Optimising green roof substrate weight and water retention using biochar

Optimisation du poids et de capacité de stockage des substrats des toitures végétalisées à base de Biochar

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RÉSUMÉ

Les toitures végétalisées sont de plus en plus utilisées pour réduire le ruissellement des eaux pluviales générées par l'imperméabilisation des sols. Afin de maximiser la rétention des eaux pluviales, on préconise la mise en place de substrats profonds et de plantes à haute consommation en eau, pouvant ainsi maximiser le volume disponible pour stocker l'évènement pluvieux. Cependant, un substrat épais augmente la masse de l'installation, et limite l'installation de toitures végétalisées sur les bâtiments existants. De plus, les plantes à forte consommation d'eau sont sensibles au stress hydrique. Le biochar constitue un amendement pouvant alléger le substrat tout en augmentant sa capacité de rétention hydrique. Cependant, en fonction du bois choisi comme matière première, la capacité de rétention du biochar peut fortement varier. Cela s'explique probablement par la structure cellulaire des diverses matières premières qui influent sur la structure des pores du biochar. Nous avons évalué 18 types de biochar fabriqués à partir de différents bois d'eucalyptus et avons relié la quantité d'eau disponible pour les plantes à la structure cellulaire du bois utilisé. En utilisant un bois de faible densité dont les cellules ont des lumières au diamètre élevé et des parois fines, nous avons obtenu une plus grande quantité d'eau disponible pour les plantes et un biochar plus léger qu'à partir d'un bois à haute densité. Il est ainsi préférable d'utiliser du biochar produit à partir de bois à faible densité comme substrat pour les toitures végétalisées, afin de réduire la masse du substrat, d'augmenter la rétention des eaux de pluie et de réduire le stress hydrique des plantes durant les épisodes de sécheresse.

ABSTRACT

Green roofs are increasingly used to reduce stormwater runoff from impervious surfaces in cities. To maximise rainfall retention, greater substrate depth and high water-using vegetation are desirable to replenish the storage between rainfall events. However, greater substrate depth increases the system weight, limiting the potential for green roofs to be built on existing buildings and high water-using vegetation is susceptible to water stress. Biochar is a substrate amendment which can decrease substrate weight whilst increasing its water holding capacity. However, biochars differ greatly in their ability to retain water due to the feedstock wood material. This is likely due to differences in feedstock cell structure influencing biochar pore structure. We evaluated 18 biochar types made from different *Eucalyptus* wood and related plant available water capacity to wood density (a proxy for cell structure). Biochar made from low density wood with greater cell lumen diameters and thinner cell walls retained greater amounts of plant available water and was lighter than biochar made from high density wood. Therefore, low density wood biochar is preferable for green roof substrates to reduce substrate weight, increase stormwater retention and reduce plant water stress during dry periods.

KEYWORDS

Biochar, *Eucalyptus*, green roof, plant available water, wood density

1 INTRODUCTION

Urbanisation and its associated infrastructure results in increased imperviousness, leading to greater surface runoff and decreased evapotranspiration, causing flooding and increased city temperatures. Green roofs are a proven green infrastructure tool to mitigate these negative effects by reducing stormwater runoff volume and increasing cooling through evapotranspiration (Stovin et al., 2015). Greater stormwater runoff reduction can be achieved by increasing green roof substrate depth (Berghage et al., 2009) and evapotranspiration can be increased by using vegetation with high water use (Farrell et al., 2013). However, greater substrate depth makes green roofs heavy, reducing their retrofitting potential on existing roofs (Wilkinson and Reed, 2009). While vegetation with high water uptake rates results in more rapid drying of substrates, causing increased plant water stress (Farrell et al., 2013). Therefore, designing light-weight green roof substrates with greater plant available water is key to improve green roof hydrological function and encourage widespread uptake.

