



Hungarian University of Agriculture and Life Sciences

**THESIS OF THE DOCTORAL (PhD)
DISSERTATION**

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**ASSESSMENT OF SELECTED
AGROECOLOGICAL PRACTICES IN
SMALL-SCALE MARKET GARDENING**

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1. BACKGROUND AND OBJECTIVES

Globally, the increasing pressure on natural resources, climate change, and the environmental costs of industrial agriculture have prompted a shift toward more, ecologically sound farming systems. Central to this transformation is the need to improve soil health, particularly in regions where soil conditions inherently limit agricultural productivity, such as sandy loam soils. In areas without vegetation cover, these soils are prone to wind erosion and surface instability. Conversely, in regions where vegetation has been established and stabilized, organic matter can begin to accumulate, slowly enhancing soil quality. However, under conventional agricultural practices, the full potential of these soils remains largely untapped, and their degradation continues to present ecological and economic challenges.

This research emerges in response to the growing demand for improved solutions in soil management, particularly within the framework of agroecology and bio-intensive farming. These approaches aim to reduce dependency on synthetic inputs, enhance biodiversity, and regenerate soil productivity through practices such as composting, crop diversification, reduced tillage, and the use of beneficial soil microbes. By integrating ecological principles into agricultural practice, such methods seek to create systems that are both productive and resilient.

The study was carried out at the SZIA Agroecological Garden. This garden provides ideal research setting for studying land use practices in real-world conditions. Its sandy loam soils, typical of many underperforming agricultural regions in Hungary, present a relevant case for examining the effectiveness of ecological interventions.

A central focus of this research is the development and assessment of a crop rotation strategy combined with agroecological soil management practices. The rotation began with a potato crop planted in the spring-summer of 2023, followed by a legume crop (peas) in 2024, and is scheduled to continue with a leafy

vegetable (lettuce) in 2025. This design supports both ecological balance and practical application by simulating conditions in an operating market garden. The study seeks to determine how such interventions affect soil structure, fertility, and overall system productivity, offering insights into scalable models of regenerative agriculture for soils.

Despite the recognized need for agroecological practices, sandy soils in Hungary remain a limiting factor in achieving consistent, high-yield crop production due to their poor structure, low organic matter, and vulnerability to compaction and erosion. Conventional methods, which often rely heavily on mechanical tillage and chemical fertilizers, tend to exacerbate these problems over time. There is a critical need for practical, scientifically validated strategies that can restore the productivity of soils while minimizing environmental harm.

This research addresses that need by evaluating the combined effects of soil inoculation, reduced tillage, and crop rotation on soil properties and productivity under real market garden conditions. The goal is to contribute knowledge that supports ecologically and economically viable farming practices in Hungary, with relevance beyond the country. In addition, the study aims to enhance the resilience of farming systems by promoting practices that improve soil structure, biodiversity, and nutrient cycling, factors that are essential for adapting to future challenges such as climate variability, resource limitations, and increasing pressures on food production.

While there is increasing interest in agroecological practices, there remains a gap between theoretical frameworks and field-based, replicable methodologies that can be applied under real farming conditions, especially in regions dominated by challenging soil types, which makes this research important.

The novelty of this study lies in its integrated, system-based approach. Rather than isolating single variables in laboratory or pot experiments, the research was

designed and implemented in a functional market garden environment. This real-world setting strengthens the applicability and relevance of the results for small-scale growers and market gardeners. By combining soil inoculation, reduced tillage, and carefully planned crop rotation, this study examines how low-input ecological interventions interact to support soil regeneration and enhance overall soil-plant system functioning.

Moreover, the study offers original contributions by evaluating how these practices influence both soil physical properties and crop performance across multiple growing seasons. Through fieldwork, soil analysis, and statistical evaluation, the research not only provides new empirical data on soil management but also contributes to the development of models that can be scaled and adapted to similar agroecological contexts (characterized by limited water availability, or nutrient management challenges).

This research is timely and innovative, bridging the divide between ecological theory and practical implementation. It plays a significant role in advancing the shift towards regenerative and climate-resilient agriculture, especially in areas characterized by naturally less fertile soils.

Research Objectives and Hypothesis

The primary objective of this research is to examine the individual and combined effects of conservation tillage practices and microbial inoculation on soil physical, chemical, and biological properties, crop yield, and the overall sustainability, including economic aspects, of small-scale agriculture in Hungary. By examining these agroecological practices, this study aims to develop evidence-based guidelines for enhancing soil productivity, reducing reliance on external inputs, and strengthening the economic resilience of small-scale farms. These aims align with Hungary's key environmental and agricultural development goals, which include improving soil quality, promoting resource-efficient and low-input

farming systems, increasing climate resilience, supporting farmland biodiversity, and ensuring the long-term viability of small and medium-sized agricultural enterprises.

