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Khan, Naser, Clark, Ian, Bolan, Nanthi, Meier, Sebastian, Saint, Christopher P., Sanchez-Monedero, Miguel A., Shea, Syd, Lehmann, Johannes, Qiu, Rongliang "Development of a buried bag technique to study biochars incorporated in a compost or composting medium", Published in Journal of Soils and Sediments Vol. 17, Issue 3, p. 656-664 (2017)

Available from: <http://dx.doi.org/10.1007/s11368-016-1359-8>

This is a post-peer-review, pre-copyedit version of an article published in Journal of Soils and Sediments. The final authenticated version is available online at:

<http://dx.doi.org/10.1007/s11368-016-1359-8>

Accessed from: <http://hdl.handle.net/1959.13/1352901>

Special Issue: Biochar for a Sustainable Environment

Development of a buried bag technique to study biochars incorporated in a compost or composting medium

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Abstract

Purpose: The purpose was to develop a netbag technique suitable for burying biochar in a compost or composting medium, followed by its collection in a clean state (i.e., free of compost debris) without loss or damage, for physicochemical analyses. Collection in a clean state is required to ensure that the analytical data of various biochars are representative and comparable. Five criteria were identified to evaluate the suitability of netbag.

Materials and methods: A small netbag (3.5 cm x 3.5 cm) was developed using nylon fabric (30 µm mesh) to contain ~1 g of biochar. A production system was developed to make fifteen netbags per batch. Unlike commonly used litterbags, polypropylene was used to seal netbags. Two experiments were conducted in which three biochars, made from macadamia nutshell, hardwood shaving and chicken litter, were co-composted with chicken manure and sawdust, and also incubated with a chicken litter based commercial compost. Biochars were added at the rates of 5 or 10% in the co-composting, and 10 or 20% in the incubation experiments. The biochar containing netbags were buried in the co-composting and incubation mediums for 133 days. Various physicochemical analyses were conducted with netbag-biochars and their compost mediums.

Results and discussion: The netbags collected after both experiments showed no visible sign of degradation. The weight of netbag biochars from co-composting and incubation systems did not reduce significantly over the experimental period thereby indicating no loss of biochar. No visible evidence of entry of solid particles from compost medium, was found on the netbag-biochars. Pretests indicated that the netbag and biochars absorbed pore solution from the medium. Findings showed that elements translocated between the netbag-biochar and compost medium. A colony of coccus bacteria was found on the surface of composted chicken litter biochar, denoting probable entry of bacteria from compost medium. Unlike conventional litterbags, the netbags were suitable for burying and extracting biochar in compost/ing mediums due to smaller size, smaller mesh, and strong sealing with polypropylene.

Conclusions: The netbags addressed all the five criteria. Therefore, it was concluded that, in the co-compost or incubated-compost medium, the biochar retained in the netbag, and the biochar mixed with the medium were exposed to a similar bio-oxidative environment, and that netbag-biochar represents the biochar in the medium. This means, these netbags can be used as a convenient means to examine the effect of the composting process or incubation in compost on biochar.

Keywords Compost • Incubation • Litterbag • Method • Microbe • Nutrients

1 Introduction

The performance of biodegradation of organic matter varies with the types of microorganisms and their population size. Bacteria, fungi and actinobacteria are the three main microbial groups involved in the biodegradation of organic matter (Insam and De Bertoldi 2007; Minz et al. 2010, references therein). Cellulose in organic matter is degraded by these three groups, while lignin is mainly degraded by fungi (white rot fungi) (Insam and De Bertoldi 2007). To ensure microbial growth, a sufficient level of moisture must be maintained in the composting medium. In general, a moisture level of 60% is satisfactory while initiating a composting process, and it should be maintained over 40% during the composting period (Diaz and Savage 2007). A number of conditions such as physical state, size of the feedstock particles, and type of composting medium determines the optimal moisture content required in the compost starting materials (Diaz and Savage 2007). Microorganisms will vary in their activities depending on the temperature in a composting pile. The microorganisms are active only at the solid-water interface. Composting breaks down ligno-cellulose materials into smaller humic-like organic molecules, and releases inorganic nutrients (major, minor and trace). The compost pore solution contains soluble organic carbon and inorganic solutes, which are subject to mass flow and diffusion.

