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ECONOMIC MODEL AND VIABILITY OF AGROECOSYSTEMS FOR SOYBEAN

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SUMMARY

A multifaceted field experiment for soybean was carried out in Croatia to assess the influence of tillage (TS) on selected economic indicators, that is, gross margin (GM), rate of profitability (ROP), cost-effectiveness (E), and productivity (P), and to provide a regression model for production planning. The investigated TS comprised the following parameters: CT - plowing (depth of 30 cm), DT - discing (depth of 8–12 cm), LT - soil loosening (depth of 35 cm), and no-tillage (NT). Randomized complete block design (RCBD) was used, with four replications. Experimental plot for a given TS measured 540 m^2. Economic indicators were calculated based on the established economic formulae and standard evaluation criteria. The **SAS** ***software version 9.3 and*** **Microsoft Excel 2016** ***were used for statistical analysis. GM was in the following range: NT (+12.9 %) > DT (+7.1 %) > LT (-15.4 %), with a significant difference concerning the CT (€278.60 ha^{-1}). ROP on the LT was lower (-14.5 %) and higher on NT (+21.4 %) significantly compared to CT. The production of one ton of soybeans on the NT took 1.75 working hours, which was significantly less compared to other TS. The results with the regression model highlight the varying economic viability of the TS, with notable differences in input costs, profitability, and efficiency, thereby offering valuable insights for sustainable and economically optimized soybean production.***

Keywords: regression model, gross margin, productivity, rate of profitability, soybean

INTRODUCTION

An agroecosystem is defined as an ecosystem under agricultural management that is interconnected with other ecosystems (OECD, 2001). Approximately 40% of the Earth's terrestrial surface is occupied by agroecosystems, like areas under crop production, livestock husbandry, aquaculture, and forestry (Lescourret et al., 2015). Agricultural practices and management interventions directly influence the dynamics of agroecosystems through chemical, physical, and mechanical modifications of soil–plant–atmosphere interactions (Alhameid et al., 2017). Consequently, global food production, quality, and storage are increasingly affected by climate change and environmental variability (Dinar et al., 2019). In this context, the integration of technological, biological, and information-based innovations is imperative to mitigate harmful impacts and enhance the sustainability of agricultural systems (Dawson et al., 2019). As noted by Wood et al. (2000), expanding the agricultural "production possibility frontier" requires coherent strategies that optimize input utilization—natural resources, labor, and capital—while maintaining ecological integrity. Although these efforts are in line with the principle of agroecosystem sustainability, the ultimate goal has not yet been achieved in modern agricultural production (Garibaldi et al., 2017, Field et al., 2014).

Historically, agricultural development has prioritized maximizing yield and profit while maintaining soil productivity, often leading to a trade-off between productivity and ecological stability (León-Sicard et al., 2018; Gaffney et al., 2019). However, as Altieri et al. (2017) claims, addressing sustainability challenges requires a holistic perspective, since agroecosystem components—soil properties, climate variability, biodiversity, and economic drivers—are intricately related (Feng et al., 2018; Ramzan et al., 2019; Panasiewicz et al., 2020). In response, conservation agriculture (CA) has emerged as a prominent framework emphasizing minimal soil degradation, permanent soil cover, and diversified crop rotation (Giller et al., 2015). Within

