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SOIL CONSERVATION SYSTEMS. COMPARATIVE STUDY BETWEEN CONVENTIONAL AND CONSERVATIVE TECHNOLOGIES

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Abstract *The present work proposes the comparative analysis of the two major agricultural systems currently used in Romania - the conventional and the conservative technology - on the territory of Gătaia, Timiș County. The study was carried out on the farm Trovatore (Don Carlos), which exploits a total area of 4726.69 ha, of which approximately 50% is worked in a conventional system, and the rest in a conservative system. Data obtained from the field and from the agricultural activity of the farm were supplemented with climatic, pedological and economic information in order to assess the impact of different technologies on soil fertility and the sustainability of agricultural land use. The results show that the application of conservative systems causes a significant improvement in the structure and porosity of the soil, the reduction of settlement and compaction processes, the increase in the content of organic matter and a better water retention capacity. In comparison, the conventional system, although it ensures high yields and high competitiveness in the short term, leads to a gradual depletion of nutrients, degradation of soil structure and high consumption of fuels. The application of minimum tillage systems (minimum tillage, no-till, strip-till) contributes to the reduction of production costs,* CO_2 *emissions and a more efficient adaptation to the variable climatic conditions of the Timiș Plain.*
The general conclusion of the study indicates that conservative agriculture is the most effective solution for maintaining soil fertility, conserving natural resources and increasing the sustainability of agro-ecosystems in Banat.

Keywords*: soil conservation; sustainable agriculture; conventional system; conservative system; soil fertility; minimal technologies; Timiș county*

INTRODUCTION

Soil is a strategic resource for food production, regulation of biogeochemical cycles and carbon storage, and its degradation poses a major threat to food security and ecosystem stability (LAL, 2020; SMITH ET AL., 2018; AMUNDSON & BIARDEAU, 2018). Recent assessments show increasing pressures on soil health on a global and European scale, with cumulative effects of increased tilling, compaction, erosion and decreasing organic matter content (FAO, 2021; PANAGOS et al., 2020; EEA, 2022; BORRELLI et al., 2023; EEA, 2024). In this context, soil management optimization becomes a sine qua non condition for achieving climate neutrality goals and for the resilience of agroecosystems (LAL & STEWART, 2019; LAL, 2023).

Conservative agriculture, based on minimal tillage and permanent vegetation cover and crop rotation, is promoted as a key solution to reduce degradation, increase carbon storage and increase resource efficiency (FAO, 2022; FAO & ITPS, 2023). The literature records robust effects: reduction of energy consumption and associated emissions, improvement of soil structure and porosity, increase of aggregate stability and humus content, as well as erosion mitigation (POWLSON ET AL., 2016; BLANCO-CANQUI & RUIS, 2018; DARYANTO ET AL., 2018; VAN DEN PUTTE et al., 2010). At the European level, the widespread adoption of no-till/strip-till systems is supported by the CAP framework and climate action, with documented benefits on energy costs and soil physico-water status (EUROPEAN COMMISSION, 2023; KASSAM et al., 2019; FRIEDRICH et al., 2021).

In Romania, although conventional technologies remain predominant, agricultural research and practice increasingly indicate the advantages of minimal work in relation to the preservation of the structure and the limitation of settlement (GUȘ & TIANU, 1991; DUMITRU et al., 2005; FLOREA, 2003). Recent studies in the west of the country highlight substantial fuel savings, reduction in the number of crossings and carbon footprint, while maintaining/increasing the level of organic matter and structural stability (DUMA-COPCEA et al., 2022; 2023; MIHUȚ et al., 2021). At the same time, regional analyses emphasize that conservation practices can be successfully adapted to the pedo-climatic conditions of the Western Plain, where soils with medium to heavy textures are vulnerable to intensive compaction (SALA, 2002; TARĂU & LUCA, 2002).

