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Research article

Biochar, compost and biochar-compost blend as options to recover nutrients and sequester carbon

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A B S T R A C T

This work assessed the potential environmental impact of recycling organic materials in agriculture via pyrolysis (biochar) and composting (compost), as well its combination (biochar-compost blend) versus business-as-usual represented by mineral fertiliser. Life cycle assessment methodology was applied using data sourced from experiments (FP7 project Fertiplus) in three countries (Spain, Italy and Belgium), and considering three environmental impact categories, (i) global warming; (ii) acidification and (iii) eutrophication. The novelty of this analysis is the inclusion of the biochar-compost blend with a focus on multiple European countries, and the inclusion of the acidification and eutrophication impact categories. Biochar, compost and biochar-compost blend all resulted in lower environmental impacts than mineral fertiliser from a systems perspective. Regional differences were found between biochar, compost and biochar-compost blend. The biochar-compost blend offered benefits related to available nutrients and sequestered C. It also produced yields of similar magnitude to mineral fertiliser, which makes its acceptance by farmers more likely whilst reducing environmental impacts. However, careful consideration of feedstock is required.

1. Introduction

A continuous supply of macronutrients, nitrogen (N), phosphorus (P) and potassium (K) is required to sustain crop yields (Malingreau et al., 2012). Typically, crop nutrients are provided by mineral (inorganic) fertiliser, but supplies of readily available P fertiliser are estimated to be exhausted in 50–100 years (Cordell et al., 2009). The inefficient use of N and P also results in negative environmental impacts such as eutrophication (N and P) (Commoner, 1970; Mackenthun, 1968) and acidification (N) (Johnston et al., 1986). Identifying innovative ways to recycle macronutrients within agricultural systems while minimising environmental impacts is of great importance and is consistent with 'circular economy' principles of 'closing the loop' by returning organic residue/waste to agricultural soils (Mirabella et al., 2014).

Technologies such as pyrolysis and composting can recycle nutrients from organic waste, residue and purpose grown catch crops (Lehmann and Joseph, 2009; Oldfield et al., 2016). Pyrolysis produces biochar, which is carbon (C) rich and contains macronutrients. Composting produces compost that contains organic matter, C and available macronutrients (Epstein, 2011). Biochar and compost offer significant potential for soil C sequestration. Biochar C contains between 70 and 90% of stable C (Hammond et al., 2011; Lehman and Joseph, 2009), while compost contains between 2 and 14% stable C (Boldrin et al., 2009). When biochar and/or compost is applied to soils, part of C is removed from the short-term C cycle (Sparrevik et al., 2013).

The blending of biochar with compost has been suggested to enhance the composting performance by adding more stable C and creating a value-added product (biochar-compost blend) that can offset potential negative effects of the composting system ((such as emissions of CH_4 (Vandecasteele et al., 2016), and NH_3 (Fischer and Glaser, 2012)) and of the pyrolysis biochar system ((such as low macronutrient content (Schulz et al., 2013), low cation exchange

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capacity (Prost et al., 2013)).

Life cycle assessment (LCA) is a technique that quantifies the potential environmental impact and resource consumption of a product, system or service from cradle to grave (ISO, 2006a,b). LCA can be used to assess biochar, compost and biochar-compost blend by modelling the system inputs throughout the full life cycle but few LCA studies consider nutrient recycling and soil C sequestration, *per se* (Laurent et al., 2014a). Historically, LCAs have focused on waste management rather than new products derived from waste (Oldfield and Holden, 2014).

Laurent et al. (2014a,b) reviewed 222 LCA studies of biowaste management that included composting (74 studies) and pyrolysis (14 studies), but none considered the blending of biochar and compost. More recent studies have investigated greenhouse gas emissions related to the application of compost, biochar, and biochar-compost blend (Agegnehu et al., 2016; Bass et al., 2016). These studies did not include other environmental impacts, such as eutrophication and acidification. Of the reviewed studies by Laurent et al. (2014a,b), ~5% defined a downstream functional unit for the resultant product (compost, biochar, crop yield, energy produced), with the majority of the reviewed studies opting for 1 tonne of waste as the functional unit. An LCA that did use a downstream functional unit and looked at the impact of utilising waste via a nutrient recovery technology for plant establishment was Martínez-Blanco et al. (2009). In their study the system boundary started with the collection of the waste and ended at the production of 1 tonne of crop. As the aim of this research is conceptually similar, the same approach as Martínez-Blanco et al. (2009) was followed.

The aim of this research was to evaluate the environmental impact of recovering nutrients and sequestering C in soil from urban or farm organic waste through pyrolysis or/and composting to produce biochar, compost and biochar-compost blend. LCA methodology was followed and five separate case studies with different crops (grapes, olives, and leek) in three European countries (Italy, Spain, and Belgium) were assessed. Diversity, reflected in crops, countries/location, soil, climate, type of compost, were chosen on purpose in order to cover broader differences, with the aim capturing realistic and relevant information to inform a general conclusion rather than focusing on a site-specific situation.