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CA, no-tillage (NT) and reduced tillage systems have gained attention for their potential to enhance sustainability and resource-use efficiency. Studies indicate that NT can reduce fuel consumption, labor requirements, and operational costs while maintaining comparable yields relative to conventional tillage (CT) (Pittelkow et al., 2015; Sørensen & Nielsen, 2005; Calcante & Oberti, 2019). However, the results of previous research are not consistent. While several investigations report higher net returns and profitability under NT systems (Naab et al., 2017; Yousefi et al., 2019), others demonstrate superior economic outcomes under CT (Gawęda et al., 2020). Fuglie (2018) noticed that agricultural land, labor, and inputs up growth had gradually decelerated due to rapid increment in their efficiency. As stated earlier, Naab et al. (2017) highlighted that CT systems enhanced soybean yields from 23 to 39% compared to NT, but on the contrary, the production costs were lower for 20-29% with NT than with CT. Moreover, NT provides higher net returns and is more profitable than CT. Contrary, a study by Gawęda et al., (2020) underlines that the average income was higher on CT than NT for €64 ha^{-1}. In some earlier study, Sørensen & Nielsen (2005) observed significant energy input reduction with NT (75–83%) compared to CT, with a similar reduction in human labor. They also emphasized that total operation costs ranged from €78 to 150 ha^{-1}, but CT increased costs up to 81%. Furthermore, Calcante & Oberti (2019) pointed out in their study, that total time for all operations in CT was 4.5 h ha^{-1}, while NT entails 2.8 h ha^{-1}, total fuel consumption for CT was 90.8 ha^{-1}, until NT generated 63 % of fuel savings. Also, assuming that human labour was €20 h^{-1}, CT had €72.8 h^{-1} and NT €38.9 h^{-1}. Net return is one of key economic factors in crop production and according to study by Yousefi et al. (2019) was higher in NT (1496.77 \$ kg^{-1}) compared to CT (US\$1444.67kg^{-1}). Consequently, profitability was 3.23 (NT) and 2.59 (CT). Additionally, Stagnari et al. (2017) accentuate that grain legumes could play a crucial role in cropping systems due to boosting demands for plant products, such as protein and oil, and also because of the intensification of environmental and economic coercion on agroecosystems. Despite their importance, comprehensive long-term economic assessments of different tillage systems in soybean-based agroecosystems remain limited. Specifically, there is a need for integrated evaluations of productivity, profitability, and gross margin performance under varying tillage regimes to guide sustainable management decisions. Although numerous studies have explored the agronomic and environmental implications of no-tillage and conventional tillage systems, long-term, economically oriented assessments of these practices—particularly within soybean agroecosystems—are rare and often unconvincing. Consequently, there is a clear need for systematic analyses that integrate economic performance indicators to better understand the sustainability and profitability trade-offs associated with different tillage practices. Therefore, the aim was to examine the impacts of tillage systems for soybeans on assessment of economic aspects such as productivity, profitability and gross margin and provide recommendations of soybean agroecosystems alternatives in a way of agricultural practicability and economic feasibility. Furthermore, the aim of the paper was to develop a regression model for predicting the costs associated with the application of low nitrogen rates (35 kg N ha^{-1}) in different tillage systems.

MATERIALS AND METHODS

A 3-year multidisciplinary field research of tillage systems (TS) for soybean (*Glicine max* L.) was applied in the continental part of Croatia (45° 37′ 48″ N, 18° 42′ 0″ E, at 83 m elevation) with a continental climate with an annual average temperature of 11.0°C and average annual precipitation of 650 mm. Gley soil (USDA, 2014) type was determined in accordance to the IUSS Working Group WRB (2015) with a silt loam texture, pH of 4.52, phosphorus content of 86.0 mg kg^{-1}, potassium content of 242.3 mg kg^{-1}, and organic matter of 2.13 % (ISO 10390: 1994; ISO 14235: 1998; Egner et al., 1960). Prior to to the research, a crop rotation consisting of winter wheat/sunflower/barley/maize was grown for 20 years using a conventional tillage system based on continuous plowing. Crop residues/straw was returned after harvest into the soil. In this long-term period of 20 years 3.55 t ha^{-1} was the average yield of soybean. This three-year field research was a part of a long-term stationary trial whose main focus was fertilization. Agricultural operations and tillage equipment used for different TS were shown in Table 1.