To achieve this aim, the research sets out to pursue the following specific objectives:

- **Evaluate the effects of minimum tillage and no-tillage systems** on key soil parameters, such as soil structure, organic matter content, moisture retention, mineral content, and biological activity. This includes assessing how reduced soil disturbance influences physical and chemical soil properties over a single growing season, particularly in the context of sandy loam soils, which are prevalent in many Hungarian farming regions and often suffer from nutrient loss and low water-holding capacity.
- **Assess the agronomic performance and soil-enhancing potential of microbial inoculants**, with an emphasis on plant growth-promoting rhizobacteria (PGPR), such as *Rhizobium spp.*, *Ensifer spp.*, *Pseudomonas spp.*, and *Bacillus spp.* This objective involves measuring their effect on soil nutrient availability (e.g., nitrogen, phosphorus), microbial activity, and enzymatic processes, as well as their influence on crop performance, including size, yield, and quality. The research aims to determine whether these bio-based inputs can serve as viable alternatives or complements to chemical fertilizers, particularly under the economic and environmental conditions faced by smallholder farmers.
- **Examine the synergistic interactions between conservation tillage and microbial inoculation**, investigating whether the combined application of these practices produces additive or multiplicative benefits in terms of soil properties, crop yield, nutrient cycling, and moisture dynamics. This includes identifying any mechanisms through which microbial inoculants may perform more effectively in the improved microenvironment created

by reduced tillage systems, potentially enhancing microbial colonization and activity.

- **Provide evidence-based, context-specific recommendations to farmers, policymakers, and agricultural stakeholders on the practical benefits and potential limitations of adopting conservation tillage and microbial inoculants.** This objective aims to clarify the realistic outcomes that can be expected within a one-year observation period, focusing on short-term effects on soil health, nutrient availability, moisture retention, yield and quality of the final product. The research considers how these practices align with existing agroecological support programs, such as the Hungarian Agroecology Program and the EU's Farm to Fork strategy, offering guidance on how such approaches can contribute to long-term goals including improved soil conservation, greater resilience to climate change, and enhanced sustainability in small-scale agricultural systems.

By fulfilling these research objectives, the research aims to contribute meaningfully to the development of agricultural systems that enhance soil properties, optimize resource use, and improve the livelihoods of small-scale farmers. It also supports broader policy goals related to food security, environmental stewardship, and climate change mitigation, both within Hungary and in the wider European context.

This study is guided by the hypothesis that conservation tillage (loosening and no-tillage) will improve soil structure and increase plant yield over multiple growing seasons. Furthermore, it is hypothesized that inoculation with beneficial bacteria will enhance nutrient availability, stimulate plant growth, and lead to higher yield and overall contribute to soil and plant quality. The study also is guided by that combining conservation tillage with microbial inoculation will generate synergistic effects, leading to greater improvements in both soil health and crop performance than either practice could achieve on its own. In this

context, soil health refers specifically to enhancements in soil physical structure, nutrient availability, and biological activity, attributes that collectively support improved crop growth and overall ecosystem functioning.

2. MATERIALS AND METHODS

Materials

This research investigated the effects of soil inoculation, crop rotation, and reduced tillage practices on soil properties, crop performance, and microbial communities. The study was conducted using potato (*Solanum tuberosum*), pea (*Pisum sativum*), and lettuce (*Lactuca sativa*) as test crops over three consecutive growing seasons (2023-2025).

Field cultivation relied on standard horticultural tools, including trowels, measuring tapes, levelling tools, weed extraction tools, buckets, harvesting containers, weighing scales, callipers, and broad forks for soil loosening.

Planting materials were provided by the garden coordinator from organic seeds sources. The inoculant comprised mixture of bacterium strains provided by Phylazonit company.

Soil physical measurements were performed using penetrometer, soil auger, drying oven, and a single-ring infiltrometer.

Soil and plant samples were analyzed at the accredited laboratory of the Hungarian University of Agriculture and Life Sciences (*MATE Agrártudományi Vizsgálólaboratórium* HUN.) using standardized national and international methods. Analyses focused on air-dried soil samples.