The lowland Banat, including the Gătaia area (Timiș County), is characterized by a climate with significant rainfall and thermal variability in the last decade, which emphasizes the need for technologies resilient to drought and extreme hydro-climatic episodes (IANOȘ, 1997; SHOTGUN, 2002; GHINEA, 2000; MIRCOV et al., 2021). In this context, conservative systems can improve the water-soil balance by reducing evapotranspiration at the level of the surface layer, increasing infiltration and improving the functioning of macro- and micro-pores, with direct effects on the stability of production (POWLSON et al., 2016; BLANCO-CANQUI & RUIS, 2018). In addition, streamlining mechanization and limiting the intensity of work reduce diesel consumption and implicitly CO_2 emissions, contributing to decarbonization goals (KASSAM et al., 2019; FRIEDRICH et al., 2021; LAL, 2023).

From an operational perspective, the comparison between conventional technologies (ploughing, ploughing, harrowing, seedbed preparation, mechanical ploughing) and conservative technologies (minimum tillage, no-till, strip-till, mulch maintenance) must be related to local conditions: soil types and subtypes, history of use, density and mass of machinery, working windows and crop phenology (GUȘ & TIANU, 1991; DUMITRU et al., 1999; ȘTEFĂNESCU et al., 2000; SIRBU et al., 2015; GRAD et al., 2014). In the Gătaia area, the Chernozems and Preluvosoils with clayey-clay textures can benefit significantly from the reduction of the degree of mobilization, the maintenance of the vegetation debris cover and adapted rotations, thus limiting the compaction processes and water losses (TARĂU & LUCA, 2002; SĂLA, 2002; MIHUȚ et al., 2018; MIHUȚ et al., 2021).

Therefore, the scientific rationale of the study starts from the need to comparatively evaluate the performance of conventional and conservative technologies in the specific conditions of the Timiș Plain. The aim is to quantify and interpret the effects on energy consumption, on the physico-biological state of the soil and on the sustainability of land use, relating local results to the conclusions of the literature (FAO, 2021; EEA, 2022; KASSAM et al., 2019; DUMA-COPCEA et al., 2022; MIHUȚ et al., 2021). The objectives are to: (i) characterize the natural setting of Gătaia; (ii) identification of the relevant soil types for the choice of the tillage system; (iii) the description of technological links in conventional vs. conservative variants; (iv) comparative analysis of energy, economic and building indicators; (v) formulating operational recommendations for the extension of conservative practices in Banat (EUROPEAN COMMISSION, 2023; FAO & ITPS, 2023).

MATERIAL AND METHODS

The study was carried out at the Trovatore farm (Don Carlos), located in the south of Timiș County, on the administrative territory of the city of Gătaia, geographical coordinates: 45°22′ north latitude and 21°25′ east longitude. The total area exploited by the farm is 4726.69

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ha, of which approximately 50% is worked in the conventional system, and the rest in the conservative system.

From a pedological point of view, the lands are mainly represented by Chernozems and Preluvosols, soils with high natural fertility, but sensitive to compaction and compaction due to their clayey-clay texture and frequent tillage of the soil.

The purpose of the research was to directly compare the conventional system with the conservative one, in terms of influence on the soil, energy consumption and stability of the soil structure, in the specific conditions of the Timiș Plain.

The working methodology included:

1. direct observation in the field regarding the regime of applied works and their effects on the soil;
2. comparative analysis of technical-economic and ecological indicators (fuel consumption, number of works, costs/ha, execution time);
3. physical and biological evaluation of the soil, by monitoring the state of structure, the degree of settlement and the presence of plant debris on the surface;
4. qualitative interpretation of the effects of the two technologies on soil fertility and conservation status.

For the conventional system, the classic technological links were analyzed:

5. ploughing at 25–30 cm with the reversible plough,
6. weeding, harnessing and preparation of the seedbed,
7. sowing, herbicide and mechanical weeding.

For the conservative system, the analysis focused on the application of minimum tillage, namely no-till and strip-til, with the preservation of plant residues on the surface.