Table 1. Agricultural machinery and tillage operations for different TSs

Tablica 1. Agrotehnika za različite sustave obrade tla

TS	Operations and equipment
CT	*TeraX Kongskilde* - Stubble mulching *Amazone spreader* - Prime NPK 2x *Regent plow*-Plowing: *Neretva OLT* - Disc harrowing 2x *Kverneland Rau* - Furrow closing *Rau Terramax* - Seedbed preparation *John Deere 750 A* - Sowing *Rau sprinkler* - Crop protection 3x Đuro Đaković *Hydroliner 3620* - Harvest
DT	*TeraX Kongskilde* - Stubble mulching *Amazone spreader* - Prime NPK 2x *Neretva OLT* - Disc harrowing 2x *Kverneland Rau* - Furrow closing *Rau Terramax* - Seedbed preparation *John Deere 750 A* - Sowing *Rau sprinkler* - Crop protection 3x Đuro Đaković *Hydroliner 3620* - Harvest
LT	*TeraX Kongskilde* - Stubble mulching *Amazone spreader* - Prime NPK 2x *John Deere subsoiler* -Subsoiling *Neretva OLT* - Disc harrowing 1x *Kverneland Rau*-Furrow closing *Rau Terramax*-Seedbed preparation *John Deere 750 A*-Sowing *Rau sprinkler*-Crop protection 3x *Đuro Đaković Hydroliner 3620*-Harvest
NT	*Rau sprinkler* - Crop protection 2x *John Deere 750 A* - Sowing *Rau sprinkler* - Crop protection 3x *Đuro Đaković Hydroliner 3620* - Harvest

Briefly, the TSs for soybean were as follows: (1) conventional tillage with plowing up to 30 cm depth - CT, (2) discing with disc harrow up to 8–12 cm depth - DT, (3) soil loosening with chisel up to 30 cm depth - LT, and (4) no-tillage - NT. All TSs were performed during a 3-year research period, and the main TS plot was 540 m^2 (30 m 18 m). The research was fitted on 2.5 hectares with a complete randomised block design in four repetitions (16 TS plots). A detailed arrangement of the number of agricultural operation passes, as well as the human (h ha^{-1}) and machinery working hours (h ha^{-1}) on different TSs, were presented in Table 2.

Table 2. Detailed schedule of different TS intensity and frequency

Tablica 2. Detaljan pregled frekvencije i intenziteta različitih sustava obrade

CT	number of passes	human labour, h ha^{-1}	machinery, h ha^{-1}
stubble mulching, NPK fertilization 2x, plowing, disc harrowing 2x, furrow closing, seedbed preparation, sowing, weed, disease, and pest protection 3x, harvesting	13	6.24	6.45
DT			
stubble mulching, NPK fertilization 2x, discing 2x, furrow closing, seedbed preparation, sowing, weeds, pest and disease protection 3x, harvesting	12	6.40	6.61
LT			
stubble mulching, NPK fertilization 2x, soil loosening, disc harrowing 1x, furrow closing, seedbed preparation, sowing, weed, pest, and disease protection 3x, harvesting	12	5.71	5.92
NT			
total herbicide 2x, NPK fertilization 2x, sowing, weeds, pests, and disease protection 3x, harvesting	8	4.52	4.73

On every TS 60 row of 'Podravka 95', cultivar was sown with an interrow spacing amounting to 0.30 m (120 kg ha^{-1}). The 'Podravka' cultivar was once widely grown in continental Croatia, so it was also used in the sowing of this field research because, as we mentioned, the three-year experiment replaced a part of a long-term stationary fertilization trial in which the 'Podravka' cultivar also was sown. In each soybean growing season 35 kg ha^{-1} N, 70 kg ha^{-1} P_2O_5 (288 kg ha^{-1} monoammonium phosphate) and 110 kg ha^{-1} K_2O (220 kg ha^{-1} potassium chloride) were applied. Likewise, mineral fertilization and crop protection were used accordingly to soil chemical analysis and recommendations. The original mission of the research was evaluation of the TS impact on economic components such as human and machinery labour, productivity, profitability and gross margin based on TS depth and frequency. According to the economic guidelines, production performance identifiers, absolute and relative, were calculated. Absolute indicators were value of production (VP), variable cost (VC), and gross margin (GM).