Biochar, a recalcitrant carbonaceous material, commonly possesses a surface that is physically and chemically reactive due to its high microporosity, and content of various reactive functional groups (Brennan et al. 2001; Kookana et al. 2011). The micropores may sorb air and common solvents (Rouquerol et al. 1999) including moisture (Pietikäinen et al. 2000; Thies and Rillig 2009). Thus, it provides a suitable habitat for various microorganisms (Ogawa and Okimori 2010; Solaiman et al. 2010). Both the biochar (Mohan et al. 2014) and compost (Bolan et al. 2011) are known to sorb trace metals. During its co-composting with another feedstock or incubation with a compost, the surface pores of biochar particles may absorb some dissolved chemicals released during the composting process; whereas its functional groups may bind organic and inorganic chemicals. Bamboo biochar was found to reduce mobility of Cu and Zn and emission of N while being co-composted with sewage sludge (Hua et al. 2009). A bio-oxidative environment and an increase in pH in a composting pile may increase its CEC (Borchard et al. 2012).

As noted above biochar co-composted with biowastes, and incubated with matured compost will undergo physical and chemical changes. The following literature on forceps and litterbag methods, however, shows that it is difficult to extract a sufficient amount of clean biochar (i.e., without deposition of compost particles on biochar surfaces) from such mixtures without damage to perform quantitative analyses of a wide range of physical and chemical properties.

Liang et al. (2006) used super tweezers under a transmitting-light microscopy to extract biochar particles (10 - 150 μm) from anthrosols. It was easy for Prendergast-Miller et al. (2011) to separate biochar (0.5 - 2.0 mm) from rhizosphere soil, which was sandy and light textured. They used a sieve to remove the majority of sand and then fine forceps to remove the biochar fragments that were easily visible against the light texture of the soil (Prendergast-Miller 2012). Hua et al. (2009) removed co-composted biochar (coBC), presumably using forceps, after composting was over (Pers. Comm. Wu, 2011). However, coBC particles extracted in this manner from compost are unlikely to be clean as some tiny non-biochar compost particles can remain stuck to their surface. Prendergast-Miller et al. (2011) cleaned the biochar surface by gentle use of a small brush; the sand particles were easily removed as they were not sticky (Prendergast-Miller 2012), but, as noted above, compost residues may stick to biochar surfaces strongly and brushing them off may damage the surfaces. Compost residues deposited on coBC or incubated biochar (inBC) would significantly change the physical and chemical data causing an error, which would be incomparable with that of initial or clean biochar. Moreover, extracting and cleaning (by brushing) coBC or inBC have been a difficult and time consuming task in this research, as a large amount of sample was required from each pile, while there were six composting piles and six incubation piles.

Litterbags are commonly used to study decomposition rates (i.e., mass loss) of plant litter such as leaves, on/in soil profile (Bärlocher 2007; Kurz-Besson et al. 2005). However, the mesh size of these conventional litterbags is generally large as the plant litter particles, unlike biochar particles, are large. Therefore, the conventional litterbag is not suitable for this research. Since the bags in this research contained biochar, which is not litter, a more generalized term 'netbag' is used in this paper. Wardle et al. (2012; 2008) used a netbag (100 μm x 1000 μm) containing a shrub-derived biochar (> 500 μm); the bags were buried in soil for 10 years before analysis. Recently, Prost et al. (2013) used a polyester based netbags (dimension 15 cm x 15 cm; mesh 125 μm ; biochar particle size 125 μm to 2 mm, weight 50 g) in a composting environment. This was the only example found, where biochar-containing netbags were buried in a composting pile. Some other studies (Anderson and Swift 1983; Bärlocher 2007; Dalias et al. 2003; Domene et al. 2014; Weyers and Spokas 2014) were noted for litterbag design, which were used in soil medium; but none of them appeared to be suitable for this research.

