2. The economic indicators were calculated using the economic equations and standards. Statistical analysis was performed with the SAS 9.3 and Microsoft Excel 2016 software. The results are pointing that the LT assigned the prime economic results. The ROP was in the following order: CT (32.67%) < DT (37.39%) < LT (40.31%) < NT (42.29%). The same order was established for the E, as follows: CT (1.33) < DT (1.37) < LT (1.40) < NT (1.42). The NT established the best P because of the lowest production costs, but due to a significantly lower yield, the NT has a limited adoption in practice. A viable agricultural production by the implementation of reduced soil tillage systems has its capabilities and potential while invigorating economic sustainability and agricultural production's financial efficiency.

Keywords: soil tillage systems, gross margin, cost-effectiveness, productivity, rate of profitability, wheat

INTRODUCTION

The emergency and necessity for adaptation in agriculture and agricultural systems is a process recently recognized by the crop producers worldwide because of a global population increase (UN, 2019). Additionally, from the producers' point of view, a lot of proactive and innovative arguments must be borne in mind, such as the agroecological characteristics, government strategies and agendas, social demands and, last but not the least, producers' abilities, competences, and qualifications (Norman, 2015; FAO, 2016). Primarily, soil tillage and tillage implement generate a rather high energy expenditure and cost. Consequently, they affect a financial and economic aspect and, ultimately, the profit. In the conventional tillage systems, the stability of higher-quality yields is ensured. However, the agricultural machinery and human labor utilization costs will be the highest bringing variability in production process.

Other practices, that is, the reduced or conservation tillage systems, proved a positive impact on the soil, environment, and soil biodiversity. On the other hand, the yield and quality may be endangered, and variability can be quite prominent between the years (Lundy et al., 2015; Feiziene et al., 2018). The basis of conservation agriculture production is founded on management set on three fundamental postulates, which contextually unify the climate-soil-plant triad while respecting the agroecological and socioeconomic differences and mimicking the natural ecosystems (Mitchell et al., 2019).

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The farmers provide a farm input and make the productional practical decisions based on their economic profit and loss situation (Schimmelpfennig, 2017). From a producer's perspective, there is an economic incentive to be engaged in the crop rotation and soil tillage method (Wittwer et al., 2020), which, in terms of a land equity, provides the greatest (net) return to the management and risk-taking in the short term, as well as other fixed production assets in the long term. Consequently, the profit-motivated producers will seek to adopt a new cropping system only if it is perceived to provide a net economic benefit relative to a currently used system in terms of the lower production costs, higher net returns, lower business risk, and the like (Li et al., 2018). The problems of agricultural production are largely caused due to the high labor costs of people, machinery, materials and energy per unit area, resulting in a low labor productivity and unprofitable production. Based on a study by Kanisek et al. (2001), it was established that the CT in wheat production consumes 19.6 h ha^{-1} of machinery operation and 121.2 l ha^{-1} of fuel consumption. The total costs amounted to €827.32 ha^{-1}, the cost price €137.89 t^{-1}, the profit amounted to €60.78 ha^{-1} and the net rate of return amounted to 7.3%. The tillage machinery costs were reduced by €40.03 ha^{-1}. The total costs were lower by while the profit increased to €99.30 ha^{-1}, whereas the net return amounted to 13.1% (Kanisek et al., 2001). One of the most critical factors while increasing the work process intensity in agriculture is to elevate the level of technical equipment and improve labor productivity (Španić and Potkonjak, 2005). Kumar et al. (2013) and Sapkota et al. (2015) reported about an enlarged productivity and profitability on the zero and reduced tillage compared to the CT, while Parihar et al. (2016) recorded an increase in the net profit under the zero tillage (+31%) and a lower production cost (for €66 ha^{-1}) than the CT. Therefore, we evaluated the impact of different soil tillage on the economic indicators such as profitability, cost-effectivity, and gross margin over a three-year period.

