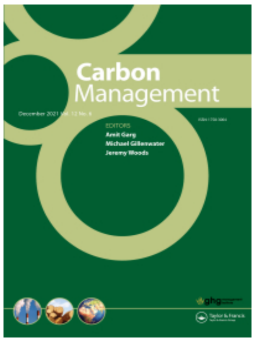

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Biochar as bulking agent for poultry litter composting

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Christoph Steiner[†,1], Nathan Melear[2], Keith Harris[2] & KC Das[2]

Bulking agents are used in manure composting in order to provide optimal bulk density and aeration of the composting mixture; they also have an impact on the quality of the final product. Biochar (carbonized organic materials) seems to have ideal properties for use as bulking agents. In this study, a significant increase in CO_2 respiration rates from poultry litter amended with biochar was found. The first respiration maxima increased by 44% and total respiration increased by 28%. The conversion of organic materials to either compost or biochar may depend on the nature of materials and both applications may supplement each other.

Composting of **manures** or sewage sludge require bulking agents for optimal composting [1–3]. Cereal straw, cotton waste and wood wastes are most frequently used as bulking agents and influence substrate properties such as pore space, moisture adsorption, carbon (C) to nitrogen (N) ratio, and particle density. Bioavailable C can reduce N losses during the composting of organic wastes with high-N concentrations [2], but may also have a negative influence on **compost stability** [4] and N availability, which may introduce N nutrition problems for organic farming systems [5]. Inorganic bulking agents do not decompose during the composting process and could be reused [3,6]. However, rubber chips from old tires used for sewage sludge composting could not adsorb sufficient water to maintain optimum moisture levels [3].

Biochar (**charcoal** for non-fuel use), the high-carbon solid residue from pyrolysis, is a highly porous material with high adsorptive capacity and might be an ideal bulking agent. Owing to its recalcitrance against decomposition, the availability of biochar carbon is limited for the microbial community [7]. Nevertheless, biochar was used to reduce N losses by volatilization from sewage sludge [8] and poultry litter (PL) [9–10] composting. Furthermore, biochar does not need to be separated from the compost again, as recent research has shown beneficial effects of biochar on soil fertility in addition to its nutrient value [11–13]. Dias *et al.* found intense humification in biochar-amended PL [9]. Since biochar can be a by-product from renewable energy production through pyrolysis [14–15], it might become available in larger quantities and carbon sequestration might favor its non-fuel use in soils and compost.

Our objective was to assess microbial activity by **respiration** (CO_2) measurements. We hypothesize that the use of biochar as bulking agent for manure composing will not reduce substrate availability and, thus, microbial activity.

Material & methods

Poultry litter is a mixture of accumulating manure and wood shavings used as bedding. The litter was obtained from a broiler house in North Georgia, USA in May 2008. Biochar was produced by pyrolysis of pine chips in a large batch reactor at 400°C using N_2 as a carrier gas. The carbonized pine chips had a C content of 758.7 g kg^{-1} and nutrient contents of 2.6 g N, 0.4 g S, 0.18 g P, 2.0 g K, 2.7 g Ca and 0.5 g Mg kg^{-1}. Pine-chip biochar was used as obtained without further modification or particle size separation. Particle size fractionation (by sieving) showed that 82% of the biochar was present in a particle size between 1.2 and 16 mm. The majority (54%) was found between 4 and 9.5 mm. Volatile matter, ash and fixed carbon contents were measured using ASTM D5142

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Key terms

Manure: Nutrient-rich organic matter used as fertilizer. Poultry litter is a mixture of feces and the bedding (organic fertilizer).

Compost stability: Moderate or low respiration characterizes compost stability. At this point respiration/mineralization is reduced.

Charcoal: The solid black residue after heating organic materials with limited oxygen supply. It was named biochar for non-fuel use for agricultural or horticultural purposes.

Respiration: Mineralization of carbon-rich organic materials measured as CO_2 flux.

(standard test method for coal, 2004) on a TGA 701 (thermogravimetric analyzer) from LECO (St. Joseph, MI) and are 32.2, 0.92, and 66.89%, respectively, based on dry weight (DW). Approximately 10 g of biochar was weighted into a 0.5 mm screen and soaked in deionized water for 24 h, after which the samples were allowed to drain for 1 h and the weight recorded. This procedure was performed in triplicate. The mean water-holding capacity of the biochar under these conditions ranged from 124 to 206% with a mean of 173%.

Three compost mixtures were prepared with PL and biochar in different mix ratios on a DW basis. Treatments included: 100% PL; 95% PL + 5% biochar; and 80% PL + 20% biochar. Each treatment was replicated three times and individual experimental bioreactors had approximately the same weight. Water was added to achieve a moisture content of 60% and the materials were mixed using a rototiller prior to placement in the bioreactors. The whole composting experiment of nine bioreactors was repeated three-times (lasting from June 2008 to January 2009).