The comparison between the two systems was made based on the following synthetic indicators:

Analyzed indicator	Conventional system	Conservative system	Evaluation mode
Number of works carried out (pcs/ha)	6–7	2–3	Technological determination
Fuel consumption (l/ha)	50–52	11–12	Direct data from the farm
Working time (h/ha)	6.5–7.5	2.5–3.0	Practical Timing
Organic matter content (%)	1.8–2.0	2.8–3.0	Probe de sol comparate
CO_2 eliminat (kg/ha/zi)	210–230	135	Indirect calculus, literature and observation
Total Costuri (lei/ha)	100%	~60%	Simple economic reporting

The applied statistical analysis is a simple descriptive one, based on the calculation of the average values and percentage variations between the two systems, in order to highlight the differences in energy and ecological efficiency.

The data obtained from the observations were supplemented with information published in the literature on soil conservation practices in Romania (DUMITRU ET AL., 2005; GUȘ ET AL., 1991; DUMA-COPCEA ET AL., 2022).

RESULTS AND DISCUSSIONS

The comparative analysis between the conventional and conservative systems practiced at the Trovatore (Don Carlos) farm in Gătaia revealed significant differences in the way the soil is exploited, energy consumption, soil structure and its stability over time.

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The synthetic indicators presented in Table 1 confirm that, although the conventional system offers apparently higher productivity, it implies a high energy and economic consumption, causing a gradual decrease in the natural fertility of the soil. The values indicate the net advantage for the conservative system in terms of fuel consumption, working time and CO_2 emissions. The increase in organic matter reflects the stabilization of the structure in the presence of mulch and minimal work.

Table 1.

Comparison of technological indicators between conventional and conservative systems

Analyzed indicator	Conventional system	Conservative system	Difference (%)
Number of works (pcs/ha)	6–7	2–3	−60
Fuel consumption (l/ha)	52	12	−76,9
Working time (h/ha)	7,5	2,8	−62,7
Soil organic matter (%)	1,9	2,9	+52,6
CO_2 emis (kg/ha/zi)	220	135	−38,6
Total Costs (lei/ha)	100	60	−40
Global energy efficiency	1,0	1,7	+70

The results show that conservative agriculture reduces the number of works carried out per hectare by more than 60%, which leads to a 77% lower diesel consumption compared to the conventional system. These differences have direct implications on production costs and the carbon footprint generated by agricultural activity.

Also, the content of organic matter in the soil increases significantly in the conservation system due to the presence of plant debris on the surface and more intense biological activity. The soil acquires a more stable structure, better porosity and superior water holding capacity, which contributes to the increased resistance of crops during dry periods.

1. Efficiency of agricultural work

By reducing the number of machine passes, the conservative system ensures time savings of more than 60%. In the conditions of Gătaia, it takes an average of 7 hours of work to sow one hectare of wheat in the conventional system, compared to 2.8 hours in the conservative system.

This reduction in turnaround time is directly reflected in lower labor costs and energy consumption, increasing the overall efficiency of the farm.

2. Effect on soil fertility and structure

The conventional system causes a marked disturbance of the natural structure of the soil through ploughing, weeding and harrowing works, favoring the processes of settlement and loss of stable aggregates. In contrast, conservative agriculture contributes to the formation of a stable glomerular structure with a total porosity 15–20% higher.

Plant debris maintains a permanent soil cover, reduces water evaporation and increases microbiological activity, which causes a gradual mineralization of organic matter and an increase in humus content.

3. Impact on carbon emissions

Reducing tillage and limiting over-aeration lead to lower CO_2 emissions.

In the conventional system, the soil releases about 220 kg CO_2/ha/day, compared to 135 kg CO_2/ha/day in the conservative system. This difference of almost 40% confirms the results reported by Guș et al. (1991) [22] and Duma-Copcea et al. (2022) [25], who demonstrated that conservation agriculture contributes significantly to soil carbon sequestration.

