Abstract

Food scarcity has historically influenced human development, but today's paradox lies in food abundance coupled with widespread waste, while millions of people still lack access to adequate nutrition. Food waste indeed represents one of the main problems of current society and it is inherently related to another pressing threat: the depletion of soil fertility. Food waste accounts for 8-10% of total greenhouse gas emissions and it consumes nearly 30% of arable land, contributing to its overexploitation and degradation. 70% of global soils are considered unhealthy, affected by nutrient imbalance, erosion, contamination, and organic carbon loss, resulting in impaired soil fertility, biodiversity, and ecosystem function, and thus threatening food systems as well.

Healthy soils are indeed crucial for producing 95% of the world's food and for regulating water and carbon cycles. Soils restoration can also help mitigate climate change by sequestering carbon, as soils store 2-3 times more carbon than the atmosphere. To address both climate and soil crises, carbon farming has emerged as a strategy to promote farming practices that reduce emissions and enhance carbon capture at the farm level. Among these practices, the use of organic amendments, such as compost, digestate, and biochar, represents a promising yet debated solution for carbon capture, but they are also a valuable solution for food waste recovery and soil health restoration, as they can replenish soils with organic matter and nutrients. When properly produced and managed, these organic amendments enhance soil fertility and reduce reliance on synthetic fertilizers, supporting circular economy and sustainable production models.

Reflecting this duality, the aim of this work is thus double. The different processes for the converting food waste into the aforementioned soil organic amendments are studied, and various operating conditions for their optimization are explored. Three representative and most abundant wastes of the food supply chain have been chosen: the organic fraction of municipal solid waste from separate waste collection, apple pomace from food processing, and wheat straw and cow manure from food production. For each stream, different operating conditions for both anaerobic digestion and pyrolysis are tested, from which digestates and biochars are produced. Additionally, the aerobic conversion of biomass is explored, with the focus on the aerobic stabilization of the solid fraction of anaerobic digestate, from which a composted solid digestate is derived. The obtained products are subsequently tested to assess their agronomic potential, with greenhouse pot experiments on tomato (*Solanum lycopersicum l.*) plant growth, and the liquid fraction of anaerobic digestate is used as a nutritive solution for the growth of lettuce (*Lactuca sativa var. capitata)* in a vertical aeroponic farming system.

This work demonstrates the feasibility of a circular productive model, in which waste becomes feedstock to produce energy and soil organic amendments that support food production and help reduce its environmental impact.