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

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

Variable costs (VC, € ha^{-1}) include the sum of costs (€ ha^{-1}) of seeds, mineral fertilizers, plant protection, human and machinery labor and were defined as follows:

$$VC = seed + mineral\ fertilizer + crop\ protection + human\ labor + machinery\ labor$$

The contribution margin (GM, € ha^{-1}) has been obtained by subtracting the variable costs (VC) of particular TS from the total value of production (VP) and was defined as follows:

$$GM = VP - VC$$

Relative performance indicators include cost price (CP), cost effectiveness (E), productivity (P) and rate of profitability (ROP) of production. The cost price (CP, € kg^{-1}) has been obtained dividing variable costs (VC) with quantity of product (t ha^{-1}) and was defined as follows:

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

Cost effectiveness (E) is calculated by dividing the amount of value of production (VP) and variable cost (VC). The following equation was used:

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

Rate of profitability (ROP) is obtained by gross margin (GM) multiplied by 100 and then divided with variable costs (VC) and was expressed by the following equation:

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

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

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

Economic indicators on TS were tested with one-way ANOVA. Statistical analysis was performed by *SAS 9.3* software package (SAS Institute Inc., NC, USA) and *Microsoft Office Excel 2016*. Comparisons between the TS were conducted using the LSD method.

3. RESULTS AND DISCUSSION

A multiple linear regression model was developed to predict the cost price associated with the application of a low nitrogen rate (35 kg N ha^{-1}) under different tillage systems—conventional tillage (CT), deep tillage (DT), light tillage (LT), and no-tillage (NT) (Table 3). The regression analysis aimed to quantify how nitrogen input levels influence production costs across tillage practices, reflecting differences in fuel consumption, labor requirements, and operational efficiency. The model can be described by a regression equation which is based on Y=I +kg NX relations. Although the regression was calibrated using two standard nitrogen levels (70 kg N and 110 kg N), it allows extrapolation to lower rates, such as 35 kg N, to estimate cost dynamics in reduced-input management scenarios. Using the regression coefficients, the predicted cost price (Y_{35}) for a low nitrogen input (35 kg N ha^{-1}) can be estimated by interpolating within the existing nitrogen response range

Table 3. Regression model

Tablica 3. Regresijski model

Model Equation	r	Intercept	70 kg N	110 kg N	ME (model error) %
CT	0,91**	-23,829	0,688	0,325	7,8
DT	0,89**	-21,893	0,686	0,321	5,2
LT	0,93**	-23,208	0,688	0,324	7,9
NT	0,94**	-30,250	0,685	0,334	9,6

Y=Tillage system (CT, DT, LT, NT) = Intercept + 70 kgNX1 + 110kgNX2

While the absolute values are model-specific and depend on scaling, the relative differences indicate that NT maintains lower overall cost sensitivity to nitrogen input, whereas CT and LT systems show a steeper cost increase even at reduced nitrogen levels. This suggests that at low nitrogen input (35 kg N ha^{-1}), no-tillage may offer greater cost efficiency due to reduced machinery operation and fuel consumption, while deep and conventional tillage exhibit higher fixed costs but lower variability (ME). Although the regression is calibrated using two standard nitrogen levels (70 kg N and 110 kg N), it also allows for prediction at lower nitrogen fertilization rates, such as 35 kg N, to estimate cost dynamics in reduced nitrogen management scenarios. Using the regression coefficients, the predicted cost price (Y_{35}) for low nitrogen input (35 kg N ha^{-1}) can be estimated by interpolation within the existing range of nitrogen responses. The cost prediction for fertilization with 35 kg N ha^{-1} shows that lower nitrogen inputs reduce overall costs, especially in conservation tillage systems, confirming their potential economic advantage in resource-limited and sustainable agricultural production.

Input values relate to the variable cost of soybean production. The expenses for seeds, mineral fertilization, and plant protection agents remain consistent across all TS. Among these costs, no statistically significant differences were observed. However, the ration of human and machine labour (VC) differed significantly among all tillage systems (TS). The lowest ration of VC were recorded under NT (8.1%) and DT (6.2%), meaning that these systems required the smallest proportion of total production costs for labour and machinery. For production value (VP), the highest ration was obtained under CT, followed by NT and DT, while the significantly lowest VP share was recorded under LT (5.8%). These percentages represent each tillage system's contribution to the total production value as shown in figure 1.