To overcome the shortcomings of conventional litterbags, smaller netbags with smaller mesh can be used to incorporate biochar in the compost/composting medium. However, to be suitable for co-composting of biochar and quantitative analyses, the netbags must:

- (i) not decompose in the composting environment,
- (ii) prohibit escape of biochar particles from inside,

- (iii) prohibit access of compost material of significant size,
- (iv) allow free access/exit of compost pore solution (Diaz and Savage 2007), and
- (v) allow free access/exit of composting microorganisms matter (Insam and De Bertoldi 2007; Minz et al. 2010, references therein).

The above criteria are important as they ensure that the netbag-biochars will experience a composting environment that is the same as that of the biochar which is external to the netbag and mixed in the compost or composting medium. However, no well-described method was found in the literature that was suitable for the production of netbags for the biochar-composting medium.

The objective of this research was to make a netbag that is suitable for burying biochar in compost or a composting pile, and extract it non-destructively after a period in a clean state. A netbag must fulfill the criteria noted above to be suitable. During this study, a nylon netbag was developed to suit a biochar-compost/ing system by modifying the design of conventional litterbag. Compared to conventional litterbag, this netbag is smaller in size (~1 g) so that microorganisms and compost pore solution can reach all biochar particles in the bag; it has smaller mesh (30 μm) to inhibit entry of significant amount of compost debris inside the bag, and to completely inhibit loss of biochar particles from the bag; and it is sealed strongly with polypropylene to keep the bag intact while a compost pile is turned.

2 Materials and methods

2.1 Selection of a fabric and sealing method for netbag

As noted in the two examples above (Borchard et al. 2012; Wardle et al. 2008), a fabric made of polyester or nylon can be used to construct a netbag. Since polyester fabric can be hydrophobic, it may affect, even if slightly, the free flow of pore solution across the net. Nylon is naturally hydrophilic and wettable, thus it would allow free movement of pore solution across the net. Strong microbial oxidation reactions take place during a composting process, which nylon can resist for a short period. It has been noted above that a nylon netbag containing biochar was buried in forest soil for 10 years followed by their successful recovery (Wardle 2012; Wardle et al. 2008). Deguchi et al. (1997) found that nylon degradation by white rot fungi, e.g., IZU-154, could be significant when there is a shortage of labile C and N in the medium. However, there would be an ample supply of labile C and N (Minz et al. 2010) in the chicken manure based compost or composting mediums during the short-term (133 days) experiments planned for this research. Therefore, nylon appeared to be a suitable fabric for the buried bag technique.

The process of composting produces humic substances that are within or below the colloidal size range. A fraction of humic substances, produced during composting, would dissolve in compost pore solution. A 30 μm mesh fabric was chosen for this research as it was large enough to

allow dissolved humic substances, dissolved organic carbon and most of the composting microorganisms to move across the net (**Table 1**). It was assumed that 30 μm was small enough to avoid significant access of solids from compost or composting medium to netbag.

Table 1 Size of microorganisms and organic chemicals in a composting medium.

Microorganism/particle	Size	Reference
Bacteria (spheres, rods and filaments)	1 - 8 μm	(Dalzell et al. 1987)
Fungi	Hyphae diameter: 3-50 μm	(Dalzell et al. 1987)
	Hyphae diameter: 10-50 μm	(Haug 1993)
	White rot fungi have a hyphae diameter of < 5 μm according to scanning electron micrographs.	(Dutton et al. 1993)
	*Fungi cannot move but its hyphae can grow in length for several centimeters.	
Actinobacteria	Filament diameter: 0.5 - 2 μm	(Dalzell et al. 1987)
Algae	10 - 100 μm	(Dalzell et al. 1987)
Protozoa	5 - 80 μm	(Dalzell et al. 1987)
Dissolved organic carbon	< 0.45 μm	(Chefetz et al. 1998)
Humic substance	< 1 μm	(Stevenson 1994)

To prevent any escape of biochar particles from a netbag with 30 μm mesh, biochar particles larger than 425 μm were used in this study. Since biochar is mainly made up of aromatic compounds (Glaser et al. 2002) only a negligible decay (Kuzyakov et al. 2014) would occur to its particles over the composting period. A large thick (i.e., fat) bag might inhibit pore solution and also the microorganisms from the biochar particles at the center of the bag. Therefore, a small thin bag was used for this research. Moreover, it was assumed that confinement of biochar in a ‘small volume’ would help in maintaining a uniform microclimatic condition inside the netbag, and that condition would be similar to that of the compost/composting medium.