MATERIAL AND METHODS

Experimental design

A three-year study's field trial was conducted in the winter wheat-soybean cropping system at research station in Slavonia and Baranja region, Croatia (45° 37′ N, 18° 42 E, at an elevation of 83 m). The investigation comprised the following tillage systems (TSs): a three-year plowing up to 30 cm depth (CT), three-year disking up to 12 cm depth (DT), three-year subsoiling up to 35 cm depth (LT) and a three-year no-tillage (NT) period. A basic tillage plot was sized 30 m x 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 for the different TSs are described in Table 1.

Table 1. Machinery and soil operations on different TSs

Tablica 1. Mehanizacija i agrotehnika za različite sustave obrade tla

TS	Operations / *Agrotehnika*
CT	Prime NPK 2x: *Amazone* (2 rotation disks) → Plowing: *Regent* (4 furrows) → Disk harrowing 2x: *Neretva OLT* (64 discs) → Seedbed preparation: *TeraX Kongskilde* (7 m) → Sowing: *John Deere 750 A* (36 rows) → Topdressing 2x: *Amazone* (2 rotation disks) → Crop protection 3x: *Rau* (18 m) → Harvest: Đuro Đaković *Hydroliner 3620* (6 m),
DT	Prime NPK 2x: *Amazone* (2 rotation disks) → Disk harrowing 2x: *Neretva OLT* (64 disks) → Seedbed preparation: *TeraX Kongskilde* (7 m) → Sowing: *John Deere 750 A* (36 rows) → Topdressing 2x: *Amazone* (2 rotation disks) → Crop protection 3x: *Rau* (18 m) → Harvest: Đuro Đaković *Hydroliner 3620* (6 m),
LT	Prime NPK 2x: *Amazone* (2 rotation disks) → Subsoiling: *John Deere* (5 frames – 50 cm spacing) → Disk harrowing 1x: *Neretva OLT* (64 disks) Seedbed preparation: *TeraX Kongskilde* (7 m) → Sowing: *John Deere 750 A* (36 rows) → Topdressing 2x: *Amazone* (2 rotation disks) Crop protection 3x: *Rau* (18 m) → Harvest: Đuro Đaković *Hydroliner 3620* (6 m),
NT	Prime NPK 2x: *Amazone* (2 rotation disks) → Sowing: *John Deere 750 A* (36 rows) → Topdressing 2x: *Amazone* (2 rotation disks) → Crop protection 3x: *Rau* (18 m) → Harvest: Đuro Đaković *Hydroliner 3620* (6 m)

In each vegetation season, 175 kg ha^{-1} of P_2O_5 (288 kg ha^{-1} of monoammonium phosphate) and 90 kg ha^{-1} of K_2O (150 kg ha^{-1} of potassium chloride) were used on a basic tillage plot as primary fertilization. Nitrogen (150 kg ha^{-1}) was applied in three occasions, that is, during the prime fertilization (35 kg ha^{-1} of monoammonium phosphate and 45 kg ha^{-1} of urea), tillering (40 kg ha^{-1}), and jointing (30 kg ha^{-1}) phase, in the form of calcium ammonium nitrate on each plot. The weeds, pests, diseases, seed amount and harvest were the same for all systems. A detailed number of passes, human working hours, and machinery working hours on TS divers is figured in Table 2.

Table 2. Detailed overview of TS intensity and frequency for winter wheat

Tablica 2. Detaljan pregled frekvencije i intenziteta različitih sustava obrade tla za ozimu pšenicu

TS	Number of passes / *Broj prohoda*	Human labor, h ha^{-1} / *Ljudski rad, h ha^{-1}*	Machinery h ha^{-1} / *Menahizacija h ha^{-1}*
CT	13	7.99	5.69
DT	12	6.94	4.39
LT	12	6.25	3.70
NT	9	5.09	2.18

Economic analysis

The TS economic analysis is founded on the tillage depth and the number of passes, in order to identify the human labor and machinery's productivity and efficiency, as well as cost-effectiveness, rate of profitability, and contribution/gross margin. Based on the calculation, the absolute and relative production performance indicators were calculated. The absolute indicators are the value of production (VP), variable cost (VC), and gross margin (GM).