2. Materials and methods

The study used observed field and laboratory data from the European Union funded project GA n. 289853 “Fertiplus” (www.fertiplus.eu).

2.1. Field trials

The field trials were conducted in Italy, Spain and Belgium ((Supplementary Information (*SI*)), which provided input and yield data for the LCA modelling. Experimental conditions for each location reflected the local agricultural production conditions for the crops selected (See SI Table 1 for description of differences).

Oak residue was used as a feedstock to produce biochar for all trials, while two composts were produced: (1) using biowaste (Italy and Belgium); and (2) using a mixture of olive mill waste, sheep manure and olive tree prunings (ratio of 50:25:25) (Spain). Two different biochar-compost blends were produced (ratio of 1:9 (biochar:compost)) based on mass whereby (1) biochar was added to bio-waste before the commencement of the composting process (Italy and Spain) (Vandecasteele et al., 2016) and (2) biochar mixed with the mature compost after its production from sheep manure and olive mill waste (Spain). See SI Table 2 for characterisation of feedstocks and SI Tables 3–4 for characterisation of biochar, compost and biochar-compost blend. We note here that it is foreseen that biochar, compost and biochar-compost blend would be applied once every three years, whilst fertiliser would be applied annually. This study focuses on year one of application, the implications of including year two and three is examined in the discussion section.

2.1.1. Spain trial

Jumilla is a semiarid area in Murcia (Spain). The soil (*SI* Table 5) was sandy loam (27.0% silt, 16.2% clay, 56.8% sand) with a pH of 8.0. In this location (38°23′ N 1°22′ W) one organic farm was used and the amendments were applied to olives.

Compost, biochar and biochar-compost blend were applied at 20 t ha^{-1} (dry mass basis) and no mineral fertiliser was used. Observed emission data was used. Additional information on Spanish trials can be found in Sánchez-García et al. (2016).

2.1.2. Italy trails

Friuli-Venezia Giulia is in north-east Italy and has a Mediterranean climate. In this location three sites were used, Buttrio (46°03′ N 13°26′ E), Spessa (46°00′ N 13°20′ E) and Lonzano (46°01′ N 13°29′ E) and the amendments were applied to three different grape varieties (Buttrio-Sauvignon, Spessa-Ribolla gialla and Lonzano-Pinot blanc). Soil (*SI* Table 6) was predominantly silty (clay) loam (Buttrio: 45.5% silt, 30.6% clay, 14.8% sand; Spessa: 58.4% silt, 9.3% clay, 32.3% sand; Lonzano: 50.9% silt, 20.3% clay, 28.8% sand) with a pH of 8.03–8.15.

Amendments were applied at all three sites based on a carbon content of 10.9 t C ha^{-1} resulting in 21.7 t ha^{-1} of biochar, 45.2 t ha^{-1} of compost and 41.3 t ha^{-1} of biochar-compost blend (wet weight). In addition, a fertiliser trial (control) with N:P:K 32.5:7.1:40.5 kg ha^{-1} was also utilised.

2.1.3. Belgium trial

Ghent is in north-west Belgium with a marine west coast climate. The soil (*SI* Table 7) was sandy loam (34.7% silt, 5.4% clay, 59.9% sand) with a pH of 6.4. In this location (51°3′N, 3°43′E) one farm was used and the amendments were applied to leek.

Amendments were applied based on a C content of 10.9 t C ha^{-1} resulting in 24 t ha^{-1} biochar, 47 t ha^{-1} compost and 49 t ha^{-1} biochar-compost blend (wet weight). Mineral fertiliser was applied to all three trials, with N:P:K of 140:0:87 kg ha^{-1}, respectively. A control trial with only mineral fertiliser with the same NPK input was also used.

3. Life cycle assessment

The LCA followed the four stage LCA methodology (ISO, 2006a; ISO, 2006b): (1) goal and scope definition; (2) inventory analysis; (3) impact assessment; and, (4) interpretation. GaBi v.6 software (ThinkStep, 2015) was used for modelling.

3.1. Goal and scope

The goal of the LCA is defined in line with the ILCD Handbook guidelines (EC, 2010). The objective was to assess the potential environmental impact of recovering nutrients and sequestering C via the amendment of organic waste materials for utilisation in agricultural soils. Pyrolysis and composting were used to produce biochar and compost and a biochar-compost blend from a combination of both. These amendments were compared with a mineral fertiliser, representing the business-as-usual scenario (only for Italy and Belgium). The reason for undertaking this study was to support strategic decision-making and the audience was assumed to be the scientific community, waste processors, regulators and farmers.