To establish baseline microbial conditions, shotgun metagenomic sequencing of soil samples was conducted as a paid service by Xenovea Szolgáltató Kft.

Normalized Difference Vegetation Index (NDVI) measurements were conducted during the pea growing season using drone-based remote sensing, in collaboration with the HUN-REN-MATE Agroecology Research Group.

To introduce a statistical dimension to the results, One-way Analysis of Variance (ANOVA) was performed using the R programming language, allowing for the calculation of p-values and visualization of differences through box plots.

Methodology

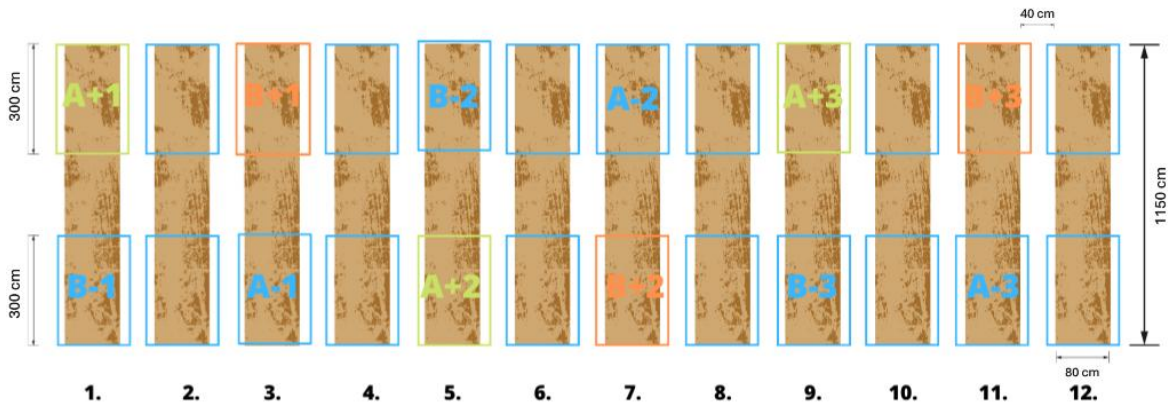
The experiment was conducted at the SZIA Agroecological Garden of the Hungarian University of Agriculture and Life Sciences (MATE) in Gödöllő, Hungary (47.5941° N, 19.3593° E). The garden operates as a bio-intensive market garden and research site, allowing realistic agricultural conditions while maintaining experimental control. In April 2023, the site was divided into twelve plots (0.8 m x 3 m), arranged in a randomized complete block design with a split-plot structure and three replications. Plots were separated by buffer zones to prevent cross-contamination. Four treatment combinations were applied:

- **A-:** Soil loosening without microbial inoculation
- **B-:** No-tillage without microbial inoculation
- **A+:** Soil loosening with microbial inoculation
- **B+:** No-tillage with microbial inoculation

A visual representation of the experimental layout is provided in *Figure 1* is offering an overview of the design and spatial organization of the study plots.

Figure 1: Experimental layout of the field plots used during the study

Layout of the study area in SZIA Garden
Plan for plots (1-12)