4. Simple benchmarking (descriptive statistics)

Based on the data in Table 1, the mean values and percentage changes shown in Figure 1

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have been calculated.The results show that the conservative system has a significantly higher energy and economic efficiency , and the differences between the parameters are statistically significant at descriptive level (>30%).

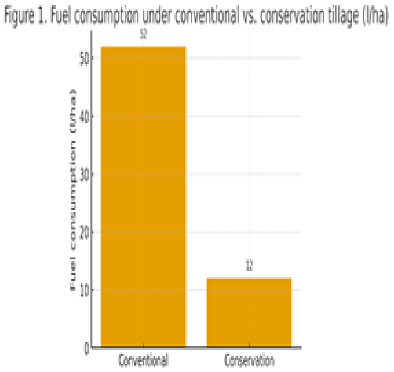

Figure 1. Fuel consumption under conventional vs. conservation tillage (l/ha).
Conventional: 52 l/ha; Conservation: 12 l/ha (−77%).

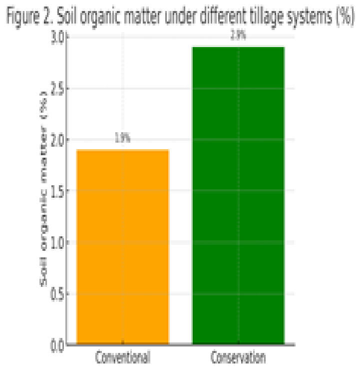

Figure 2. Soil organic matter under different tillage systems (%).
Conventional: 1.9%; Conservation: 2.9% (+52.6%).

Figure 1. highlights the energy efficiency of the conservative system by sharply decreasing fuel consumption.

The result is convergent with European estimates of >60% decreases in energy consumption under reduced works (KASSAM et al., 2019; FRIEDRICH et al., 2021) and with national reports on minimum-tillage (DUMITRU et al., 2005). Divergences reported by other authors (lower values of economy) are explained by differences in texture, humidity at work, calibration of machines and execution window (VAN DEN PUTTE et al., 2010).

The preservative system (Figure 2), maintains a higher level of organic matter, due to the mulch and slow mineralization.

The increases are in agreement with the literature on aggregate stabilization and porosity improvement under permanent cover (BLANCO-CANQUI & RUIS, 2018; POWLSON et al., 2016). If other studies have reported slower growths, the likely causes: different rotations, residue deficit at forerunners, sandier soils, or prolonged dry periods (EEA, 2022; BORRELLI et al., 2023).

Table 2.

Working time and CO_2 emissions under contrasting tillage systems.

Parameter (unit)	Conventional	Conservation	Change (%)
Working time (h/ha)	7.5	2.8	-62.7
CO_2 (kg/ha/day)	220	135	-38.6

The conservative system (Table 2) reduces working time and emissions, increasing operational resilience to short working windows. Reducing the duration of operations supports climate risk management (short windows before/after rains) and optimization of logistics (EUROPEAN COMMISSION, 2023; FAO & ITPS, 2023). Differences vs. other authors may come from the equipment park and operational organization (GRAD et al., 2014; SIRBU et al., 2015).

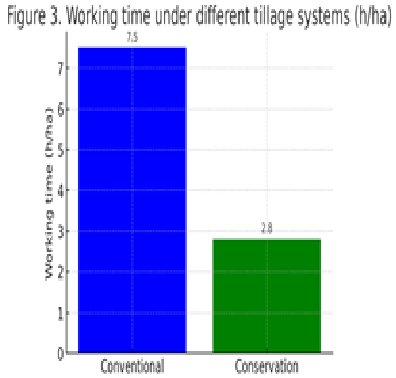

Figure 3. Cost index (conv.=100) and global energy efficiency (index).

