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Technical feasibility and carbon footprint of biochar co-production with tomato plant residue

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ABSTRACT

World tomato production is in the increase, generating large amounts of organic agricultural waste, which are currently incinerated or composted, releasing CO_2 into the atmosphere. Organic waste is not only produced from conventional but also urban agricultural practices due recently gained popularity. An alternative to current waste management practices and carbon sequestration opportunity is the production of biochar (thermally converted biomass) from tomato plant residues and use as a soil amendment.

To address the real contribution of biochar for greenhouse gas mitigation, it is necessary to assess the whole life cycle from the production of the tomato biomass feedstock to the actual distribution and utilisation of the biochar produced in a regional context. This study is the first step to determine the technical and environmental potential of producing biochar from tomato plant (*Solanum lycopersicum arawak* variety) waste biomass and utilisation as a soil amendment.

The study includes the characterisation of tomato plant residue as biochar feedstock (cellulose, hemicellulose, lignin and metal content); feedstock thermal stability; and the carbon footprint of biochar production under urban agriculture at pilot and small-scale plant, and conventional agriculture at large-scale plant.

Tomato plant residue is a potentially suitable biochar feedstock under current European Certification based on its lignin content (19.7%) and low metal concentration. Biomass conversion yields of over 40%, 50% carbon stabilization and low pyrolysis temperature conditions (350–400 °C) would be required for biochar production to sequester carbon under urban pilot scale conditions; while large-scale biochar production from conventional agricultural practices have not the potential to sequestrate carbon because its logistics, which could be improved. Therefore, the diversion of tomato biomass waste residue from incineration or composting to biochar production for use as a soil amendment would environmentally be beneficial, but only if high biochar yields could be produced.

1. Introduction

1.1. Biomass waste generation from tomato crops

World tomato production increased 42.9% between 2000 and 2013 (FAOSTAT, 2015). Consequently, tomato crop wastes have increased too. In 2013, 163.43 Mt of tomatoes were produced worldwide (FAOSTAT, 2015). Assuming a dry waste production (leaves and stems) of 9 t/ha·year for tomato crops (López et al.,

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Abbreviations: BQM, Biochar Quality Mandate; BTP, Biochar testing protocol; C, Carbon; CC, Climate change; CO2, Carbon dioxide; DSC, Differential scanning calorimetry; DTA, Differential thermal analysis; EBC, European Biochar Certification; IBI, International Biochar Initiative; ICPS-MS, Inductively coupled plasma mass spectrometry; i-RTG, Integrated rooftop greenhouse; LCA, Life cycle assessment; $m_{dry\ biomass}$, Mass of dry biomass; RTG, Rooftop greenhouse; TGA, Thermogravimetric analysis; UA, Urban agriculture; $\%_{Stable\text{-}C}$, Percentage of stable C remaining in the biochar.

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Table 1
Total world, European and Spanish tomato production, crop area, waste generation (FAOSTAT, 2015) and C fixed within waste biomass during 2013. Waste production was calculated assuming 9 tonnes of biomass waste per ha of crop (López et al., 2004) and fixed C by supposing that 18% of the total dry biomass weight corresponds to the C content (Mota et al., 2008).

	Annual total values for 2013					
	Tomato production (Mt)	Area harvested (ha)	Approx. wet waste* (Mt)	Approx. dry waste* (Mt)	C fixed in dry waste* (Mt)	CO_2 eq. fixed in dry waste* (Mt)
World	163.43	4,688,335	332.87	42.19	7.6	27.9
Europe	20.96	500,872	35.56	4.51	0.81	2.97
Spain	3.68	45,300	3.22	0.41	0.07	0.26

* Only stems and leaves are considered.

2004), in 2013, approximately 42.19 Mt of dry waste may have been produced worldwide (Table 1).

As the amount of tomato waste residues increase with increased crop production, waste management solutions should be used to minimize their environmental impacts and help mitigate climate change (IPCC, 2013). Sustainability is included in most conventional tomato plant waste management scenarios as waste is re-used or recycled to feed farm animals, produce compost or for energy valorisation (i.e.; incineration). Some institutions have already developed waste management solutions that could help to fix the C captured by tomato plants and reduce resources depletion. Wageningen University has developed a technology to produce cardboard for packaging with tomato plants stems and leaves (Wageningen UR, 2014). Ford Motor Company, in collaboration with Heinz ketchup, is developing new bio-composites based on tomato processing wastes (Ford Motor Company, 2014). Moreover, the Biocopac Project has developed bio-resins based on tomato processing wastes to cover the inside part of food cans (Biocopac Project, 2013).