Biochar is a light-weight product of pyrolysis (heat treatment under oxygen depleted conditions). Biochar added to green roof substrates at 30-40% by volume has been shown to increase plant available water, whilst reducing substrate weight (Cao et al., 2014). However, biochars differ greatly in their properties due to differences in feedstock and processing method (Sohi et al., 2010). The most commonly used feedstock for biochar production worldwide is hardwood (IBI, 2015). However, there is great variation amongst different hardwood species regarding their cell structure and density. Generally, hardwoods with greater wood density have smaller cell lumen diameters and thicker cell walls (Zieminska et al., 2013). This feedstock cell structure is retained in the pore structure of the resulting biochar (Wildman and Derbyshire, 1991) which will likely affect water availability for plant uptake. Plant available water is determined by pore size, with pores between 0.2 µm and 50 µm storing water which can be extracted by plants. Whereas, water held in pores < 0.2 µm is held too tightly and pores > 50 µm drain under gravity (Horn et al., 2010). Therefore, we hypothesised that differences in feedstock wood density, as a proxy for cell structure, would result in differences in plant available water and bulk density (weight) of biochar.

2 MATERIALS AND METHODS

We measured wood density of 18 *Eucalyptus* species, grown in a common garden experiment at the Burnley campus of the University of Melbourne/Australia, by using a X-ray densitometer (Silviscan3) (Evans et al., 2000). Wood samples were then pyrolysed at 550 °C (± 50 °C) in an industrial, batch-pyrolyser (MPP20, Earth Systems Pty., Melbourne, Australia). Following pyrolysis, each biochar sample was manually crushed and standardised to ensure that they all had the same particle size distribution and their physical properties including plant available water and bulk density were measured. Plant available water was calculated as the difference between the volumetric water content at field capacity (-10 KPa) and at permanent wilting point (-1500 KPa). Field capacity was measured on a tension table according to the method described by Carter and Gregorich (2008) and permanent wilting point was determined by the filter paper method described by Greacen et al. (1989). The bulk density of the biochar samples was determined according to the Australian Standard for Potting Mixes (AS 3743-2003) as described by Cao et al. (2014).

3 RESULTS AND DISCUSSION

Wood density of the feedstock material was strongly correlated with biochar plant available water (Figure 1). Therefore, to reduce plant water stress and increase green roof rainfall retention, we recommend the use of biochar made from low density woods as an amendment in green substrates.

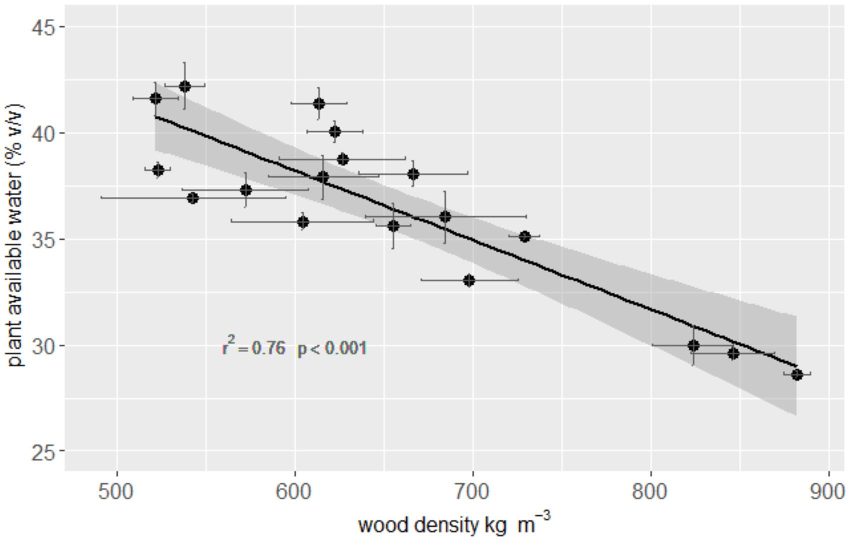

Figure 1 Relationship between feedstock wood density and plant available water of biochar. R-square and significance value in grey as figure annotations. Shaded area indicates 95% confidence region for regression fit.

Figure 2 shows the cell structure of two contrasting wood types: low density *E.nitens* wood (521 kg m^{-3}) and high density *E. polybraktea* wood (881 kg m^{-3}). The low density wood produced biochar that had greater amounts of plant available water (41% v/v) than the high density wood (29% v/v). The images illustrate the cell structure differences between the two wood species, with thinner cell walls and greater lumen diameters in *E. nitens* wood compared with thicker cell walls and smaller lumen diameters in *E. polybraktea* wood. Therefore, greater plant available water is likely due to differences in biochar pore structure which were inherited from the feedstock cell structure (Wildman and Derbyshire, 1991). We conclude that biochars made from low density hardwood retain greater amounts of plant available water than biochar made from high density hardwood. This finding extends the mechanistic understanding of how feedstock cell structure influences biochar pore structure, and thereby plant available water.