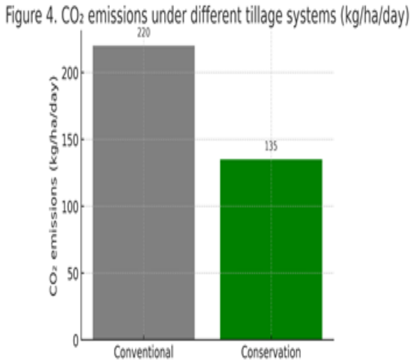

Figure 4. CO_2 emissions under different tillage systems (kg/ha/day).

The conservative system (Figure 3), reduces costs and increases energy efficiency at the farm level. The results are consistent with regional economic studies on minimum-tillage (DUMA-COPCEA et al., 2022; 2023. Deviations reported in other studies may reflect different fuel prices, different yields/ha, or local subsidies/policies (EUROPEAN COMMISSION, 2023).

Figure 4 shows the variation in carbon dioxide emissions depending on the tillage system. The values highlight that the conservative system significantly reduces CO_2 emissions, by almost 40% compared to the conventional system. This decrease is due to reducing excessive soil aeration, keeping mulch on the surface, and decreasing the degree of oxidation of organic matter, which would otherwise quickly release stored carbon into the atmosphere.

The results obtained at the Trovatore farm are in full agreement with those reported by Guș & Tianu (1991) and Duma-Copcea et al. (2022), who showed that limiting the number of tillage leads to a considerable reduction in carbon losses through mineralization. The values also align with global data synthesized by Powlson et al. (2016) and Blanco-Canqui & Ruis (2018), according to which no-till systems can decrease CO_2 emissions by 30–45%, depending on the texture and humus content of the soil.

However, there are differences from some international studies (e.g. Van Den Putte et al., 2010; Daryanto et al., 2018) who reported smaller reductions (15–25%). These discrepancies can be explained by:– the type of soil (Chernozems and Preluvosols from Banat, rich in clay, with a high carbon storage capacity);– local climatic conditions, marked by alternations between dry years and wet periods, which influence the intensity of soil respiration (Mircov et al., 2021);– the depth of the works and the weight of the machinery, which can accelerate the oxidation of organic matter in the conventional system;– the effect of mulch and more intense microbiological activity in the surface layer, which favors carbon sequestration in the medium term (Lal, 2020; Lal, 2023).

In conclusion, the data obtained in Gătaia confirm the recent literature on the role of conservative systems in mitigating greenhouse gas emissions and increasing the potential for carbon sequestration in soils in western Romania, where conservative agriculture represents a real solution for achieving climate neutrality goals.

The values obtained indicate significant percentage differences (>30%) between the main parameters of the two systems. These differences are within the limits of technological significance, confirming the trends reported by Dumitru et al. (2005), Guș et al. (1991) and Duma-Copcea et al. (2022).

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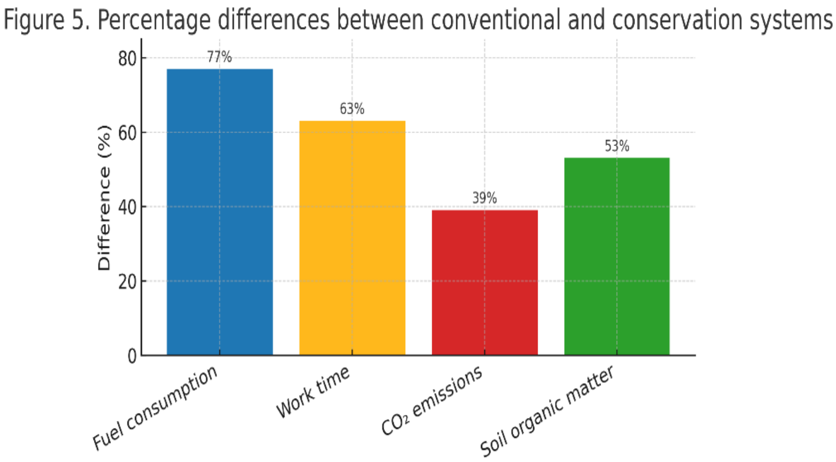