The value of production (VP, € ha^{-1}) is based on the wheat grain yield and is computed by multiplying the quantity of product (t ha^{-1}) with the selling price (€ ha^{-1}), defined as follows:

$$VP = quantity\ of\ product \times selling\ price$$

The variable costs (VCs, € ha^{-1}) include the sum of (€ ha^{-1}) seed, mineral fertilizer, plant protection and human and machinery labor costs and are defined as follows:

$$VC = seeds + mineral\ fertlizer + plant\ protection + human\ labor + machinery\ labor$$

The gross margin (GM, € ha^{-1}) was computed by subtracting the variable costs (VCs) of a particular TS from the total value of production (VP) and is defined as follows:

$$GM = VP - VC$$

The relative performance indicators include the cost price (CP), cost-effectiveness (E), productivity (P) and the production's rate of profitability (ROP). The cost price (CP, € kg^{-1}) was computed by dividing the variable costs (VCs) by the quantity of product (t ha^{-1}) and is defined as follows:

$$CP = \frac{VC}{quantity\ of\ product}$$

Cost-effectiveness (E) was calculated by dividing the amount of value of production (VP) by the variable cost (VCs). The following equation was applied:

$$E = \frac{VP}{VC}$$

The rate of profitability (ROP) was obtained from the gross margin (GM) multiplied by 100 and then divided by the variable costs (VCs) and is expressed by the following equation:

$$ROP = \frac{GM \times 100}{VC}$$

Productivity represents a ratio of human labor consumption (h ha^{-1}) to the quantity of product (t ha^{-1}) and is calculated pursuant to the following equation:

$$P = \frac{labor}{quantity\ of\ product}$$

Data analysis

All data obtained were subjected to an analysis of variance (ANOVA) using the Principal Component Analysis (PCA) and general linear model procedures of the Statistical Analysis System (*SAS 9.3* software package, SAS Institute, Inc., Cary, NC, USA).

RESULTS AND DISCUSSION

With regard to the different tillage types, the basic wheat production economic indicators demonstrated that the NT costs were the lowest, amounting to 13.5% (VC) and 9.9% (VP), respectively. Regarding the GM, the values were detected to be higher in relation to the CT, amounting to 9.7% in the DT, 16% in the LT, and 8.8% in the NT.

A higher CP was determined for the NT when compared to that of the CT (13.5%), but it was lower for the DT and the LT (4.4%). The E value was averagely 5% higher in all treatments if compared to that of the CT. The P value was lowest on the NT when compared to all other TSs, amounting to 20.6%. On all TSs, a higher ROP was found in relation to the CT, DT (12.5%), LT (18.9%) and the NT (22.7%). Financial results' statistical analyses (ANOVAs) were also estimated for each TS. The input values refer to the wheat production's variable cost. The costs of seeds, mineral fertilization, and plant protection agents were identical for all TSs. There were no statistically significant differences between these costs. Human and machine labor (VC) had different values, with significant differences between all TSs, and the lowest one was obtained by the NT. The significantly lowest VC was determined in the NT when compared to the DT, CT, and LT. The highest GM was the one on the LT, while the lowest GM was the one on the CT, with significant differences between a reduced TS when compared to the CT. The highest VP was recorded by the LT > DT > CT sequence, and the significantly lowest one was obtained by the NT (Fig. 1).