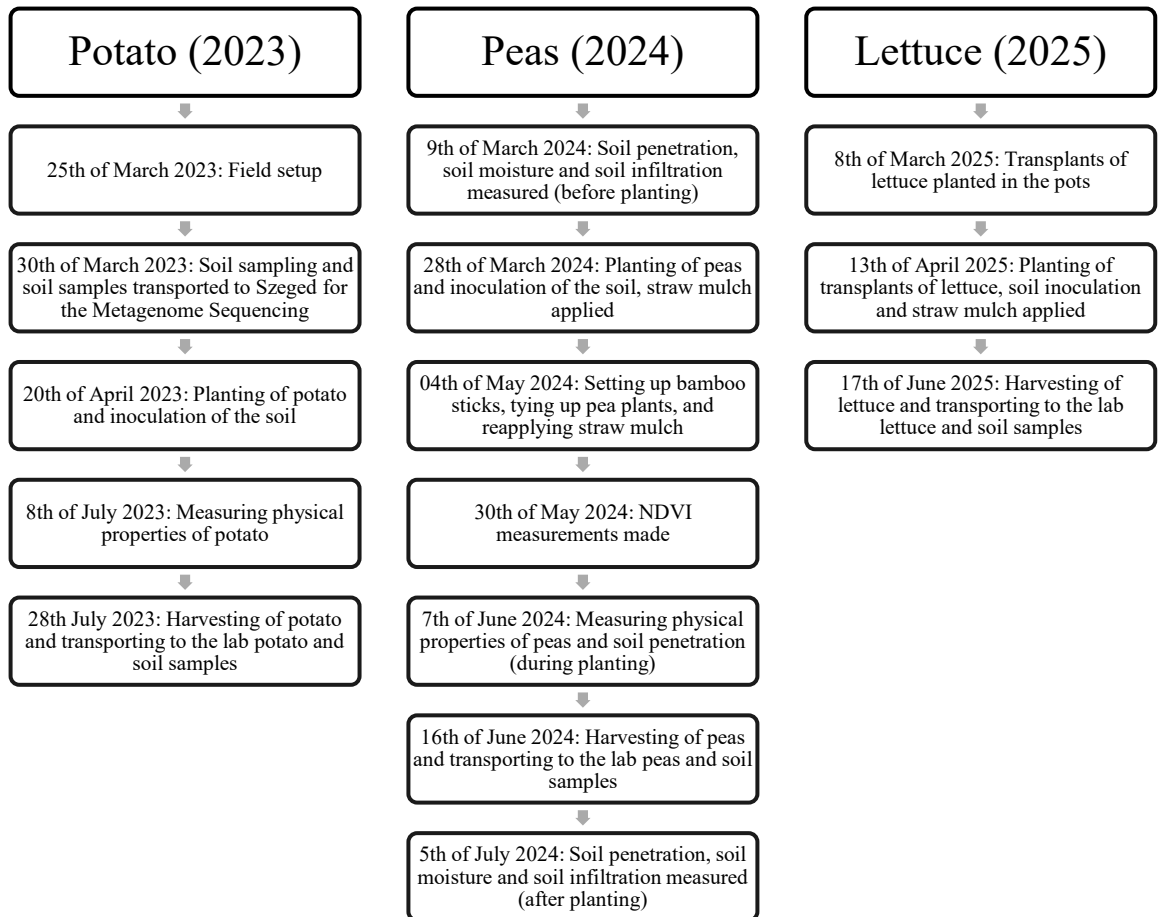
LEGEND of treatments:

- A- - loosening (no microbes)
- B- - no tillage (no microbes)
- A+ - loosening with microbes
- B+ - no tillage with microbes

Source: Own work

Potato was planted in April 2023 and harvested in July 2023. Peas were planted in March 2024 and harvested in June 2024. Lettuce was transplanted and direct-seeded in March-April 2025 and harvested in June 2025. Straw mulch was applied during pea and lettuce cultivation to suppress weeds, conserve moisture, and moderate soil temperature. The timeline of field activities is presented in *Figure 2*.

Figure 2: Detailed timeline of field activities and sampling for potato, peas, and lettuce throughout the study period



Source: Own work

Microbial inoculants provided by Phylazonit were applied during planting for inoculated treatments. The products contained consortia of beneficial bacteria native to the Carpathian Basin, with a concentration of approximately 10^9 CFU cm^{-3} .

- **Potato (2023):** *Pseudomonas putida*, *Azotobacter chroococcum*, *Bacillus circulans*, and *Bacillus megaterium*

- **Peas (2024):** *Rhizobium leguminosarum*, *Ensifer kummerowiae*, *Pseudomonas putida*, *Pseudomonas fluorescens*, *Bacillus megaterium*, and *Bacillus subtilis*
- **Lettuce (2025):** *Pseudomonas putida*, *Pseudomonas fluorescens*, *Bacillus megaterium*, and *Bacillus subtilis*

Inoculants were applied directly into planting holes or rows at sowing depth using a water suspension (15 mL per 2.4 m² plot). This ensured close contact between microorganisms and plant roots to enhance nutrient availability and rhizosphere activity.

Soil sampling was conducted after harvest for each crop following SOILGUARD project guidelines. Composite samples were collected from each plot using a zigzag pattern within the crop root zone. Samples were transported to the laboratory for physicochemical analysis, including pH(H₂O and KCl), organic matter, carbonate content, plant-available nutrients, and macro- and micronutrients.

Plant samples were collected at harvest to assess yield, biomass, and quality parameters. Potato, peas, and lettuce were analyzed for moisture, nutrient content, protein, starch, sugars, vitamins, and mineral composition using standardized laboratory methods.

Soil physical properties were evaluated during pea and lettuce cultivation. Penetration resistance was measured at depths of 0-40 cm using penetrometers. Soil moisture content was determined gravimetrically by oven drying samples collected from multiple soil depths. Soil infiltration rate was assessed using a single-ring infiltrometer, with water infiltration recorded over a 30-minute period.