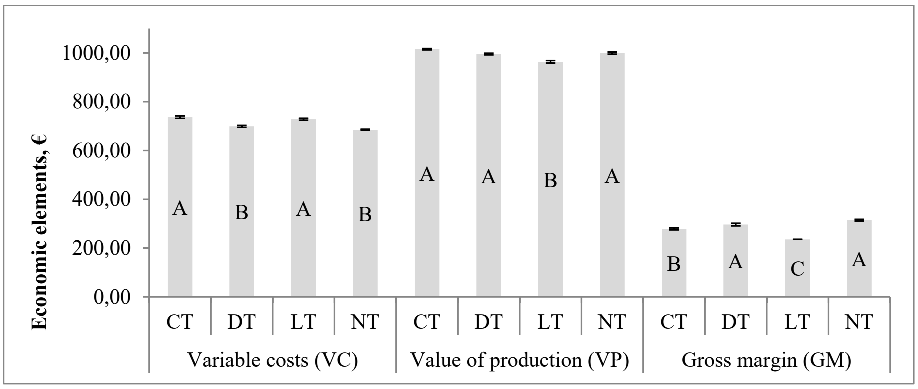

Figure 1. Calculation of soybean production under different TSs (TS: CT - plowing, DT - discing, LT - soil loosening, NT - no-tillage).

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

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

Through the TS analysis, various GM values in euros per hectare were identified. Using the base index approach, the CT system was set as the reference point, and the variations among the analysed TS were assessed. Gross margin was highest at NT (12.9 %) and DT (7.1 %) while the lowest GM was at LT (15.4 %), with significant differences compared to CT (€278.60 ha^{-1}). Considering CP (fig. 2.), a statistically significant difference was found between all TS, with the highest cost by LT (3.45 %), while lowest CP was recorded at DT (3.45 %) and NT (6.90 %).

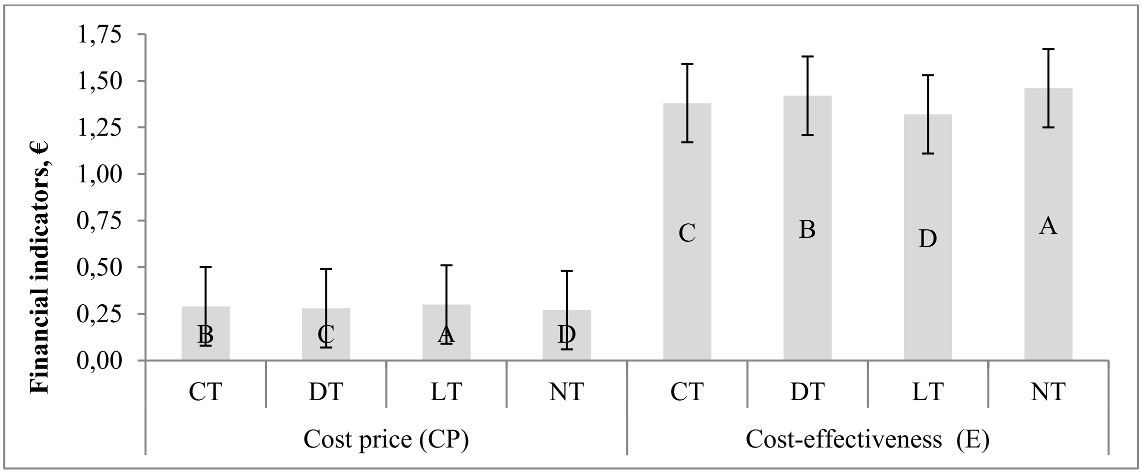

Figure 2. Financial indicators according to different TSs (TS: CT - plowing, DT -discing, LT - soil loosening, NT - no-tillage)

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

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

Cost-effectiveness (E) as an indicator of investment profitability was significantly lower by 4.35% with the LT, while significantly higher values were found in DT (2.90 %) and NT (5.80 %) in comparison with CT. Rate of profitability (ROP) is an indicator of the effectiveness of the resources invested in production (fig. 3).

