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Boosting circular economy and closing the loop in agriculture: Case study of a small-scale pyrolysis–biochar based system integrated in an olive farm in symbiosis with an olive mill

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ABSTRACT

Carbon sequestration and soil quality improvement coupled with bio-energy generation are important issues to be addressed in agriculture by valorising crop residues and by-products. The aim of this work is to study a pyrolysis–biochar system applied to an olive farm in symbiosis with a 2-phase olive mill. The set-up of a closed-loop productive system is proposed. The results have shown that the valorization of 70.0 t of solid and semi-solid wastes issued from both 10 ha olive grove and milling process can be converted via pyrolysis into 13, 11, 12 t of liquid fuel, biochar and gas fuel, respectively. The liquid and gas fuels can fulfill the olive milling energy needs and produce an electricity surplus of ~13.00 MW h_{el} resulting in an extra income (4000€) if sold to the grid. In the case of solar drying of the raw material, ~30.00 MW h_{el} could provide 8900€ per year. A SWOT analysis shows that pyrolysis of agri-residues targeting biochar can fulfill the aim of closing the loop in agriculture and circular economy objectives.

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1. Introduction

Renewable energy could play a basic role to meet present energy demands and mitigate global warming (Mathiesen et al., 2011). Agricultural biomass represents an attractive and suitable feedstock for energy conversion, particularly in rural areas and can also play a fundamental role in preserving or improving soil quality (Del Gado, 2010; Johnson et al., 2010; Bakht et al., 2009; Limon-Ortega et al., 2008).

Biomass thermochemical conversion processes have several advantages over other methods, in terms of feedstock flexibility and energy co-products diversification (Chhiti and Kemiha, 2013; Jahirul et al., 2012; Panwar et al., 2012). Particularly in rural areas, decentralized energy systems operating at small scale, fuelled with processing wastes and locally available residues can combine heat and power generation (CHP units). However, combustion of agricultural residues is associated with environmental concerns (Demirbas et al., 2006).

The feasibility of using agricultural residues and by-products as renewable energy source by means of pyrolysis processes has been widely reported in literature (Damartzis and Zabaniotou, 2011; Zabaniotou et al., 2000; Caglar and Demirbas, 2002; González et al., 1997). The closeness of the pyrolysis facility to the feedstock catchment is a crucial factor in determining the economic viability of the supply chain and its logistics costs, also considering the abatement of CO_2 equivalent emissions (Sohi et al., 2010).

These facilities can operate off-grid, thus creating a complete stand-alone energy system, or in-grid, to allow energy exchange outside the system. A relevant effect resulting from the return of agricultural residues and by-products to the soil is the contribution to carbon sequestration in the form of stable humus. In contrast, a persistent removal of crop residues from agricultural soils may impair its fertility, cause carbon losses, organic matter decline, nutrients depletion, also triggering a significant increase in soil erosion risks (Blanco-Canqui and Lal, 2009; Lafond et al., 2009; Lal, 1997).

Carbon sequestration and soil quality improvement coupled with bio-energy generation are important issues to be addressed and properly face the mitigation of global climate change (Tilman et al., 2009). Therefore, a trade-off between atmospheric CO_2 sequestration into long-persistent soil carbon pools and the development of carbon-neutral fuel sources should be achieved. On this respect, to find a win–win solution applied to an olive farm (Laird, 2008), pyrolysis could be a suitable process for the above win–win solution for both, carbon-rich solid biochar and liquid product that can be used as an alternative to diesel oil in a combustion engine fulfilling the energy needs of the olive farm.

The nature of the pyrolysis products depends on several factors, including pyrolysis temperature, heating rate, pressure, residence time, etc (Chhiti and Kemiha, 2013). In general, pyrolysis can be classified as slow, fast, rapid, flush, although there are no sharp boundaries to determine the differences between those alternatives and derived products (Demirbas et al., 2006). For biochar targeted product, slow pyrolysis is the appropriate method.

The aim of this study was to investigate the application of a small scale pyrolysis plant integrated in an olive farm, that operates also a 2-phase milling facility, for the production of extra-virgin olive oil, fuelled with olive pruning and olive pomace and aiming to provide: (a) the energy to power the milling process and (b) the biochar to be used as soil amendment in the olive grove. Based on experimental data obtained from laboratory pyrolysis experimentation, mass and energy balances were estimated for the whole process. The set-up of a closed-loop productive system was proposed, according to fundamental ecological criteria, in the frame of concepts like circular economy and industrial symbiosis.

2. Biochar benefits in agriculture

Biochar is attracting attention as a potentially powerful tool for mitigating anthropogenic climate change. Consequently, combining pyrolysis for renewable energy generation with the application of biochar to soil offers a very attractive strategy to reduce greenhouse gas emissions (Gaunt and Lehmann, 2008).

Biochar obtained as co-product from pyrolysis can be recycled in the same olive grove from which pruning are derived and used as a soil amendment to improve the physical–chemical and microbiological soil fertility. This agricultural practice is perfectly in line with the principles of sustainable farming. Additionally, pyrolysis of agricultural residues targeting biochar production can fulfill the aim of “closing