Abstract

This doctoral research is developed within the framework of the PNRR Italian National Research Centre for Agricultural Technologies AGRITECH, with a specific focus on Spoke 8, dedicated to circular economy in agriculture through waste valorization and recycling. The work integrates technological development and sustainability assessment, contributing to Tasks 8.3.2 and 8.4.2, which respectively address the production of bio-based fertilizers and the multidimensional evaluation of circular solutions.

The research follows a structured and progressive approach. Initially, environmental footprint methodologies—including Carbon Footprint (CF), Water Footprint (WF), and Ecological Footprint (EF)—ar e applied to a high-quality red wine production system in Piedmont, Italy, adopting a cradle-to-gate perspective. This phase provides methodological grounding and highlights key environmental hotspots, further explored through sensitivity analysis across different geographical and production scenarios.

In parallel, a critical review of Life Cycle Assessment (LCA) applications to agri-food waste valorization is conducted, with the aim of identifying methodological gaps and proposing indicators capable of capturing the degree of circularity in terms of waste utilization as process feedstock.

Building on this framework, a case study on orange peel waste (OPW) valorization for biopolymer production is developed through a multicriteria assessment approach, integrating environmental, technological, and scalability considerations. This work represents a core contribution to Task 8.4.2 and reflects the challenges and opportunities of industrial collaboration within circular bioeconomy systems.

The research then shifts toward technological development under Task 8.3.2, starting with a comprehensive review of biofertilizer production from agro-industrial waste. This is followed by a series of experimental studies on biochar application in agriculture, including laboratory- and pilot-scale trials on strawberry, lettuce, and spinach crops. These experiments investigate the agronomic performance of different biochar types and introduce integrated monitoring approaches combining traditional measurements with proximal sensing techniques to enable non-destructive crop assessment.

Overall, the thesis demonstrates how circular economy principles can be operationalized through the integration of waste valorization technologies and sustainability assessment frameworks. It highlights the importance of interdisciplinary collaboration and provides methodological and experimental contributions toward the development of scalable, environmentally sound, and economically viable circular solutions for agriculture.

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