NDVI measurements were conducted during pea cultivation using drone-based multispectral imaging. NDVI values ranged from -1 to 1 and were interpreted to

assess plant health, canopy development, and spatial variability in crop performance. Peas were selected for NDVI analysis due to their dense canopy structure.

Statistical analyses were performed using the R programming environment. One-way Analysis of Variance (ANOVA) was applied to test for significant differences among treatments, with a significance threshold of $p < 0.05$. Box plots were used to visualize data distribution. When significant differences were detected, Tukey's Honest Significant Difference (HSD) test was used for pairwise comparisons.

3. RESULTS AND DISCUSSION

Physical and Chemical Properties of Plants

Over the three-year study, crop performance showed positive responses according to the available literature, across all treatments, though no statistically significant differences were detected in physical properties of potato (2023), peas (2024) and lettuce (2025).

Chemical analysis revealed that microbial inoculation and soil management practices influenced crop composition. Pea total sugar content showed the only statistically significant difference, with no-tillage treatments (B-) achieving average highest total sugar content, while loosening with microbes (A+) showed average lowest values. This suggests that microbial activity may redirect carbon allocation toward protein synthesis rather than sugar accumulation.

Table 1 represents a summary of the examined physical and chemical properties of the plants.

Soil Properties and Biological Effects

Soil chemical analysis after potato (2023) revealed two statistically significant differences: soil plasticity according to Arany and pH(KCl). The Tukey HSD test indicated that loosening with microbes (A+) differed significantly from no-tillage without microbes (B-), with A+ showing lower soil plasticity and pH values. This suggests that microbial activity and soil disturbance may enhance soil structure development over time.

Soil physical measurements during pea cultivation (2024) revealed significant differences in penetration resistance, with no-tillage with microbes (B+) showing reduced resistance compared to non-inoculated treatments, indicating improved soil structure despite minimal mechanical disturbance. Soil moisture showed significant variation between B+ and B- treatments, with B+ exhibiting lower moisture retention, possibly reflecting enhanced microbial decomposition activity. Soil infiltration rates showed no significant differences, aligning with literature suggesting that single-season interventions may require longer periods to produce measurable changes in water movement properties.

Table 1 represents a summary of the examined soil properties during the research.

Table 1: Summary of Examined Parameters

Soil Analysis	Crop Quality (Yearly Samples)	Physical And Biological Data
Annual Soil Parameters (2023, 2024, 2025)	Potato Samples (2023)	Physical Properties: Potato (2023)
pH(H ₂ O), pH(KCl)	Moisture content	Avg. Number of Plants / Plot
Soil plasticity (Arany)	Protein content	Average Height
Organic matter	Starch content	Average Amount of Weeds
CaCO ₃	Vitamin C content	Average Harvest
All water-soluble salts		Average Dimension
P ₂ O ₅ (AL)	Peas Samples (2024)	
K ₂ O (AL)	Moisture content	Physical Properties: Peas (2024)
(NO ₂ ⁻ +NO ₃ ⁻)-N (KCl)	Crude protein content	Average Height
Na (AL)	Potassium content	Average Pod Length
Cu (EDTA)	Phosphorus content	Avg. Number of Seeds in Pod
Mn (EDTA)	Starch content	Total Harvest in g (with Pods)
Zn (EDTA)	Total sugar content	
Mg (KCl)	Chlorophyll content	Additional Measurements
SO ₄ ²⁻ (KCl)		Soil Penetration
	Lettuce Samples (2025)	Soil Moisture
	Moisture content	Soil Infiltration
	Phosphorus content	NDVI
	Calcium content	Metagenome Sequencing
	Potassium content	
	Magnesium content	
	Iron content	

Source: Own work

Microbial Community Structure

Shotgun metagenomic sequencing revealed a diverse soil microbiome characterized by high taxonomic richness. Approximately 94% of reads remained unclassified, consistent with known "microbial dark matter" in soil ecosystems. Classified reads were dominated by *Actinobacteria*, particularly *Streptomyces* species and related genera, which function as primary organic matter

decomposers. *Proteobacteria* constituted a secondary component, with plant-beneficial genera including *Bradyrhizobium*, *Rhizobium*, and *Pseudomonas* detected across samples. Firmicutes, represented primarily by *Bacillus* species, completed the functional profile.