A total of three replicates of each treatment were placed in nine bioreactors to undergo composting for 42 days. The bioreactors were insulated stainless-steel vessels with a diameter of 38 cm, depth of 39.5 cm and volume of 0.057 m^3. A detailed description of the experiment is provided by Steiner *et al.* [10] and more information on the bioreactors is provided by Das *et al.* [16]. Air was introduced every 20 min for a duration 30 s, providing an effective aeration of 0.0425 $m^3 h^{-1}$. The compost was homogenized once a week by removing the contents of the bioreactor into a clean wheel barrow and thoroughly mixing with a shovel. At this time, samples were taken for respiration measurements.

Respiration measurements

A sample of 10–15 g DW was placed in a sample bottle and then located into a water bath heated to 37°C. The headspace gas in the bottles was analyzed for CO_2 concentration at 2 h intervals for a period of 72 h using a computer-controlled respirometer (Micro-Oxymax, Columbus Instruments Inc.). The sample bottle and the gas analyzers are in a closed-circuit loop and headspace volumes and initial gas concentrations are measured automatically. The bottle was aerated with ambient air at a flow rate of 4 l m^{-3} each time the oxygen concentration changed by 5% within a sample interval. The air exiting the chamber was dehydrated by a condenser and condensed water returned to the samples. The procedure ensured a constant moisture content and temperature.

Only a very small fraction of biochar carbon (condensates from the bio-oil) are available to soil microorganisms for use as an energy source within a short timeframe [7]. This is supported by our own research with pine chip biochar produced at 400°C. This biochar was applied to a Tifton series (Fine-loamy, siliceous, thermic Plinthic Kandiudults) at 22 Mg ha^{-1}. Soil was wetted to 55% water-filled pore space and incubated at 25°C for 24 days. An unamended soil was used as a control. The mean cumulative, C, respired over 24 days from the biochar amended soil was 51.7 mg kg^{-1} soil while the control soil respired 43.4 mg kg^{-1} soil. The respiration rates of the two treatments were not significantly different ($p < 0.18$) based on student t-test. The soluble C concentration of the switchgrass biochar studied by Smith *et al.* was 3.4 mg g^{-1} biochar [7]. The pine-chip biochar used in this study contained only 0.13 mg g^{-1} soluble C [17]. Carbonized ryegrass decomposed at a rate of 0.5% per year under optimal conditions [18], whereas the carbon loss of PL during the experiment was approximately 40% [10]. Therefore, we assumed the biochar's supply of volatile solids (VS) is irrelevant and that biochar did not undergo significant decomposition. Under this assumption we calculated respiration rate based on PL (VS in mg-CO_2 g-PL^{-1} h^{-1}).

Statistical analysis

Treatment effects were analyzed by univariate general linear model in a randomized complete-block design. Significant differences between the treatments were marked by the least significant difference value ($p < 0.05$). Statistical analyses and plots were performed using SPSS Statistics 17.0 and SigmaPlot (SPSS Inc.).

Results & discussion

Respiration rates were higher in the treatments with 20% biochar additions (Figure 1). There is a direct relationship between volatile solids (substrate availability) and CO_2 respiration [19], but determining the extent to which biochar does mineralize in such an environment would need further investigation. However, the first respiration peak was significantly higher ($p < 0.05$) in the treatment with 20% biochar addition, compared with 5% addition and treatments without biochar (5.06, 4.32 and 4.38 $CO_{2\ mg}$ g^{-1} h^{-1}, respectively) even when the biochar mass was considered as VS and not deducted from the PL mass. The availability of oxygen during the process is of primary importance and the presence of biochar particles in the mix might decrease bulk density and increase aeration [20]. The microspores in the biochar may be responsible for adsorbing more moisture and the biochar particles may also provide some structure (secondary porosity) as expected from bulking agents.

The respiration not only peaked on a higher level, but also reached this peak faster with 20% biochar additions (Figure 1A). This indicates a better substrate availability and, thus, faster microbial population growth [21].

Conclusion & future perspective

Bulking agents are essential for enhancing aerobic conditions in manure composting. The recalcitrance against decomposition and ability to absorb moisture makes biochar an exceptional bulking agent. Although the carbon seems to be unavailable for the microbial population, biochar amendments do increase respiration rates owing to a better aeration of the compost mix. Other beneficial effects were described by Dias *et al.* [9] and Steiner *et al.* [10].