Wardle (2012) suggested that a netbag could be either stitched or heat sealed. Dalias et al. (2003) described a method of making a multi-compartment litterbag by wrapping the fabric around a wire and plastic frame. This appeared to have no sealing, and was suitable for placing only on the soil surface. In our study, the composting pile required periodic turning. Therefore, heat sealing was preferred to stitching as the latter could result in weak joints that might break during the turning of the compost pile.

Thus, a nylon netbag of 30 μm appeared to be appropriate for this research. It was assumed that the biochar particles inside a 30 μm nylon netbag of small size would experience a biophysicochemical environment that is the same as that of the biochar particles outside the bag. A conceptual diagram of interactions between compost medium and biochar is presented in Fig. 1.

Fig. 1 A conceptual diagram of interchanges of elements and other components between compost medium and biochar that is placed in a nylon netbag. This image has been adapted from Khan et al. (2016). (i) compost or composting medium, (ii) nylon netbag (mesh 30 μm) and (iii) co-composting or incubating biochar (>425 μm).

Prior to making netbags in large numbers, two pretests were conducted to verify movement of compost pore solution. In the first pretest, a nylon netbag (mesh size 200 μm) containing dry biochar, was buried for 48 hours in wet compost (60% moisture). A second pretest was conducted by burying a nylon netbag (mesh size 30 μm) containing dry biochar, for 10 days in a wet compost.

2.2 Netbag making

Fifteen netbags (3.5 cm x 3.5 cm) were prepared in each batch from a pair of sheets of nylon fabric (23.5 cm x 16.5 cm, Fig. 2a). Thick polypropylene sheet protector, due to its low melting point, was used as a heat sealing material. Initially, each netbag was sealed at three sides. The open side was sealed after filling it with ~1 g of biochar that was previously dried at 40 °C. Plastic tags, bearing identification numbers, were attached to some designated netbags using nylon zip ties (Fig. 2b). The nylon zip ties were placed between two parallel lines of seals to avoid dislodgment from the netbag due to frictions as a result of rotation of the composting pile.

Fig. 2 (a) Fifteen netbags were produced in each batch; (b) a tagged netbag filled with ~1 g of biochar; and (c) a nylon netbag extracted from composting pile.

The steps of making of netbags are described below.

1. Microsoft Publisher 2010 was used to develop the main netbag template shown in a supplementary file (SF) as Fig. SF 2. This template is made available as a PDF for printing on a standard paper (A4, 100 gsm). This template was used to develop three printed templates: Template 1 to cut the nylon net sheet as shown in supplementary figure (Fig. SF 3a), Template 2 to hold and align a nylon sheet inside a clear plastic sheet protector (Fig. SF 3b, c), and Template 3 to hold the plastic sheet protector and a pair of nylon sheets for heat sealing (Fig. SF 4a-e). These three templates were pasted on cardboard for strength.
2. Nylon net sheets were cut into small pieces using Template 1 (Fig. SF 3a).
3. A pair of nylon net sheets were placed in a clear plastic protector sheet (Fig. SF 3c - d).
4. The protector sheet (along with the pair of nylon net sheets) was set on Template 3 (Fig. SF 4b).
5. The pair of nylon net sheets were sealed along red lines using a common heat sealer (Fig. SF 1, Fig. SF 4c - e); heating was repeated on each line three times to ensure a sufficient amount of

plastic material of protector sheet melted, and subsequently entered the pores of the nylon net. Heating along the red lines resulted in the sealing of three sides of each of fifteen netbags.