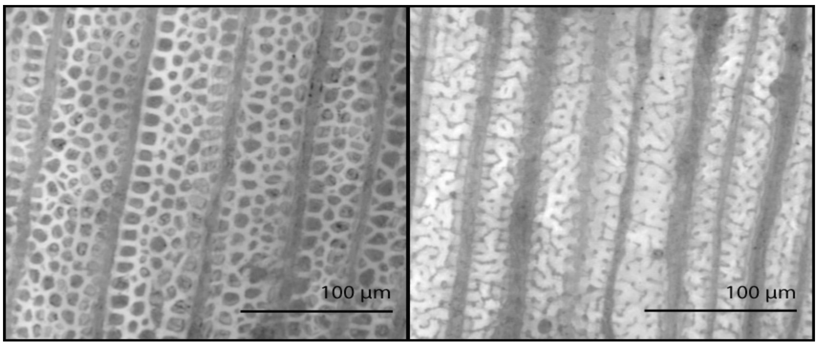

Figure 2 Transmitted light micrographs of *Eucalyptus* wood species with different densities at 100x magnification. Left: low density wood (521 kg m^{-3} *E. nitens*); Right: high density wood (881 kg m^{-3} *E. polybraktea*). White to light grey circular structures are cell walls, dark grey circular structures are fibre lumen, dark grey vertical bands are parenchyma.

Feedstock wood density was also strongly correlated with biochar bulk density (Figure 3). This finding is supported by Byrne and Nagle (1997), who also found a linear relationship between wood density and biochar bulk density. We conclude that low density biochar made from low density wood is preferable for green roof substrates as this reduces green roof weight, making them applicable to a wider range of buildings.

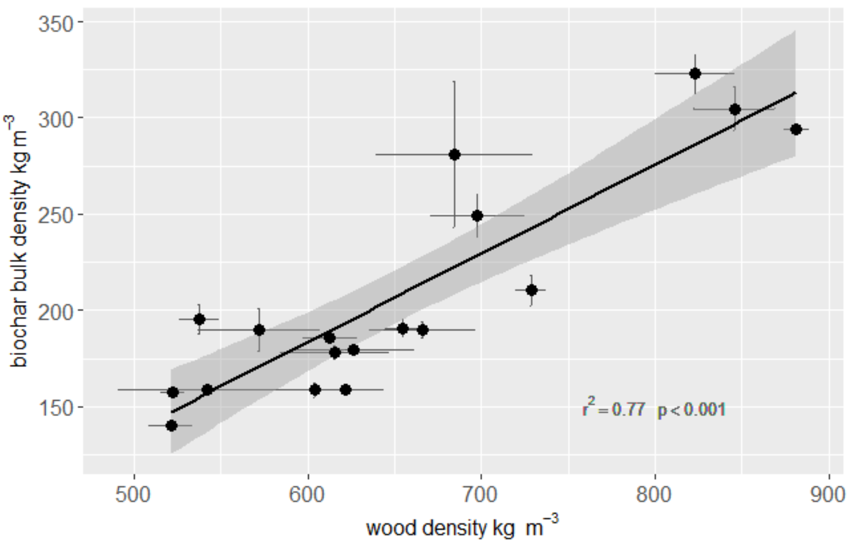

Figure 3 Relationship between feedstock wood density and biochar bulk density. R-square and significance value as figure annotation. Shaded area indicates 95% confidence region for regression fit.

4 CONCLUSIONS

Our results show that biochar made from low density wood retains greater amounts of plant available water and is lighter than biochar made from high density wood when produced under equal pyrolysis conditions. The ability to predict biochar water retention based on the simple measure of feedstock wood density can inform feedstock choices for producing optimal biochar for green roof substrates as an amendment to reduce plant water stress and increase stormwater retention whilst keeping green roofs light weight and applicable to a wide range of buildings as a retrofitting option to reduce the stormwater volume in cities on a catchment scale.

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