Discussion

This three-year study demonstrates that integration of microbial inoculation with soil management practices creates a compatible agroecosystem supporting productive crop growth without compromising plant health or yield. While statistical significance was limited to specific parameters, the results consistently favored combined treatments, particularly A+ (loosening with microbial inoculation), with improvements in plant height, pod development, and nutrient accumulation, including enhanced iron bioavailability in lettuce, aligned with findings reported in the literature. The lack of significant differences in overall yield suggests that microbial effects operate through subtle improvements in nutrient cycling, water retention, and soil structure rather than immediate productivity increases.

Soil physical properties improved under microbial treatment, with significantly reduced penetration resistance in B+ despite absence of mechanical loosening, indicating that microbial activity can partially compensate for reduced tillage by promoting aggregate stability and porosity. The significant difference in total sugar content of peas between A+ and B- treatments suggests that microbial communities influence metabolic partitioning, potentially through enhanced nitrogen fixation (following legume cultivation) promoting protein synthesis over carbohydrate accumulation.

Metagenomic analysis revealed that the soil microbiome remained functionally diverse and biologically active throughout the experimental period, with bacterial community composition persisting through crop transitions. The persistence of

inoculated strains alongside native soil microbiota supports the integration of microbial amendments into sustainable agricultural systems. These findings emphasize that ecological interactions between soil management, microbial activity, and plant development are complex and multifaceted, requiring long-term observation to resolve mechanistic pathways.

4. CONCLUSION AND RECOMMENDATIONS

This research evaluated the combined influence of conservation tillage (loosening, no-tillage) and microbial inoculation on soil quality and crop performance, potato (*Solanum tuberosum*), pea (*Pisum sativum*), lettuce (*Lactuca sativa*), in sandy loam soil conditions characteristic of small-scale Hungarian agriculture.

Across the crop rotation, no statistically significant differences were detected in physical plant properties (plant size, biomass, tuber/root development). However, treatments combining microbial inoculation with reduced soil disturbance (loosening or no-tillage) consistently supported improved plant establishment and growth stability, reflecting enhanced soil-plant-microbe interactions that may require longer periods to result in measurable physiological differences.

Regarding the chemical properties of plants, all measured nutrient and biochemical parameters fell within the ranges reported in scientific literature, confirming optimal plant physiological functioning. One statistically significant difference was found in peas, where total sugar content varied between treatments. Peas grown under loosening and microbial inoculation showed a decrease in sugar content compared to the no-tillage, no inoculation. This suggests that microbial activity may influence carbon allocation in developing seeds, possibly shifting resources from simple sugar accumulation toward protein metabolism.

For soil parameters, significant differences were detected in the first year in soil plasticity (Arany value) and pH(KCl) between inoculated and non-inoculated soils, proving that microbial inoculants can alter soil structure and chemical conditions even within one growing season.

Across the measured soil physical properties, significant treatment effects were detected for soil penetration resistance and soil moisture, while infiltration rate showed no significant differences. Microbial inoculation consistently improved soil physical conditions: it reduced penetration resistance in both loosening and no-tillage systems, with the strongest effects observed in B+ (no-tillage with microbes), where resistance was significantly lower than in A+ (loosening with microbes) and B- (no-tillage without microbes). These results indicate that microbes can enhance soil structure and mitigate compaction, particularly under no-tillage. Soil moisture also differed significantly among treatments, with B+ (no-tillage with microbes) exhibiting consistently lower moisture content than B- (no-tillage without microbes) before drying and A- (loosening without microbes) after drying, confirming that management and microbial inputs measurably affected water retention. In contrast, infiltration rates remained statistically unchanged across all treatments, and between pre- and post-planting measurements, suggesting that short-term or single-season interventions were insufficient to alter infiltration dynamics. Overall, the significant results demonstrate that microbial amendments and conservation tillage practices can influence soil compaction and moisture dynamics, even when infiltration remains stable.

The absence of additional significant differences can be explained by the prior management history of the experimental area. Before the trial, the field had not been subjected to regular conventional ploughing and had remained fallow for a period, resulting in relatively undisturbed and moderately improved soil conditions at the outset. Under such circumstances, large contrasts among

treatments are less likely to emerge within the first years of the experiment, as the baseline soil state was already favourable. Consequently, the effects of microbial inoculation were incremental rather than immediate. Soil regeneration is a gradual process, with early improvements often appearing as enhanced moisture regulation or subtle gains in soil structure before becoming statistically significant.