6. Individual netbags were cut out using scissors (Fig. 2a, b).

7. Protector sheet was removed from netbags (Fig. 2b, c) using small scissors; but protector sheet along the green line (Fig. SF 4e) was left intact for later sealing.

8. A hole was punched at one corner of the netbags to fit tags using a nylon zip tie (Fig. 2b). This was followed by weighing of the netbags (W_1).

9. The netbags were filled with ~1 g dry biochar (40 °C). This was followed by weighing of the netbags (W_2). Therefore, the weight of initial biochar in a netbag, $W_x = W_2 - W_1$.

10. The top (along the green line) of netbags were heat sealed (Fig. SF 4f). Extra tape of sheet protector was used to seal the top line, when required. All remaining protector sheet was removed from netbags using scissors. The netbags were then incorporated in a composting or compost pile in the co-composting or incubation experiment, respectively.

After extracting from a compost pile, the netbags were gently brushed to remove compost residue. This was followed by weighing of the netbags (W_3). Then the netbags were partially cut near one edge, and biochar was taken out. This was followed by weighing of the empty netbags (W_4). Therefore, the weight of composted or incubated biochar in a netbag, $W_y = W_3 - W_4$.

2.3 Co-composting and incubation experiments

A co-composting and an incubation experiment were conducted in which the buried bag technique was applied. The co-composting experiment has been detailed in Khan et al. (2014). In short, three different biochars, made from macadamia nut shell (MS), hardwood shavings (WS) and chicken litter (CL) were co-composted with chicken manure and pine sawdust in plastic vessels (pile ~125 L; vessel ~153 L). Biochars were added at the rates of 5 and 10% (wet weight) in the co-composting mixture. Accordingly, the composting piles were labeled as coMS5, coMS10, coWS5, coWS10, coCL5 and coCL10. For an easy collection of coBC, ~1 g of an initial biochar (425 – 2360 μm) was sealed in each of nylon netbags (30 μm). Thirty four netbags were placed in each of 6 composting piles; 5 netbags had tags to determine the change in weight of netbag-biochar. The composting piles were turned on weekly basis. The maturity indices temperature, dissolved organic carbon, germination index, C:N ratio, Solvita[®] maturity index, and $\text{NH}_4^+\text{-N}:\text{NO}_3^-\text{-N}$ ratio showed that the composting ended by day 126 (Khan et al. 2014). Therefore, the netbags were extracted after a week i.e., day 133.

The incubation experiment has been detailed in Khan et al. (2016). In brief, the three biochars mentioned above were incubated with a commercial compost (Neutrog Australia Pty Ltd) made

from wood shaving based chicken litter in plastic vessels. Biochars were added at the rates of 10 and 20% (dry weight) in the incubation mixture. Accordingly, the incubation piles were labeled as inCNT, inMS10, inMS20, inWS10, inWS20, inCL10 and inCL20. Biochars were also buried in nylon netbag as mentioned above. The incubating piles were turned on weekly basis. The netbags were harvested on day 133.

2.4 Physical and chemical analyses

The initial and final weights of biochar in tagged netbags were measured to determine decomposition of biochar over the period of composting or incubation. Various chemical analyses were conducted using the initial BCs, coBCs, inBCs and compost medium samples collected from both experiments. These included pH, EC, and total element contents of C, N, P, K, S, B, Ca, Mg, Cu, Mn, Mo and Zn. The initial BCs, coBCs and inBCs were analyzed for specific surface area (Brunauer-Emmett-Teller, BET) and pore volume (Barrett-Joyner-Halenda, BJH). The methods of these analyses are described in Khan et al. (2014). Total elements (P, K, S, B, Ca, Mg, Cu, Mn, Mo and Zn) of samples were measured by ICP-OES after microwave digestion of 0.1 g of oven dried sample with 4 mL 69% HNO₃ and 1 mL 33% H₂O₂ (Sparks et al. 1996). The cation exchange capacity (CEC) of initial BCs, coBCs and inBCs sample (1 g) was determined by the BaCl₂ compulsive exchange method (Gillman and Sumpter 1986). Since the coBCs and inBCs were sieved at 425 - 2360 µm prior to filling the nylon bags, initial BCs were also subjected to the same sieving prior to CEC measurement. Scanning electron micrographs (SEM) of microorganisms on biochar samples were obtained using a FEI Quanta 450 FEG environmental scanning electron microscope equipped with an energy dispersive X-ray spectrometer. Samples were mounted on an aluminum stud using carbon tape for imaging.

