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Climate-change and health effects of using rice husk for biochar-compost: Comparing three pyrolysis systems

Ali Mohammadi [a,*], Annette L. Cowie [a,b], Thi Lan Anh Mai [c], Miguel Brandão [d,e], Ruy Anaya de la Rosa [f], Paul Kristiansen [a], Stephen Joseph [a,g,h]

[a] School of Environmental and Rural Science, University of New England, Armidale, NSW 2351, Australia
[b] NSW Department of Primary Industries, Beef Industry Centre, Trevenna Rd., Armidale, NSW 2351, Australia
[c] Thai Nguyen University of Sciences, Thai Nguyen University, Thai Nguyen Province, Viet Nam
[d] Department of Sustainable Development, Environmental Science and Engineering (SEED), KTH Royal Institute of Technology, Stockholm SE 100-44, Sweden
[e] Department of Bioeconomy and Systems Analysis, Institute of Soil Science and Plant Cultivation, Czartoryskich 8 Str., 24-100 Pulawy, Poland
[f] Starfish Initiatives, Armidale, NSW 2350, Australia
[g] Discipline of Chemistry, University of Newcastle, Callaghan, NSW 2308, Australia
[h] School of Materials Science and Engineering, University of New South Wales, Sydney, NSW 2052, Australia

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ABSTRACT

This study presents a comparative analysis of the environmental impacts of different biochar-compost (COMBI) systems in North Vietnam relative to the conventional practice of open burning of rice husks. Three COMBI systems, using different pyrolysis technologies (pyrolytic cook-stove, brick kiln and the BigChar 2200 unit) for conversion of rice husk into biochar were modelled. Biochar was assumed to be composted with manure and straw, and the biochar-compost produced from each system was assumed to be applied to paddy rice fields. Life Cycle Assessment (LCA) showed that the three COMBI systems significantly improved environmental and health impacts of rice husk management in spring and summer compared with open burning, in terms of climate change, particulate matter (PM) and human toxicity (HT) impacts. The differences between the three COMBI systems in the climate change and PM impacts were not significant, possibly due to the large uncertainties. In all systems, the suppression of soil CH_4 emissions is the major contributor to the reduced climate effect for the COMBI systems, comprising 56% in spring and 40% in summer. The greatest reduction in the HT impact was offered by the BigChar 2200 system, where biochar is produced in a large-scale plant in which pyrolysis gases are used to generate heat rather than released into the atmosphere.

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1. Introduction

Crop residue management can modify carbon (C) and nitrogen (N) dynamics and consequently induce significant changes in greenhouse gas (GHG) emissions, soil nutrients and crop productivity (Zhang et al., 2015). Vietnam is one of the largest rice-exporting countries with around 8 million ha of land under paddy rice (FAO, 2014), and in excess of 46 million tonnes (t) of rice residues (husk and straw) produced annually (Lim et al., 2012). These crop wastes constitute a potentially valuable resource, but most of these residues are not used, and their disposal often has negative environmental impacts. Open burning of rice straw and rice husk is still common in Vietnam despite being prohibited by the government (Pandey et al., 2014). Biomass burning in the field emits large quantities of gaseous and particulate pollutants to the atmosphere, which has a negative impact on the climate and the health of the population (Sanchis et al., 2014). Burning rice residues is particularly dangerous to human health since most of the particulate matter with a diameter of less than 10 μm (PM_{10}) is easily able to penetrate deep into the lungs causing respiratory and heart problems (Lee et al., 2007). Open burning of rice residues was also found to be an important source of polycyclic aromatic hydrocarbons (PAHs) which have significant toxicological properties and are potential carcinogens (Estrellan and Iino, 2010).

* Corresponding author. Tel.: +61 2 6773 2223; fax: +61 2 6773 3238.
E-mail addresses: amoham23@myune.edu.au, mohammadia2011@gmail.com (A. Mohammadi).

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In Vietnam, some rice farmers add rice straw to manure to make compost which is applied to paddy fields. Composting may be a preferable alternative to open burning of crop residues. It converts waste materials into stabilized organic fertiliser that can be used as a partial replacement or supplement for mineral fertilizers and fresh manure in agricultural activities (Malińska et al., 2014). Numerous studies have reported the benefits of compost application for improving soil quality and soil structure (Butler et al., 2001; Xin et al., 2016). However, compost production can have environmental costs, such as CO_2 emissions from fossil fuel use in transport, and methane (CH_4), nitrous oxide (N_2O) and ammonia (NH_3) emissions from methanogenic and denitrification processes during composting (Saer et al., 2013; Mulbry and Ahn, 2014).

Over the past decade, biochar, a solid product of thermal decomposition of biomass, has been demonstrated to be a promising option to improve soil properties as well as other ecosystem services, like storing carbon in soil for climate change mitigation (Lehmann and Joseph, 2015). Biochar use in rice cropping systems has been advocated as a potential way to reduce GHG emissions from soils (Liu et al., 2014; Qin et al., 2016), enhance soil C stocks and N retention (Liu et al., 2012) as well as improving soil function and crop productivity (Dong et al., 2013). Recent studies also show that biochar can enhance the composting process by improving aeration, as well as retaining nutrients and improving the quality of the end-product (Malińska et al., 2014; Sanchez-Garcia et al., 2015; Bass et al., 2016). Moreover, 52% reduction in N losses, which result largely through NH_3 volatilisation, have been achieved with the addition of pine chip biochar at 20% to composting poultry litter (Steiner et al., 2010) suggesting that biochar might be a suitable amendment for composting of N-rich waste materials. Emissions of N_2O were reduced by 31% where biochar made from bamboo was added at 3% wet weight basis (w/w) to a mix of pig manure, sawdust and wood chips prior to composting (Wang et al., 2013).