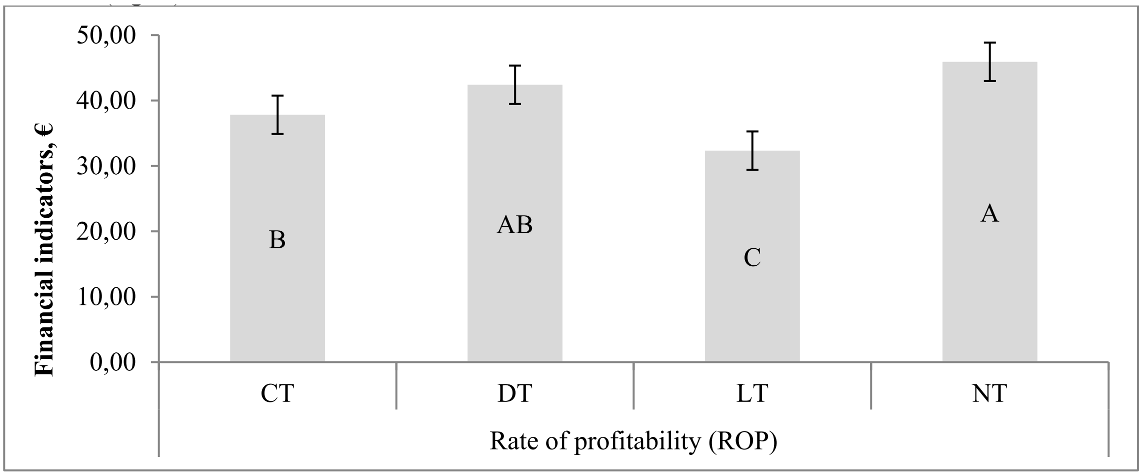

Figure 3. Rate of profitability according to different TSs (TS: CT - plowing, DT -discing, LT - soil loosening, NT - no-tillage)

Grafikon 3. Profitabilnost na različitim sustavima obrade tla (TS: CT - oranje, DT - tanjuranje, LT - rahljenje, NT - no-tillage).

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

A lower value of ROP was found in the LT (14.5%) and higher by 21.4% in the NT with compared to CT with significant differences.

Productivity (P) is an indicator of the efficiency of human work and shows the amount of work used per unit of work performance (fig. 4).

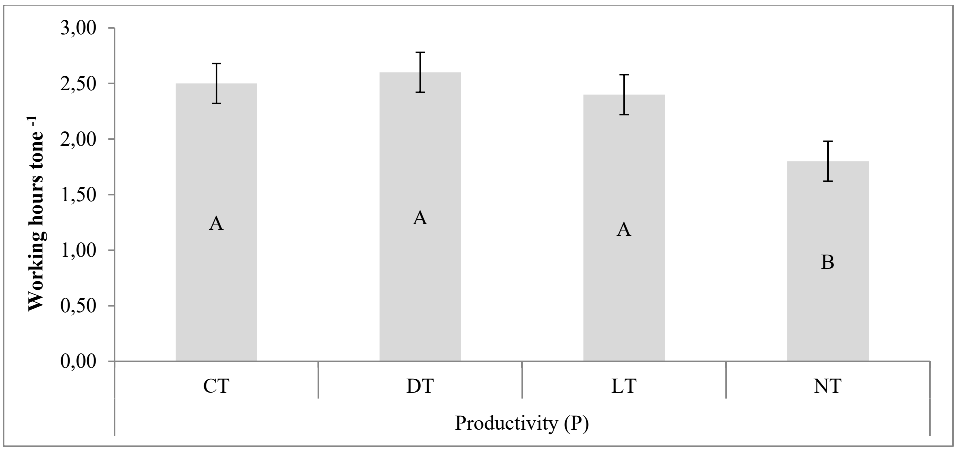

Figure 4. Productivity of one ton of soybean production according to different TSs (TS: CT -plowing, DT - discing, LT - soil loosening, NT - no-tillage).

Grafikon 4. Produktivnost proizvodnje jedne tone zrna soje na različitim sustavima obrade tla (TS: CT - oranje, DT - tanjuranje, LT - rahljenje, NT - no-tillage).