3 Results and discussion

Fig. 2 shows the images of fifteen netbags that were produced per batch (a), a tagged netbag containing biochar (b), and a netbag extracted from a composting pile (c). The netbags collected from the co-composting (**Fig. 2c**), and the incubation experiment showed no visible sign of degradation; this addressed the criterion (i) (Section 1). This means that the netbag fabric mesh size (30 µm) remained unchanged, indicating that the biochar particles would not escape from the bag. The weight of netbag coBC and inBC did not reduce in the co-composting experiment and incubated experiment, respectively (Fig SF 5); this addressed the criterion (ii) (Section 1).

This netbag is probably the first example of a litterbag where plastic material (polypropylene) was used to seal the sides. The netbag seals remained intact throughout the composting period.

There was an advantage of heat sealing: it was easy to seal the last open side of tightly-filled netbag.

Fig. 1a shows an image of an aggregate formed by non-biochar compost particles (compost residues) and inBC; this image was taken at the end of the incubation experiment. Fig. 1b shows some compost residues deposited on coBC particles that were collected later from one of the co-composts produced. However, Fig. 1c shows no sign of non-biochar compost particles on coBC particles that were collected from a netbag after 133 days of composting period. This means that non-biochar compost particles of significant size did not enter the netbag from the compost or composting medium; this addressed the criterion (iii) (Section 1).

Fig. 1 (a) An image of an aggregate formed by non-biochar compost particles and incubated hardwood shaving biochar; this was collected from biochar-compost medium where wood shaving based chicken litter compost and hardwood shaving biochar were mixed and incubated for 133 days; (b) sample collected from co-composted medium (i.e., external to netbag) after 133 days of composting shows non-biochar compost particles deposited on biochar surfaces (Olympus Microscope XZX12); (c) sample collected from a nylon netbag shows clean biochar particles (hardwood shaving); the netbags were placed in co-composting medium for 133 days.

The first pretest, which was conducted to verify movement of compost pore solution, showed that the weight of the netbag (200 μm) increased from 1.9362 g to 2.2664 g (by 17.1%), after 48 hours in wet compost. The second follow up pretest showed that the weights of nylon netbag (30 μm) and biochar, after burial in wet compost for 10 days, increased by 20% and 24.39%,

respectively. These results indicate that the netbag and/or biochars absorbed pore solution which addressed criterion (iv) (Section 1).

The findings in regard to elemental translocation and modification in CEC are detailed in Khan et al. (2016). However, the summary of the findings is presented below. The CEC of composted hardwood shaving biochar, and composted chicken litter biochar increased 6.5 and 2.2 times, respectively, in the co-composting experiment (Fig. SF 5). This showed that composting affected CEC of netbag-biochars probably by thermophilic oxidation.

The biochar C demonstrated recalcitrance in both composting and incubation mediums (Fig. SF 5 and Fig. SF 6). The weights of netbag-biochars were generally increased over 133 days of composting and incubation (Fig. SF 5). Significant correlations have been found between % increase of weight of coBC ($r = 0.93$, Pearson; $p = 0.007$) or inBC ($r = 0.53$, Pearson; $p = 0.281$) and their C content. The minimum size of biochar particles used in this study was $0.429\ \mu\text{m}$. But, it is now clear that biochar of smaller size, such as $100\ \mu\text{m}$, will not slip out of a netbag that has a mesh size of $30\ \mu\text{m}$, as the biochars are recalcitrant.