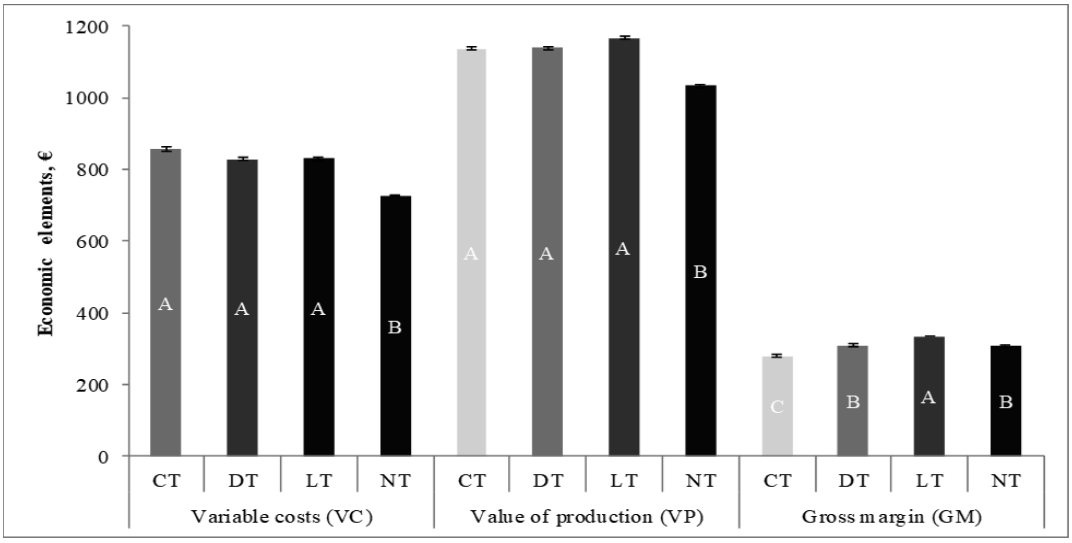

Figure 1. Wheat production calculation under different TSs (TS: CT— plowing, DT—disking, LT—soil loosening and NT—no-tillage)

Grafikon 1. Kalkulacija proizvodnje pšenice na različitim sustavima obrade tla (TS: CT — oranje, DT —tanjuranje, LT — rahljenje i NT — no-tillage)

The means followed by different letters are significantly different ($p < 0.05$) / *Razlike između vrijednosti koje sadrže istu slovnu oznaku nisu statistički značajne ($p < 0,05$)*

Considering the CP, a statistically significant difference was detected between all TSs, with the statistically highest cost being that of the NT. E, as the invested funds' efficiency indicator, had the highest LT value and the lowest NT value, with the significant differences between all TSs (Fig. 2.)

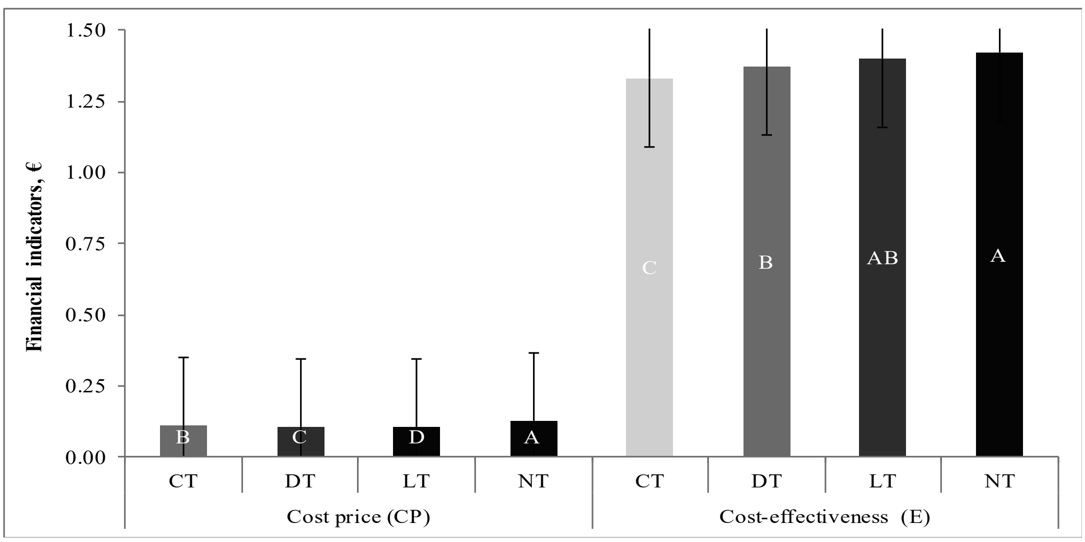

Figure 2. Financial indicators according to different TSs (TS: CT— plowing, DT—disking, LT—soil loosening and NT—no-tillage)

Grafikon 2. Financijski indikatori na različitim sustavima obrade tla (TS: CT — oranje, DT — tanjuranje, LT — rahljenje i NT— no-tillage)

The means followed by different letters are significantly different ($p < 0.05$) / *Razlike između vrijednosti koje sadrže istu slovnu oznaku nisu statistički značajne ($p < 0,05$).*

The P values were best with the NT, because it took less hours to produce one ton of wheat if compared to other TSs. Specifically, in our research, the results circumstantiated that 0.75 working hours were necessary for the production of one ton of wheat on the NT, which was significantly less when compared to other TSs (Fig. 3.).