Notes: 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 most work per unit of performance is required for the DT (+5.23 %) than for the CT. Lower productivity was recorded in the LT (-3.41 %) whilst NT (-28.03 %) was significantly lower compared to the CT.

The selected nitrogen rate of 35 kg N ha^{-1} was determined in accordance with EU Regulation 2021/2115, which emphasizes the green transition by reducing mineral fertilizer use and minimizing NOx emissions from agricultural production. Incorporating this policy framework into the regression model allowed the assessment and prediction of cost prices associated with different tillage systems under conditions aligned with sustainable and environmentally conscious agricultural practices (Estelle et al., 2023).

The accuracy of the regression model was evaluated by comparing actual production costs with predicted cost prices derived from model equations. The difference between observed and predicted values, expressed as a percentage, represents the model error (ME; Siegel, 2012). Across all tillage systems, the models demonstrated strong correlations ($r = 0.89–0.94$; $p < 0.01$) and acceptable prediction errors (ME = 5.2–9.6%), confirming their robustness. Models of this nature are valuable for production planning, as they offer a practical means of estimating potential costs and can be adapted to diverse cropping systems and management conditions (Logeshwaran et al., 2024).

Integrated regression models that incorporate multiple economic variables—such as nitrogen response, market prices, and labor costs—serve as essential tools for farm-level decision-making (Kyveryga et al., 2007; Tarkalson & King, 2017). Differences in tillage intensity and fertilization strategies can substantially alter the structure of production costs; thus, model integration provides critical insights for optimizing economically viable nitrogen management under the EU's sustainability framework (CEAT, 2021; Webb, 2008; Alskaf et al., 2020).

Economic analysis revealed distinct differences in profitability among tillage systems. The gross margin results identified deep tillage (DT) and no-tillage (NT) as the most efficient systems, with margins of €297 t^{-1} and €314 t^{-1}, respectively. In contrast, conventional tillage (CT) and light tillage (LT) showed lower economic efficiency (€279 t^{-1} and €236 t^{-1}, respectively), primarily due to higher mechanization and operational expenses, as also reported by Bojarszczuk and Ksiezak (2023).

Production costs, representing total resource expenditure per production unit, were highest under CT and LT, while the value of production followed the trend CT > NT > DT > LT, consistent with Zhichkina et al. (2021). Energy-related expenses were notably lower in NT systems due to reduced machinery use and fuel consumption, though partially offset by greater herbicide inputs required for weed management (Yiridoe et al., 2000). The cost price for LT was 3.45% lower than that of CT; yet its cost-effectiveness (E) was 4.35% lower, reflecting reduced return on investment. As reported by Faleiros et al. (2018), labor accounts for a considerable portion of production costs—32.5% on average—while on smaller farms, labor contributes 13–15% of total costs, comparable to expenses for agrochemicals and seeds. Among the analyzed tillage systems, NT exhibited lower productivity (−27%) compared to CT, directly related to reduced mechanization intensity, but achieved the highest profitability rate (+21%), reflecting superior input-use efficiency. Conversely, LT showed the lowest profitability (−16%), illustrating the trade-offs between mechanization costs, input use, and yield potential.

Although yield reductions were observed under NT, the associated savings in fuel, machinery, and labor costs offset these losses, producing competitive net returns. Incorporating soybean as a rotational or intercrop further enhances system resilience and resource-use efficiency, supporting diversified cropping and higher income stability (Parihar et al., 2024).

From a practical perspective, the regression model provides a data-driven decision-support tool for farmers seeking to maintain economic viability under reduced nitrogen inputs, in compliance with EU green transition objectives. By simulating cost outcomes under varying tillage and fertilization regimes, the model enables producers to assess trade-offs between operational costs and productivity, facilitating site-specific management decisions. At the nitrogen level of 35 kg N ha^{-1}, the model indicates that no-tillage and deep tillage offer the most favorable balance between cost savings and profitability. These systems are therefore particularly suitable for producers facing high fertilizer prices, limited access to inputs, or stricter environmental regulations. Moreover, the ability to forecast cost dynamics empowers farmers to adjust fertilization and tillage intensity according to farm size, soil type, and machinery availability, enhancing both budget planning and risk management. For small and medium-sized farms, in particular, the model supports the identification of low-input, cost-efficient strategies that maintain compliance with EU environmental directives while sustaining profitability. In the broader context, such modeling approaches contribute to sustainable intensification, fostering a transition toward climate-resilient, economically optimized farming systems that align with the EU's long-term sustainability goals.