Referring to the *Hypothesis that conservation tillage improves soil structure and enhances plant physical properties*, the physical characteristics of plants, including growth, root development, and yield quality, did not show significant differences between treatments in the first years. However, plots with loosening and no-tillage consistently supported higher averages in plant establishment and growth. Reduced tillage maintained higher soil moisture and lower soil resistance, creating more favorable rooting conditions. These observations indicate that soil structure was already beginning to respond positively to reduced disturbance, supporting the Hypothesis 1 even though yield differences were not yet statistically measurable.

Referring to *Hypothesis that Microbial inoculation enhances plant biochemical properties and improves crop quality*, for plant chemical parameters, all crops remained within the expected physiological ranges reported in the literature, confirming the stability of the production system. A statistically significant difference appeared in total sugar content of peas, where the no-tillage, no microbes showed the highest sugar concentration and the loosening + microbes treatment resulted in lower sugar content. This outcome aligns with findings from literature demonstrating that soluble sugars in peas are highly sensitive to environmental and management conditions. A possible explanation is that microbial inoculation stimulates root nutrient uptake, especially nitrogen, redirecting carbon away from sugar accumulation and toward protein synthesis.

Hypothesis 2 is partially supported: Microbial inoculation influenced plant biochemistry, but not always in the expected direction.

Referring to *Hypothesis that The combination of conservation tillage and microbial inoculation results in synergistic benefits for soil and crop performance*, for soil parameters, statistically significant treatment effects appeared in: soil plasticity (Arany) and soil pH(KCl) after first year of research, with these changes occurred after only one year, indicating that microbial inoculation can initiate measurable shifts in soil behaviour. Soil moisture and resistance also improved under reduced tillage, particularly when inoculation was combined with loosening or no-tillage. In the second and third year, soil parameters remained within agronomically acceptable ranges, but differences between treatments were no longer statistically significant, most likely because the site had already been managed under agroecological principles before this study, giving it a head start in soil regeneration. Hypothesis 3 is supported: The combination treatment consistently performed well, even without a strong first-year statistical separation.

Thus, the research bridges the gap between short-term agronomic observations and long-term soil regeneration, contributing unique data on how microbial inoculants function as part of an integrated agroecological system.

While short-term measurable differences were limited, the study clearly demonstrated that:

- Microbial inoculants are safe, compatible with conservation tillage, and may influence plant biochemical pathways.
- Conservation tillage improves soil moisture retention and lowers compaction, critical functions in sandy soils.

- Combined treatments produced the most favourable results (in terms of highest averages) and are likely to improve further with ongoing application.
- Soil and plant responses in regenerative systems are gradual and cumulative, and sandy soils particularly require time to show measurable improvement. The observations indicate that the system is moving in a regenerative direction, and continued monitoring will likely reveal more pronounced differences as soil structure, organic matter, and microbial communities become increasingly stable.

In summary, this research demonstrates that integrating microbial inoculation with reduced tillage is a promising approach for improving plant performance and soil quality, supporting the transition toward agroecological and climate-resilient farming systems.

5. NEW SCIENTIFIC RESULTS

The novelty of this research lies in its integration of multiple sustainability-oriented agronomic dimensions that are rarely examined simultaneously within a single field experiment:

- **Combined evaluation of microbial inoculation, conservation tillage intensity (loosening vs. no-tillage), and a market-garden crop rotation (potato-pea-lettuce)**, a rotation specifically designed for small-scale agroecological vegetable systems.
- **Simultaneous assessment of plant performance (physical and chemical traits) and soil quality (physical, chemical, and biological indicators)** across three consecutive cropping seasons under identical field conditions.

- **Three years monitoring**, allowing the cumulative and time-dependent effects of microbial inoculation to be captured, an aspect often missing in studies limited to single-season trials.
- **Holistic soil assessment**, including penetration resistance, moisture dynamics, infiltration, chemical fertility parameters, and biological indicators, far beyond the single scope (e.g., pH or SOM only) commonly found in existing publications.
- **Comprehensive plant analysis**, assessing multiple traits (e.g., nutrient content, biochemical) each year, whereas many existing studies examine only a single parameter such as vitamin C or chlorophyll.
- **High replicability**, as the experimental structure can be easily scaled to larger fields by proportionally adjusting microbial inoculant doses according to manufacturer recommendations.