Biochar can be produced from various biomass sources at large industrial facilities, village scale and even at the household level using pyrolysis technologies that are commercially available. Pyrolysis technology converts crop residues into biochar which may have health benefits in addition to environmental benefits by offering a solution for reducing air pollutant emissions such as PM_{10}, PAHs and sulphur dioxide (SO_2) from open burning of biomass (Sanchis et al., 2014; Schweikle et al., 2015). Shackley et al. (2012) suggested that biochar technologies should be designed to ensure environmental and health safety, by minimising non-CO_2 GHG and soot emissions, that exacerbate climate change, and controlling emissions of dust and crystalline particles that affect human health.

Life Cycle Assessment (LCA) is a useful approach for estimating the environmental impacts of production processes and systems, i.e. through the product's entire life cycle. It is an internationally standardized methodology (ISO, 2006) that compiles an inventory of inputs and outputs involved in generating a product or a service, and investigates their potential environmental impacts. In order to evaluate the climate change effects of biochar, LCA has been applied to different feedstocks such as coarse wood chips and rice straw (Iribarren et al., 2012; Peters et al., 2015; Mohammadi et al., 2016b) and pyrolysis systems (Bailis et al., 2013; Scholz et al., 2014). A review of biochar LCAs found that biochar systems are generally estimated to provide emissions reduction in the range 0.4–1.2 t CO_2-eq t^{-1} (dry) feedstock (Cowie et al., 2015). Hammond et al. (2011) compared the GHG emissions abatement of biochar production for various pyrolysis technologies. They estimated that small-scale pyrolysis biochar systems are less efficient than large-scale systems at delivering carbon abatement because the small-scale system recovers less energy than the large-scale system. Sparrevik et al. (2013) used LCA to investigate the human toxicity and particulate matter emissions of producing biochar from maize cobs by different pyrolysis technologies. They found that top-lit updraft stoves that allow the use of the gas for cooking purposes improved the health impacts of biochar production relative to traditional earth-mound kilns without gas recovery.

Some authors have conducted LCA studies to investigate the climate effects of compost in paddy rice systems (Bacenetti et al., 2016) and vegetable production (Zhong et al., 2013). In contrast, LCA of applying a combination of biochar and compost to paddy soils has not been documented.

In this study, LCA was applied to estimate the climate-change and health impacts of using rice husk to make biochar that is added to buffalo manure and straw compost, and applied to paddy rice fields in Vietnam. Three alternative pyrolysis technologies are compared: pyrolytic cook-stove, brick kiln and the BigChar 2200 unit. The traditional practice of open burning of rice husk was modelled as a baseline scenario for all compost-biochar (COMBI) systems. In order to test the effects of uncertainty related to the parameters and variables used in the calculation of climate change impact, a sensitivity analysis was conducted on the three COMBI systems.

2. Materials and methods

2.1. Goal and scope definition

The goal of this LCA study is to evaluate the climate change and health effects of using rice husk to produce biochar that is co-composted with buffalo manure and straw for application to paddy fields during spring and summer seasons. Pyrolysis biochar systems were evaluated at small-, medium- and large-scale technologies estimated to process 2.6, 29 and 4670 t dry feedstock per year respectively. These three COMBI systems were compared between themselves, relative to the common baseline of biomass open burning, which is the most typical practice for rice husk management in North Vietnam, in order to evaluate alternative options for rice husk management.

2.2. Functional unit and system boundaries

The functional unit (FU) commonly used in LCA studies of biochar systems is mass of feedstock (e.g. 1 tonne of biomass residues) (Hammond et al., 2011; Ibarrola et al., 2012; Clare et al., 2015) or mass of a crop grown in biochar-amended soils (e.g. 1 kg of grain) (Liu et al., 2015; Mohammadi et al., 2016a). In this study, the FU is the management of 1 tonne of dry rice husk.

The system boundary included all processes from residue collection to soil application of COMBI amendment and assessed three different rice husk management systems. Biomass open burning, the conventional method of rice husk disposal, was considered as the baseline scenario for all systems and was included as an avoided process in each system. In all systems, rice husk is utilised to produce biochar which is then composted with buffalo manure and rice straw, and applied to soil. The three systems differ in the technology used for biochar production.

2.2.1. System A: biochar produced in a household level pyrolytic cook-stove

In this system rice husk is utilised in a small-scale pyrolytic cook stove where it is pyrolysed to produce heat for cooking as well as biochar for addition to composting mixtures (Fig. 1A). Wood (20% of the total feedstock mass) is used in the centre chamber of the stove to provide heat for pyrolysis and cooking purposes.

It is common practice that households in the research area use wood, in traditional three-stone cook-stoves (3S-stoves), and liquefied petroleum gas (LPG) stoves as their primary devices for

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