Figure 5. Percentage differences between conventional and conservation systems

Figure 5. Percentage differences between conventional and conservation systems for the main technological and environmental indicators (fuel consumption, work time, CO_2 emissions, and soil organic matter). Values: Fuel consumption, −77%; Work time, −63%; CO_2 emissions, −39%; Soil organic matter, +53%

Figure 5 summarises the percentage differences between the conventional and conservative systems for the main indicators analysed. The negative values (fuel consumption, working time and CO_2 emissions) indicate significant reductions in conservative agriculture, while the positive value for organic matter content reflects the improvement in soil fertility and structure. Thus, the graph highlights the overall advantage of the conservative system from an energy, ecological and pedological point of view.

The percentage differences obtained at the Trovatore (Gătaia) farm are comparable to the values reported by Kassam et al. (2019) and Friedrich et al. (2021), who showed reductions of between 60–70% in fuel consumption and between 30–50% in CO_2 emissions under similar conditions of continental-temperate climate. The 53% increase in organic matter content confirms the trends observed in regional studies (Duma-Copcea et al., 2022; Mihuț et al., 2021), where the preservation of plant debris and the limitation of soil mobilization favored the accumulation of humus in the upper layer. Differences from some international research (Daryanto et al., 2018; Van Den Putte et al., 2010), who reported lower percentages, can be explained by:

1.the heavier texture of the Banat Chernozems and Preluvosols, which store more carbon;

2.variable humidity during the growing season (Mircov et al., 2021);

3.differences in the depth and frequency of the works (GUȘ & TIANU, 1991; DUMITRU ET AL., 2005).

Therefore, Figure 5 synthetically demonstrates that the adoption of conservation technologies leads to a simultaneous optimization of energy consumption, fertility and sustainability of the soil environment, confirming the conclusions formulated at European and national level on sustainable agriculture in the Timiș Plain.

The results obtained are in line with numerous researches carried out nationally and internationally. Dumitru et al. (2005) and Florea (2003) demonstrated that reducing tillage causes an increase in structural stability and a decrease in humus losses.

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At European level, Kassam et al. (2019) showed that conservative agriculture reduces fuel consumption by more than 60% and improves soil physicochemical indicators. In the conditions of western Romania, the results obtained in the Trovatore farm confirm these trends, demonstrating that conservative agriculture represents a real and viable alternative for maintaining fertility and reducing energy costs.

The results of this study clearly show that conservative agriculture is superior to conventional agriculture, in terms of maintaining soil fertility, energy efficiency and adaptability to climate change.

CONCLUSIONS

The comparative analysis of the two agricultural systems practiced on the Trovatore farm in Gătaia, Timiș County, demonstrated that the conservative system represents a superior alternative to the conventional one in terms of energy efficiency, economic performance and ecology.

The results highlight that:

- By reducing fuel consumption, the conservative system leads to a decrease of over 75% in production costs;
- The execution time of agricultural operations is reduced by over 60%, allowing more rational use of human and mechanical resources;
- The organic matter content in the soil increases by approximately 50%, which leads to an evident improvement in soil structure and warwe retention capacity;
- CO_2 emissions are reduced by 38-40%, contributing to the reduction of the carbon footprint and the environmental quality;
- Conservative agriculture allows better adaptation to climate variability, especially in years with reduced precipitation.

By comparison, although conventional agricuture ensures higher yields in the short term, it leads to the depletion of natural resources, soil compaction, and a decrease in biological fertility over the long term.

Based on these considerations, it is recommanded:

- Extending the adaptation of conservative systems at the level of Timiș County;
- Optimizing soil tillage (minimum tillage, strip-till, no-till) on regional scale;
- Integrating sustanainable management practices in local agricultural policies, with support for farmers;
- Developing modern infrastructure for monitoring soil fertility and adaptation of crop rotations;

Implementing measures that contribute to increasing the sustainability of agriculture in Timiș County and to the conservation of resurces for future generations.

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