Carbonization could be a supplementary approach to biomass composting. The nutrient contents of biochars may be enriched by co-composting with nutrient-rich materials. Such applications were already recommended by Allen in 1846 [22]. In general, nutrient-rich materials or materials and high-moisture content make good compost, whereas materials with low nitrogen content are less suitable for composting. Woody materials are rather resistant to decomposition, require long composting times and additional N fertilization. Therefore, such biomass waste is frequently burned or is deposited

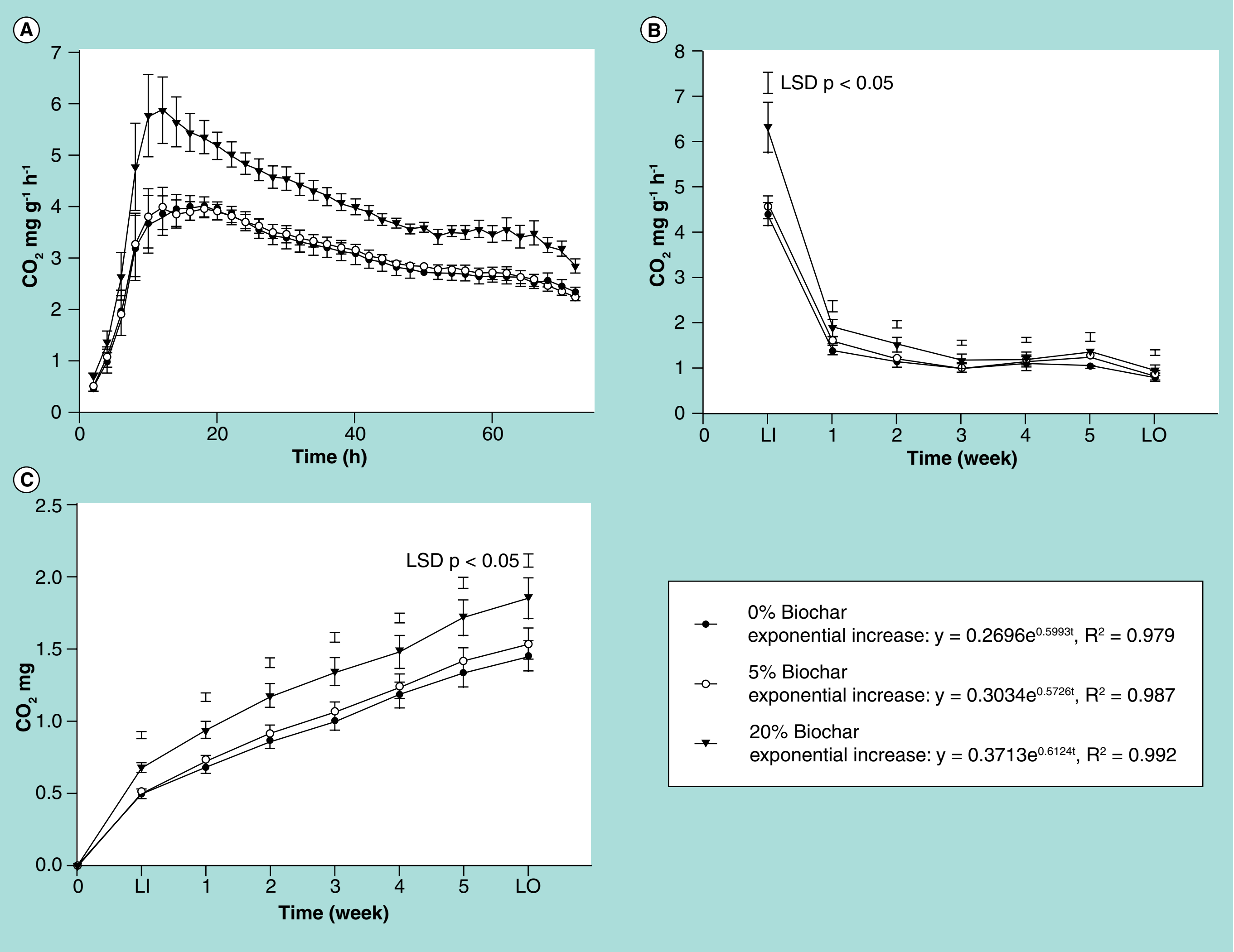

Figure 1. Respiration of poultry litter during composting with biochar as bulking agent. The respiration refers to poultry litter mass only (CO_2 per gram poultry litter per hour; n = 9; LSD $p < 0.05$). **(A)** Respiration curve over the first 72 h. The equation for the exponential increase is provided in the figure legend. **(B)** Respiration maxima after weekly sampling from the compost pile (3 h means). **(C)** Cumulative respiration calculated from the means in every week.
LSD: Fisher's least significant difference test.

in landfills. These biomass sources are ideally suited for biochar production and can either be mixed with compost or used as a bulking agent during composting. While N losses were reported from composting [23] and biochar production [17], the production of biochar from materials with low N content and its use as bulking agent for the compositing of N-rich manures may have important implications for a more efficient nutrient cycling and waste biomass utilization. However, biochar also has great impact on climate change, it transfers C from a labile into a long-lasting C pool.

Financial & competing interests disclosure

The authors have no relevant affiliations or financial involvement with any organization or entity with a financial interest in or financial conflict with the subject matter or materials discussed in the manuscript. This includes employment, consultancies, honoraria, stock ownership or options, expert testimony, grants or patents received or pending, or royalties.

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