4. CONCLUSION

The results of this research demonstrate that the applied regression model represents a valuable analytical tool for agricultural production planning. By providing a simple estimation of expected production costs, the model offers flexibility and adaptability across different cropping systems and crop types, thereby facilitating data-driven and economically informed decision-making. The results confirmed that the assumption of reduced tillage systems (TS) contributes to environmentally sustainable agricultural practices, primarily through decreased machinery use, lower fuel consumption, and reduced labor requirements. Among the examined systems, no-tillage (NT) emerged as the most advantageous overall, showing the highest gross margin and rate of profitability, while maintaining the lowest production costs. However, its practical applicability remains limited due to the variability and inconsistency of yields often observed under NT conditions, particularly in environments with weedy soil with low physical properties. The comparative economic analysis and regression model outcomes suggest that transitioning from conventional tillage (CT) to reduced tillage systems can be achieved without short-term or long-term economic losses. Such transitions align with both economic viability and environmental sustainability goals, making them suitable strategies for producers seeking to comply with the EU's green transition policies while maintaining profitability. Despite these promising results, the study is constrained by its focus only on a nitrogen level (does not include phosphorus and potassium fertilization) and specific environmental and management conditions, which may limit the generalization of the model across regions with differing soil types, climatic conditions, or crop management systems. So, the future research should therefore aim to expand model validation across diverse agroecological zones and crop rotations to enhance its predictive robustness, integrate long-term environmental indicators, such as soil organic carbon dynamics and greenhouse gas emissions, to assess the sustainability of reduced tillage systems comprehensively and to incorporate dynamic market factors (e.g., input price volatility, policy incentives) to refine the model's applicability for real-time decision support.

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EKONOMSKI MODEL I ODRŽIVOST AGROEKOSUSTAVA ZA SOJU

SAŽETAK

Terensko istraživanje na soji provedeno je u Hrvatskoj s ciljem procjene utjecaja sustava obrade tla (TS) na odabrane ekonomske pokazatelje: bruto maržu (GM), stopu profitabilnosti (ROP), ekonomičnost (E) i produktivnost (P), kao i izrade regresijskoga modela za planiranje proizvodnje. Ispitivani sustavi obrade tla obuhvaćali su sljedeće: CT – oranje (dubina 30 cm), DT – tanjuranje (dubina 8 – 12 cm), LT – rahljenje tla (dubina 35 cm) te obradu bez oranja (NT). Korišten je slučajni blok-dizajn (RCBD) s četiri ponavljanja. Parcele za TS bile su 540 m^2. Ekonomski pokazatelji izračunani su na temelju utvrđenih ekonomskih formula i standardnih kriterija vrjednovanja. Za statističku analizu korišten je SAS, verzija 9.3 i **Microsoft Excel 2016**. ***GM bila je u sljedećem rasponu: NT (+12,9 %) > DT (+7,1 %) > LT (-15,4 %), sa značajnim razlikama u odnosu na CT (278,60 € ha^{-1}). ROP kod LT-a bila je niža (-14,5 %), a kod NT-a viša (+21,4 %) u odnosu na CT. Za proizvodnju jedne tone soje u NT-u bilo je potrebno 1,75 radnih sati, što je značajno manje u usporedbi s ostalim TS-om. Rezultati, uključujući regresijski model, ukazuju na razlike u ekonomskoj učinkovitosti između TS-a, s izraženim razlikama u troškovima, profitabilnosti i radnoj učinkovitosti, pružajući time korisne smjernice za održivu i ekonomski optimiziranu proizvodnju soje.***