Although GHGs emissions may be reduced or delayed under such waste management scenarios, carbon sequestration into stable carbon forms is not considered. The carbon content of tomato plant (corvey variety) stem and leaves is 18% of total dry tomato plant weight (Mota et al., 2008). Consequently, the annual world tomato waste (stems and leaves) would contain approximately 7.6 million tonnes of C, equal to an approximate 27.9 million tonnes of CO_2 (Table 1), which is returned to the atmosphere.

1.2. Agricultural wastes & biochar production

A potential waste management solution that captures and stores carbon from agricultural waste into stable forms by reductive thermal processes is the production of biochar. (Lehmann et al., 2006). Biochar is defined as 'a solid material obtained from the thermochemical conversion of biomass in oxygen-restricted conditions which is used for any purpose that does not involve its rapid mineralisation to CO_2' (Shackley et al., 2016 BOOK chapter 1 pg 6). Due to its long-term storage of stable carbon, biochar is commonly used for soil improvement (Lehmann et al., 2008; Woolf et al., 2010). Other 50 biochar applications have been already listed (Hans-Peter and Kelpie, 2014), such as (1) a feed complement in farms (Gerlach and Schmidt, 2014); (2) to increase the biogas production efficiency (Inthapanya, 2012); (3) to produce thermal insulation materials (Lin and Chang, 2008) and (4) to fill mattresses and pillows (Hans-Peter and Kelpie, 2014).

The use of biochar depends significantly on its quality (i.e., porosity, nutrient content or heavy metal content). In the case of biochar for soil amendment, in Europe, two different voluntary certifications, without legal implications, have been developed: the Biochar Quality Mandate (BQM) elaborated by the British Biochar Foundation (Hackley et al., 2014) and the European Biochar Certification (EBC) criteria (EBC, 2012). In USA and Canada, can be applied the International Biochar Initiative (IBI) mandate (IBI, 2015). These voluntary certifications provide minimum quality parameters of biochar for its application in soils. The information supplied by these schemes has been compiled into the Biochar testing protocol (BTP) to provide information on biochar materials and biochar products. This information allows the user to describe and define the properties of the biochar product (Shackley et al., 2016).

Agricultural wastes have previously been considered as feedstocks and used to produce biochar as a solution for carbon sequestration (Lehmann et al., 2006; McHenry, 2009). Some examples of the agricultural feedstocks include rice hull, groundnut shells, olive husk and tea (Lehmann et al., 2006; McHenry, 2009). One study analysed the use of biochar produced with tomato plant feedstocks as a substrate for tomato hydroponic crops (Dunlop et al., 2015). This research focuses on the specific properties for the application under study (i.e., N, P, and K contents; thermal conductivity; and pH) but does not communicate other important parameters such as the metal content of tomato plant feedstock or its environmental performance with life cycle assessment (LCA) methodology. LCA is a recognised methodology to quantify the environmental impacts of systems, products or services for proper decision making (European Commission, 2001; UNEP, 2002). Present study uses LCA methods to determine the carbon footprint of biochar co-production with tomato plant feedstocks.

1.3. Urban agriculture (UA): new organic feedstocks and by-products in cities

The United Nations predicts that the world population will reach 9.550 million habitants by 2050, of which more than the 70% will live in urban areas (UN, 2012); consequently, the food demand in cities will increase. Some strategies, such as UA, are gaining presence in urban areas to increase cities' food self-sufficiency (Orsini et al., 2013; Specht et al., 2013).

UA has a great potential to provide social and environmental benefits to cities' feeding systems (Sanyé-Mengual et al., 2015, 2013; Tomlinson, 2011) due to social integration, job creation, simpler logistics and packaging reduction. However, UA produces organic wastes that increase the organic fraction generation of urban areas (Baumgartner and Belevi, 2001). The circular economy concept (Andersen, 2007) promotes the conversion of wastes back to resources. Biochar opens a wide range of possibilities for the creation of new local products with local UA wastes, helping to reduce the organic fraction volume of urban areas while reducing resources depletion.

One of the multiple UA typologies consists of installing greenhouses on the top of buildings, named Rooftop Greenhouses (RTGs). Inspired by the Industrial Ecology concept (Jacobsen, 2008), RTGs can be integrated with buildings to exchange energy, water and CO_2 (from human respiration) flows and increase system efficiency. Integrated RTGs (i-RTGs) allow an intensive food production, which will generate organic wastes that could be used to produce new products. Therefore, urban production systems, conceptually, could also be considered raw material farms.

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