The study provides several new scientific contributions. This study has:

1. **Demonstrated that microbial inoculation produces measurable, positive improvements in soil physical properties**, including enhanced moisture retention, reduced penetration resistance, significant difference in soil plasticity by Arany value, in both loosening and no-tillage systems. These effects were most pronounced under no-tillage combined with microbial amendments, reflecting early regenerative changes in soil structure that create favorable rooting conditions. These soil improvements supported better plant establishment, growth stability, and early indications of enhanced nutrient uptake, highlighting the integrated benefits of conservation tillage and microbial inoculation.
 2. **Identified significant differences in soil moisture dynamics**, particularly between no-tillage with microbes and no-tillage without microbes, revealing strong treatment-dependent effects on water retention.
- Confirmed that short-term interventions did not significantly affect**

infiltration rate, supporting the hypothesis that infiltration improvements require longer-term or more transformative soil management practices.

3. **Provided a comprehensive, multi-year dataset integrating soil physical, chemical, and biological indicators** with plant morphological, physiological, and biochemical traits, representing one of the most detailed field-level assessments of microbial inoculant effects. This integrated dataset captures soil-plant-microbe interactions, early indicators of soil regeneration, and the influence of microbial amendments on plant establishment, growth stability, nutrient accumulation, and key quality parameters, including a significant increase in total sugar content in peas under inoculated treatments.
4. **Addressed an important knowledge gap**, by integrating microbial inoculation, conservation tillage, and market garden vegetable rotation within a controlled field experiment, an approach that has been rarely examined in published research while evaluating both soil and plant responses.

6. LIST OF PUBLICATIONS

1. Romdhane, A., Riahi, A., Ujj, A., Ramos-Diaz, F., **Marjanović, J.**, Hdidier, C., 2023. Comparative Nutrient and Antioxidant Profile of High Lycopene Variety with hp Genes and Ordinary Variety of Tomato under Organic Conditions. *Agronomy*, 13(3), 649.
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2. Lopičić, L., **Marjanović, J.**, 2023. Mapping agroecology in Montenegro. In: Wezel, A., Grard, B. and Gkissakis, V. (eds). *Mapping agroecology in Europe. Country Reports Series, Vol. 1*, ISARA, Lyon, France; Agroecology Europe, Corbais, Belgium (PDF) Mapping the development of agroecology in Europe; Mapping Agroecology in Montenegro. Available from:
https://www.researchgate.net/publication/377499304_Mapping_the_development_of_agroecology_in_Europe_Mapping_Agroecology_in_Montenegro#fullTextFileContent [accessed 31/01/2026]
3. **Marjanović, J.**, Zubairu, A. M., Varga, S., Turdalieva, S., Ramos-Diaz, F., Ujj, A., 2024. Demonstrating Agroecological Practices in Potato Production with Conservation Tillage and *Pseudomonas* spp., *Azotobacter* spp., *Bacillus* spp. Bacterial Inoculants-Evidence from Hungary. *Agronomy*, 14(12), 2979.
<https://doi.org/10.3390/agronomy14122979>
4. Jug, D., Jug, I., Brozović, B., Šeremešić, S., Dolijanović, Ž., Zsembeli, J., Ujj, A., **Marjanović, J.**, Smutny, V., Dušková, S., Neudert, L., Macák, M., Wilczewski, E., Đurđević, B., 2025. Conservation Soil Tillage: Bridging Science and Farmer Expectations-An Overview from Southern to Northern Europe. *Agriculture*, 15(3), 260.
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<https://doi.org/10.3390/horticulturae11020213>
6. Ujj, A., Nagyné Pércsi, K., Ramos-Diaz, F., **Budimir-Marjanović, J.**, Horstink, L., Queiroga-Bento, R., Mukosha, C. E., Moudrý, J., Diána, K. G., Jancsovszka, P., 2025. Agroecological Adoption Pathways in Europe: Drivers, Barriers, and Policy Implication Opportunities in the Czech

Republic, Hungary, and Portugal. *Agriculture*, 15(23), 2414.
<https://doi.org/10.3390/agriculture15232414>

7. Zubairu, A.M., *Marjanović, J.*, Abdulkadir, M., Eldawwy, N., Takács, A., Ocansey, C. M., Gulyás, M., 2025. Conceptual framework for restoring soil fertility in arid Borno state, Nigeria with biochar from agricultural wastes. *Discover Sustainability* 7, 7.
<https://doi.org/10.1007/s43621-025-02008-9>

Other conference posters and abstracts are available at ResearchGate and MTMT:

<https://www.researchgate.net/profile/Jana-Marjanovic-3>

<https://m2.mtmt.hu/gui2/?type=authors&mode=browse&sel=10095136>