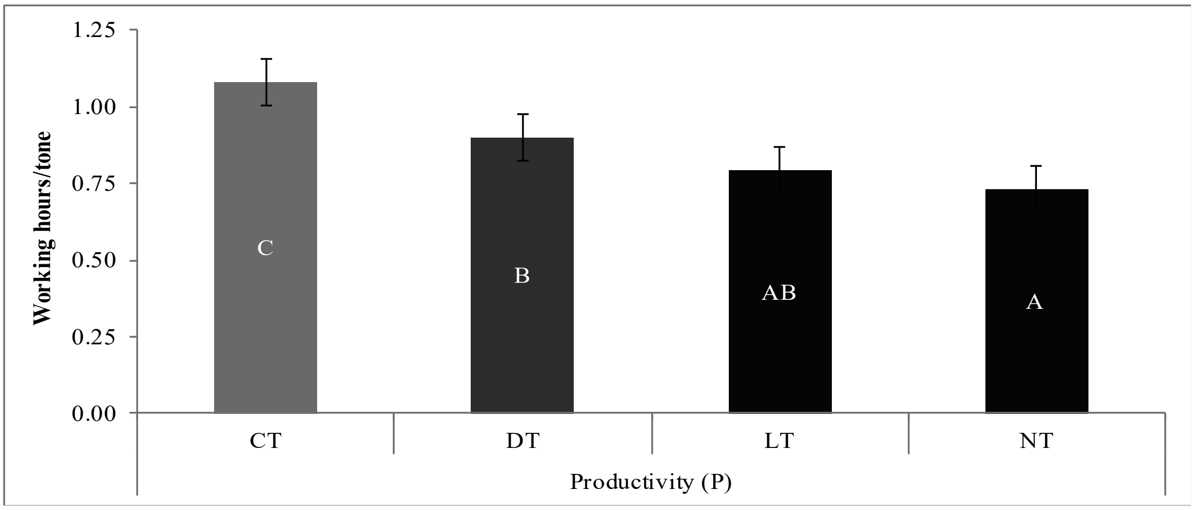

Figure 3. One-ton wheat productivity according to different TSs (TS: CT— plowing, DT—disking, LT-soil loosening and NT-no-tillage)

Grafikon 3. Produktivnost jedne tone zrna pšenice na različitim sustavima obrade tla (TS: CT — oranje, DT — tanjuranje, LT — rahljenje i NT — no-tillage)

The means followed by different letters are significantly different ($p < 0.05$) / *Razlike između vrijednosti koje sadrže istu slovnu oznaku nisu statistički značajne ($p < 0,05$).*

The same ratios and significant differences were determined for the ROP's LT maximum and NT minimum (Fig. 4).

