BIOMASS AND BIOENERGY XXX (2014) 1–14

Available online at www.sciencedirect.com

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BIOMASS & BIOENERGY

What is the potential for biogas digesters to improve soil carbon sequestration in Sub-Saharan Africa? Comparison with other uses of organic residues

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ARTICLE INFO

Article history:
Received 1 March 2013
Received in revised form
12 November 2013
Accepted 9 January 2014
Available online xxx

Keywords:
Biogas
Soil carbon sequestration
Sub-Saharan Africa
Anaerobic digestion
RothC

ABSTRACT

Using bioslurry from anaerobic digestion as an organic fertilizer has great potential to increase carbon sequestration by supplying organic matter to the soil. This paper examines this potential in Sub-Saharan Africa compared to other uses of organic residues, including burning on pyrolysis cook-stoves and composting. Measurements of loss of carbon on treatment of organic residues indicate that the proportion of carbon lost from organic residue during treatment is greater for anaerobic digestion than for aerobic composting or pyrolysis. The stability of organic residue is increased by treatment, and is similar for composted and anaerobically digested material, but is higher for material treated by pyrolysis. Simulations using the RothC model, driven by parameters based on incubations of the organic residues with soil, suggest that on the basis of decomposability alone, treated organic residues sequester significantly more carbon than untreated organic residues, and despite the differences observed in stability, unless biochar contains a high proportion of inert organic material that does not decompose at all, the potential carbon sequestration by incorporating biochar is similar to that for compost or bioslurry. However, if losses of carbon during treatment are also taken into account, incorporating bioslurry sequesters only approximately the same amount of carbon as if the organic residue had been left untreated. By contrast, incorporating compost and biochar sequesters significantly more

Abbreviations: C, carbon; CH_4, methane; CO_2, carbon dioxide; DPM, decomposable plant material; HUM, humus; IOM, inert organic matter; N, nitrogen; N_2O, nitrous oxide; P, phosphorus; RothC, Rothamsted Carbon Model; RPM, resistant plant material; SSA, Sub-Saharan Africa.

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http://dx.doi.org/10.1016/j.biombioe.2014.01.056

carbon than incorporating the untreated organic residue. Therefore using bioslurry as an organic fertilizer sequesters less of the carbon in the soil from organic residue than burning on pyrolysis cook-stoves or composting.

1. Introduction

The soils of Sub-Saharan Africa (SSA) are often deficient in soil organic matter and have great potential to sequester carbon (C) [1]. Lal [1] identified SSA as a global hotspot of soil degradation with a high priority for soil restoration and C sequestration. It has been suggested that a critical limit for soil organic C concentration in most soils of the tropics is 1.1% [2] (that is 1.1 kg C per 100 kg dry soil). However, Nyamangara [3] indicated that on average in SSA, the organic C content of soils is less than 1%. Different local studies reveal similar results. For instance, Assefa and van Keulen [4] reported organic C contents between 0.9 and 1.1% on continuously cultivated soil of the north highlands of Ethiopia. At the same time, solid organic waste removal from urban areas has become an ecological problem in SSA. In a review of the average solid waste generation rate in 23 developing countries, Troschinetz and Mihelcic [5] quantified the average solid organic waste generation by each person to be 770 g d^{-1} and increasing. Biogas digesters have potential to treat this organic waste, greatly increasing the potential for application of organic wastes to soils. If increased recycling of organic wastes can be achieved through implementation of biogas digesters and application of the bioslurry produced, this could have a profound impact on C sequestration in the region.

Africa is one of the most vulnerable regions to climate change and climate variability in the world [6], and the IPCC recognizes that agricultural production and food security is likely to be severely impacted by climate change in many African countries [6]. Increased temperatures, more frequent droughts and floods, and increased climatic variability are all expected [7]. A significant proportion of the historical increases in soil temperature are attributed to losses of soil organic C. Globally, losses of soil organic C due to human disturbance are estimated to have contributed 11–35 $cm^3\ m^{-3}$ to the atmospheric carbon dioxide (CO_2) concentration from 1850 to 2000 [7], which in turn equates to a temperature increase of about 0.7 °C [8]. Widespread installation of biogas digesters could reduce greenhouse gas emissions by reducing C losses due to deforestation [9] and increasing C sequestration in the soil, both directly by increased C inputs and indirectly by increased plant inputs due to improved growth [10]. This, in turn, may help to reduce the contribution of human disturbance to climate change, but whether improved C sequestration in the soil is actually achieved depends on the alternative uses of the organic residues.

The rate of loss of soil organic matter tends to increase with increased temperature and moisture content of the soil, up to the point where the soil is so hot that micro-organisms cannot function, or the soil is so wet that oxygen supply limits microbial activity [11]. However, the inputs of plant material also tend to increase with temperature and moisture. Whether soils gain or lose C is a balance between increased rates of decomposition and increased plant growth, resulting in higher plant inputs. A global simulation of future changes in soil organic matter using the RothC model [12] predicts that in most regions of SSA, the organic matter content of the soil will increase over the next 100 years due to a climatically induced increase in plant inputs that counteracts the increased rate of loss due to increased temperatures. Only in the grasslands of the south and forest soils converted to arable in central regions is a decrease in soil organic matter due to insufficient gains or reductions in plant inputs predicted [12]. This suggests that these soils are capable of sequestering C, and a further increase in organic inputs by the recycling of organic residues could significantly increase the C content of the soils in SSA.

Organic residues are a limited resource in SSA that are used for a range of different purposes. Traditionally, cattle dung cakes [13,14] and other organic residues [15] have been dried and burnt as a fuel, leaving ash residues that do not greatly enhance the organic matter content of the soil [15]. Another traditional use is as a building material [16]; this application means that none of the C content of the organic residues is returned to the soil in the short term. If this organic residue was instead used to produce biogas, significant increases in C inputs to the soil are likely in addition to the provision of an improved household fuel supply (although the C impacts of replacement building materials should also be considered). However, with other uses, the impacts of diverting the organic residues to biogas production are not so easily determined. All of the C in the organic residues may be incorporated directly in the soil without prior treatment [17]. Organic residues can also be composted under aerobic conditions to provide an important organic fertilizer. A proportion of the organic C is lost during composting, but when composts are incorporated into the soil, increases in organic matter content are observed [18]. Some types of organic residues can be burnt in pyrolysis stoves or larger scale pyrolysis plants [19]. Pyrolysis occurs when organic materials are burnt under low oxygen conditions [20,21], releasing a proportion of the C as CO_2 or carbon monoxide, but leaving a highly resistant form of C, known as biochar, which can be further combusted or incorporated into the soil [22]. When biochar is incorporated into the soil, it is resistant to decomposition, and so sequesters C. Anaerobic digestion, incorporation of untreated residues, aerobic composting and pyrolysis all have potential to improve C sequestration by adding organic matter to the soil, but which method sequesters most C? A direct comparison is needed of the C sequestered using the same quantity and quality of