Translocation of elements, between netbag-biochar and compost or composting medium, occurred in both directions (Fig SF 6). In most cases, biochars gained elements under the influence of a positive difference of concentrations (i.e., when compost or composting medium had higher concentration of elements than biochar), while in some cases they lost elements despite a positive difference. Biochar lost some elements (WS: B; coCL: B, Mg and S) under the influence of negative difference of concentrations during co-composting experiment. Hardwood shaving and macadamia nut shell biochars generally showed a strong affinity for N and S: the concentration of these elements gained by biochars surpassed the concentration in the respective compost or composting medium. The material difference in the biochars did not have an influence on N retention: the netbag-biochars generally increased their N content. Therefore, in addition to pretests for moisture access to netbag, the translocation of elements addressed the criteria (iv) (Section 1).

The SEMs in Fig. 2 depict comparative dimensions of microorganisms and mesh size ($30\ \mu\text{m}$) of nylon netbag. Fig. 2a-c shows SEMs of microorganisms in biochar-compost medium, in which macadamia nutshell was mixed with commercial compost. These three micrographs show dense colonies of various types of microorganisms. From the size and shape they can be identified as bacteria (cocci, rod and filamentous) and fungi. Fig. 2e shows a thin population of coccus bacteria on the surface of (non-netbag) incubated BC (made from hardwood shaving) collected from the compost medium. This thin population may be attributed to the low pore volume ($0.011\ \text{cm}^3\ \text{g}^{-1}$) of incubated BC, which means that the BC surfaces did not provide good habitat (refuge) for the microorganisms. Fig. 2d shows SEM of a colony of coccus bacteria on the surface of composted

BC (made from chicken litter) collected from netbag. It is possible that this colony pre-existed on the biochar surfaces. However, no such colony was found on initial biochar surfaces. Therefore, it is more likely that the bacteria entered the netbag from compost medium; this addressed the criterion (v) (Section 1). Wainwright et al. (2002) found that bacteria could pass through small pores (0.2 μm) of nylon membrane. Composting microorganisms use dissolved oxygen for respiration. It is likely that compost pore solution entering the netbags carries dissolved oxygen to the microorganisms living on the netbag-biochar surfaces.

Fig. 2 Scanning electron micrograph of colonies of microorganisms in (a), (b) and (c) biochar-compost medium, in which macadamia nutshell was mixed with commercial compost; (d) incubated BC (made from hardwood shaving) collected from biochar-compost medium; and (e) composted BC (made from chicken litter) collected from netbag. The samples in (a) to (d) were collected from the incubation experiment and (e) from the co-composting experiment. The dimension ($30\ \mu\text{m} \times 30\ \mu\text{m}$) of each of the images (a-d) is equivalent to the mesh size ($30\ \mu\text{m}$) of nylon netbag.

4 Conclusions

The objective of the development of buried bag technique was to make a netbag that is suitable for burying biochar in compost or composting pile followed by its extraction after several months in a clean state without damage or loss. A netbag was made using nylon fabric of 30 μm mesh to contain ~ 1 g of biochar. A simple production method was developed to make fifteen netbags per batch. The biochar containing netbags were buried in co-composting and incubation systems for 133 days. Five criteria were identified to justify the suitability of the netbag. Performance of netbags was evaluated in composting and incubated systems. After harvesting the netbags from these systems, it was found that all the five criteria were met. Therefore, it may be concluded that, in the co-compost or incubated-compost medium, the biochar retained in the netbag and the biochar mixed with the medium were exposed to a similar bio-oxidative environment. This means, the netbags can be used to examine the effect of composting process or incubation in compost on biochar. Unlike conventionally designed litterbags, the netbags were suitable for burying and extracting biochar in compost/ing mediums due to smaller size, smaller mesh, and strong sealing with polypropylene.

Acknowledgement

Publication of this article was supported by a scholarship awarded to Naser Khan by the Centre for Environmental Risk Assessment and Remediation (CERAR), University of South Australia, Australia. The authors are grateful to Mr. Peter Wadewitz of composting organization Peats Soils of South Australia for their invaluable collaboration. The authors also express their gratefulness to Dr. Joe Herbertson of The Crucible Group of New South Wales for providing one of the biochars.

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