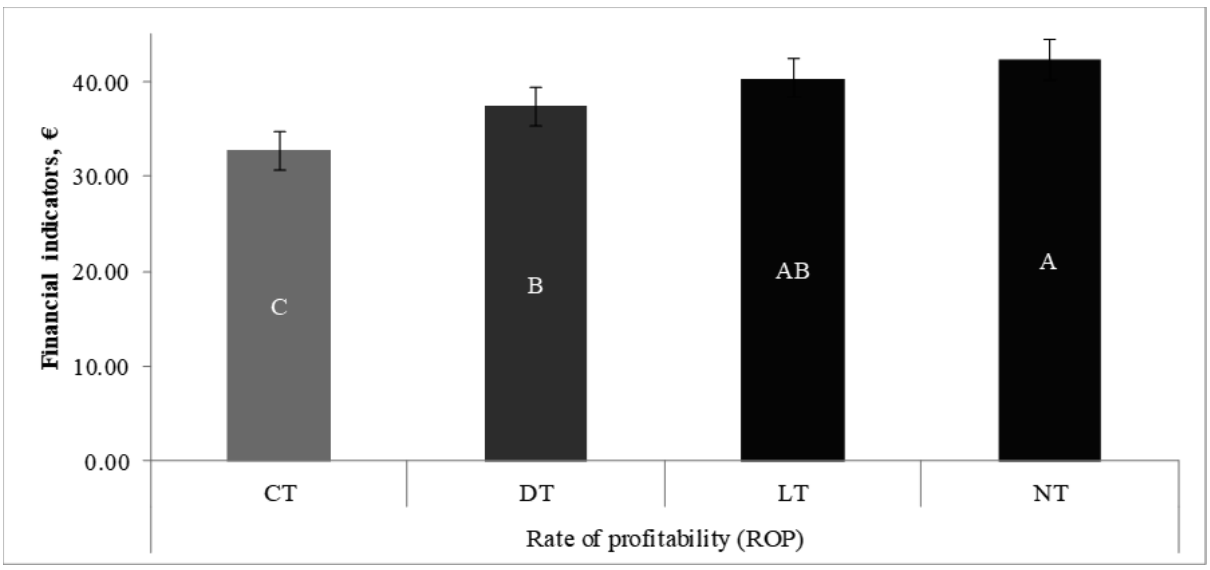

Figure 4. Rate of profitability according to different TSs (TS: CT— plowing, DT—disking, LT—soil loosening, NT—no-tillage)

Grafikon 4. Profitabilnost na različitim sustavima obrade tla (TS: CT — oranje; DT — tanjuranje; LT — rahljenje i NT — no-tillage)

The means followed by different letters are significantly different ($p < 0.05$) / *Razlike između vrijednosti koje sadrže istu slovnu oznaku nisu statistički značajne ($p < 0,05$).*

Economic analysis indicates a significant difference in profits between the different tillage systems. The LT is most efficient, with a gross margin amounting to €335 t^{-1}. The poor economic results were achieved with a CT system, with the gross margin o amounting to €280 t^{-1}. According to Jabran and Aulakh (2015), the zero and reduced tillage obtained the highest net returns, amounting to US$558 and US$535, respectively, while the lowest net return was attained by a conventional tillage (US$445). Žurovec et al. (2017), Shahzad et al. (2017), and Dzoma (2017) obtained the similar results. The indicators that are a direct outcome of the income-cost ratios, such as cost-effectiveness and profitability rate, have the same tendencies and are most favorable within the LT. The cost price and productivity were most favorable with a reduced NT tillage, requiring less machinery operations and less human labor. Fuentes-Llanillo et al. (2018) claim that the "NT systems had higher gross margins which were associated with longer use of the no-till system, ownership of machinery and equipment, specialization in grains, rotation of the commercial crops used, and higher variable costs. Therefore, a decrease in the NT costs is not justified, because it did not result in an adequate yield. Generally, the production costs' share in the NT production value amounted to 70%, while the LT amounted to 72%, DT to 73%, and the CT to 74%.

Given that, the investment is an important factor in any agricultural production, the results obtained can be used to introduce the different tillage types to the farmers due to the reduced costs. Likewise, a positive effect of different TSs on the agricultural production's economic and ecological aspect was established. The previous studies have found similar results, and Canales et al. (2020) claimed that a combination of no-till systems and cover crops could boost soil benefits, while Clark (2008) and Teklewood et al. (2013) detected complementarities between the conservation tillage and other soil and water conservation practices.

