SUMMARY
of the doctoral thesis entitled:

ECO-EFFICIENCY IN THE PRODUCTION AND APPLICATION OF MICROBIAL BIOSTIMULANTS FOR CONSERVATION AGRICULTURE SYSTEMS

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The paper explores the eco-efficiency of microbial biostimulant production and use in conservation agriculture systems through a comparative study of conventional and organic agricultural systems.

The introductory section presents the current state of research on practices in conservation agriculture, recognized as a sustainable farming system. Research has demonstrated that incorporating the core principles of conservation agriculture—minimal soil disturbance (no-till), permanent soil cover (mulching), and diverse crop rotations—can provide numerous advantages over both conventional and organic farming systems. These benefits include reduced soil erosion, improved water availability, carbon sequestration, reducing the impact on climate change, and long-term farm profitability. The advantages and best practices regarding the use of mulch and soil cover are also explored, highlighting their role in water conservation, weed suppression, soil temperature regulation, and nutrient recycling. However, challenges such as weed and pest management, initial yield decreases, and the need for specialized equipment are also discussed.

The study continues by exploring the two farming systems (conventional and organic) in comparison to conservation agriculture, analyzing the main advantages and disadvantages associated with each one. Research shows that traditional agriculture, traditionally characterized by intensive tillage, monoculture, and extensive use of pesticedes and synthetic fertilizers, has significantly added to global food production. However, its practices raise concerns about soil health, biodiversity loss, water pollution, and greenhouse gas emissions due to dependency on external inputs and intensive methods. In contrast, organic agriculture promotes soil health through practices such as crop rotation, green manures, and composting, relying on biological pest control methods that have demonstrated improvements in soil quality, including biodiversity enhancement and reduced environmental impact. At the same time, organic agriculture faces challenges like lower yields, higher labor costs, and limited market access, especially for small-scale farmers.

The study proceeds with an analysis of the scientific literature on biostimulants. Scientific findings show that biostimulants can be derived from various sources, including algae extracts, protein hydrolysates, humic substances, and beneficial microorganisms like *Trichoderma*. Microbial biostimulants are defined as products containing beneficial organisms, such as Trichoderma, a fungal genus known for plant growth promoting and disease suppression. These biostimulants are recognized for improving nutrient absorption, increasing stress resilience, and enhancing crop quality. Recent findings suggest that these microorganisms promote plant growth and health by facilitating nutrient solubilization and mobilization, producing phytohormones, providing biocontrol, and boosting tolerance to both biotic and abiotic stress factors. Additionally, microbial biostimulants have shown potential in improving crop yields, nutrient absorption, and stress tolerance, including resistance to water shortage and disease.

In the final part of the research review, the technico economical analysis and the life cycle assessment (LCA) are introduced and analyzed as determinative tools for evaluating the sustainability of the agricultural systems. The study outlines the stages involved in conducting techno-economic analyses and LCAs for conservation agriculture systems, highlighting examples from the literature that emphasize the need for a combined approach to assess economic profitability and environmental impact. The main conclusions from identified scientific studies are discussed, highlighting the economic and ecological advantages of biostimulant use in agriculture and the trade-offs that need to be taken into consideration.

According to literature review, three main objectives were identified for further research, which focuses on original research:

- Optimization of microbial biostimulant production processes and their integration into biorefining processes;
- The role of compounds produced by microbial biostimulants (polyphenols and root exudates);
- Eco-efficiency of microbial biostimulant production and use in conservation agriculture.

The original research provides evidence of the positive effects of microbial biostimulants on tomato yield and quality, mediated by their influence on polyamine production. The application of microorganisms led to notable increases in marketable yield and enhanced the amount of bioactive compounds on tomato fruits. These findings highlight the potential of polyamine-producing microbial biostimulants as valuable tools for sustainable agriculture, promoting crop productivity and nutritional quality. The original method developed in this study, which integrates two patented components, demonstrated that the application of oligosaccharide-type elicitors, released from plant material by the action of *Trichoderma asperellum* T36 fungi, induces the bioactive compounds production in tomato plant roots, resulting in a biostimulant effect (enhanced tolerance of model plants to abiotic stress, particularly water stress).

The final section thoroughly evaluates the life cycle of microbial biostimulant production and use in conservation agriculture, focusing on the eco-efficiency generated by their impact on environmental indicators and economic profitability. The environmental impacts of microbial biostimulant production using plant residues are analyzed in detail. The assessment emphasizes the ecological compatibility of this production method, primarily attributing the environmental effects to electricity consumption. Using plant residues as a substrate aligns with circular economy principles, effectively reducing waste generation and promoting sustainable resource management in agriculture. The second part extends the life cycle analysis to include the use phase of biostimulants in conservation agriculture. The results indicate a substantial decrease in environmental impact compared to conventional agricultural practices, mainly due to reduced fertilizer and pesticide use. However, the economic analysis presents a less optimistic perspective, suggesting limited short-term profitability. This underscores the need to improve production efficiency and develop effective marketing strategies to ensure the economic viability of biostimulant use in conservation agriculture.

The reported environmental benefits of biostimulant production using plant residues could be enhanced by exploring renewable energy sources for powering the manufacturing process (e.g., agrovoltaic practices). This would further reduce the environmental impact associated with electricity generation, making the production system even more sustainable. Investigating value-added pathways could also improve the economic profitability of microbial biostimulant production and application in conservation agriculture. This could involve developing new biostimulant formulas that provide multiple benefits, such as improved nutrient use efficiency, stress tolerance, and disease resistance. As a result, higher-quality agricultural products and new multifunctional biostimulants could be sold at premium prices, improving profitability.

Life cycle analysis provides valuable insights into the economic and environmental sustainability of microbial biostimulant production and application in conservation agriculture. The findings highlight the eco-efficiency of microbial biostimulant production and use, which has the significant potential to contribute to more sustainable agriculture.