Our research improves the earlier efforts in several ways. First, we provided a detailed, deep-screening economic analysis, demonstrating that significant reductions in finances (i.e., the alleviation of tillage costs, a reduced tillage frequency, diminished GHG emissions, a decrease in fuel consumption, etc.) can be achieved with the application of some reduced tillage systems, for example, of the DT and the LT, while attaining a high yield (Ahmed et al. 2020). Secondly, these systems' application can significantly improve and maintain the soil quality, for example, the phosphorus and potassium content, the availability thereof, and the enlargement of different phosphorus fractions, ultimately leading to an increased eco-friendly sustainability (Xomphoutheb et al. 2020). These strategies' endorsement could boost the usage efficiency of P and K, essentially declining the new fertilizer intake and promising financial cutbacks in the forthcoming decades (Pavinato et al. 2020). Third, the agricultural production's economic and environmental aspects can largely determine the success of agricultural production itself, and these research efforts' results established that the greatest sustainability potential exists within the implementation of reduced tillage systems. The authors Žuža and Marković described the maize production calculations in terms of a direct drill and conventional tillage (Tables 6 and 7), having demonstrated that direct seeding obtained the higher profits with regard to an individual producer amounting to cca. 0.04 € ha^{-1}, that is, those of 27.93%. This result is obtained through the savings in diesel fuel expenditures that exceed the cost of an increased herbicide usage. Ultimately, these systems' application could assist the farmers to combat the climate change and aberrations, modify a high and expensive production, reduce the usage of high fertilizer quantities of fertilizers, obtain averaged biodiversity (Sheibani and Ahangar, 2013), since tillage is one of the agricultural production operations that suggest benefits in agroecosystem (Osewe et al. 2020). A future research challenge remains to certify the production systems' research results, quantifiable in the direction of the long-term agronomic, economic, and soil conservation and preservation impacts.

CONCLUSION

We examined the tillage systems as a function of agricultural production's economic sustainability, having demonstrated their effectiveness. In other words, the use of different tillage systems ensures an environmentally friendly agricultural production, which is primarily reflected in a reduced number of mechanizations passes, lower fuel consumption, decreased human labor and a reduced degradation of soil's chemical properties. In this study, the NT tillage stood out as the most favorable aspect concerning both characteristics studied. On the one hand, it guarantees the conservation of soil's organic matter and is most profitable due to the favorable wheat production's input and output ratios. On the other hand, this tillage method does not ensure sufficient wheat yields, so its use in practice is limited. The promising systems for economic viability were the LT and the DT tillage systems that ensure the high yields, with the satisfactory economic results. Moreover, these tillage systems can be a good solution for the agroclimatic areas in which a climate change is pronounced, especially in arid conditions. Nevertheless, the farmers have a major role in the dictation of agricultural production.

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EKONOMSKA ODRŽIVOST SUSTAVA OBRADE OZIME PŠENICE

SAŽETAK

Multidisciplinarni terenski pokus za ozimu pšenicu izveden je u Hrvatskoj tijekom triju sezona . Namjera ove studije bila je ispitati učinak sustava obrade tla (TS) na ekonomske pokazatelje kao što su bruto-marža (GM), stopa profitabilnosti (ROP), isplativost (E) i produktivnost (P). TS su bili sljedeći: CT — oranje do 30 cm dubine, DT — tanjuranje 8-12 cm dubine, LT — rahljenje do 35 cm dubine i NT — bez obrade tla. Eksperimentalni je dizajn bio randomiziran i blokni, u četiri ponavljanja, pri čemu je osnovna TS parcela iznosila 540 m². Ekonomski pokazatelji izračunani su korištenjem ekonomskih jednadžba i standarda. Statistička analiza provedena je softverom **SAS 9.3** ***i*** **Microsoft Excelom 2016*****. Dobiveni rezultati ukazuju da je s aspekta ekonomskih proračuna LT ostvario najbolje ekonomske rezultate. ROP je redom bio sljedeći: CT (32,67%) < DT (37,39%) < LT (40,31%) < NT (42,29%). Isti redoslijed utvrđen je i za E, i to redom: CT (1,33) < DT (1,37) < LT (1,40) < NT (1,42). NT je ostvario najbolji P zbog najnižih troškova proizvodnje, ali zbog znatno nižega prinosa NT ima ograničeno usvajanje u praksi. Održiva poljoprivredna proizvodnja implementacijom reduciranih sustava obrade tla ima svoje mogućnosti i potencijal, i to posebno ekonomski, potencirajući eko-održivost i financijsku učinkovitost poljoprivredne proizvodnje.***

Ključne riječi: sustavi obrade tla, bruto marža, isplativost, produktivnost, stopa profitabilnosti, pšenica

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