Journal of Environmental Management 161 (2015) 173–180

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Algal biochar enhances the re-vegetation of stockpiled mine soils with native grass

David A. Roberts*, Andrew J. Cole, Nicholas A. Paul, Rocky de Nys

MACRO – the Centre for Macroalgal Resources and Biotechnology, College of Marine and Environmental Sciences, James Cook University, Townsville, Australia

ARTICLE INFO

Article history:
Received 27 April 2015
Received in revised form
29 June 2015
Accepted 1 July 2015
Available online xxx

Keywords:
Biochar
Macroalgae
Mine rehabilitation
Terrestrial restoration
Mining
Metals

ABSTRACT

In most countries the mining industry is required to rehabilitate disturbed land with native vegetation. A typical approach is to stockpile soils during mining and then use this soil to recreate landforms after mining. Soil that has been stockpiled for an extended period typically contains little or no organic matter and nutrient, making soil rehabilitation a slow and difficult process. Here, we take freshwater macroalgae (*Oedogonium*) cultivated in waste water at a coal-fired power station and use it as a feedstock for the production of biochar, then use this biochar to enhance the rehabilitation of two types of stockpiled soil – a ferrosol and a sodosol – from the adjacent coal mine. While the biomass had relatively high concentrations of some metals, due to its cultivation in waste water, the resulting biochar did not leach metals into the pore water of soil-biochar mixtures. The biochar did, however, contribute essential trace elements (particularly K) to soil pore water. The biochar had very strong positive effects on the establishment and growth of a native plant (Kangaroo grass, *Themeda australis*) in both of the soils. The addition of the algal biochar to both soils at 10 t ha^{-1} reduced the time to germination by the grass and increased the growth and production of plant biomass. Somewhat surprisingly, there was no beneficial effect of a higher application rate (25 t ha^{-1}) of the biochar in the ferrosol, which highlights the importance of matching biochar application rates to the requirements of different types of soil. Nevertheless, we demonstrate that algal biochar can be produced from biomass cultivated in waste water and used at low application rates to improve the rehabilitation of a variety of soils typical of coal mines. This novel process links biomass production in waste water to end use of the biomass in land rehabilitation, simultaneously addressing two environmental issues associated with coal-mining and processing.

© 2015 Published by Elsevier Ltd.

1. Introduction

Australia relies on mining and mineral exports for 8% of gross domestic product, 50% of foreign trade income and 80% of power generation through the combustion of coal (ABS, 2013; Smart and Aspinall, 2009). The federal government has also approved the development of several new coal mines in the Galilee Basin and, consequently, the amount of mined land in Queensland has increased by over 30% in just a few years (Worrall et al., 2009). While mining is an important contemporary component of the Australian economy, it is also a temporary land-use and the rehabilitation of mined land to its pre-disturbance state is a part of the mining industries social licence to operate (Burton et al., 2012; Doley and Audet, 2013; Maczkowiack et al., 2012; Worrall et al., 2009). While the rehabilitation of land with native vegetation is a condition imposed on most new mines, it is a difficult task and is often met with limited success (Bell, 2001; Maczkowiack et al., 2012; Vickers et al., 2012). In the northern state of Queensland, mining companies must achieve pre-determined rehabilitation success criteria before their legal liability for land can end. Consequently, the mine closure process remains a sensitive issue for both the mining industry and alternative land users (Morrison et al., 2005; Neldner and Ngugi, 2014).

Many factors can complicate the rehabilitation of soil at coal mines. One factor in Australia is that coal mines, in particular, are associated with saline-sodic soils (Bell, 2001) and ferrosols with low pH and high concentrations of Al and Fe-oxides that limit the availability of P for plant growth (Sinclair et al., 2010). The intrinsically poor health of these soils is further exacerbated during mining. Waste rock and topsoil are stockpiled at mines during initial land

---

* Corresponding author.
E-mail address: david.roberts1@jcu.edu.au (D.A. Roberts).

http://dx.doi.org/10.1016/j.jenvman.2015.07.002
0301-4797/© 2015 Published by Elsevier Ltd.

disturbance and can be left for many years before they are used to recreate landforms (Grigg et al., 2000). During this period of stockpiling many of the properties of these soils, such as a near absence of organic matter and nutrients, are exacerbated and the soils are effectively sterile when the rehabilitation effort commences (Kelly et al., 2014; Loch and Orange, 1997). As a consequence, mine rehabilitation in Australia is heavily reliant on fertilizers to establish plants and overcome the poor health of stockpiled soils (Kumar, 2013). However, these synthetic fertilizers have a limited duration of effectiveness and do not address the issue of depleted soil organic carbon (SOC) that arises during stockpiling.

While not widely recognised within the mining industry, biochar is an additional soil ameliorant that could greatly improve the rehabilitation of stockpiled soil (Fellet et al., 2011; Kelly et al., 2014). Biochar is a carbon-rich charcoal produced through a process known as slow pyrolysis which involves heating biomass in an oxygen-limited atmosphere (Lehmann and Joseph, 2009). The amelioration of soil with biochar can improve the retention of nutrients in soil (thereby extending the benefits of synthetic fertilizers) and rebuild an organic C pool in depleted soils (Lehmann and Joseph, 2009). Ultimately this leads to improvements in the growth and productivity of plants on biochar-amended soils (Jeffery et al., 2011). An emerging literature base has shown that macroalgae (large, freshwater and marine algae) are a promising source of biomass for biochar production, and, furthermore, that algal biochar could be particularly well suited to the rehabilitation of mine sites (Bird et al., 2012; Roberts et al., 2015a). Unlike biochar produced from wood-based materials, algal biochar has a very high exchangeable nutrient content (N, P, K, Ca, Mg and Mo) and can directly contribute essential nutrients to soils, in addition to providing a recalcitrant source of SOC (Bird et al., 2011; Roberts et al., 2015a, 2015b). Consequently, algal biochar can outperform ligno-cellulosic ("woody") biochar as an ameliorant for the soils that are typical of mine rehabilitation projects (Bird et al., 2012).

Another advantage of algae as a feedstock for biochar is that it can be cultivated on non-arable land using waste water from mining and mineral processing industries. In particular, freshwater macroalgae from the genus *Oedogonium* can be cultivated in waste water at coal-fired power stations, using CO_2 from flue gas emissions to support photosynthesis (Ellison et al., 2014; Roberts et al., 2013, 2015). This approach to biomass production has been validated at scale at an Australian power station (Roberts et al., 2015). While the biomass cultivated in waste water can be enriched in some metals, slow pyrolysis of this high-ash biomass immobilises the metals in a biochar which can then be applied to soils to improve the yield of crops with no transfer of potentially toxic elements to either soil pore water or plants grown in the biochar soil mixtures in the short-term (Roberts et al., 2015a). These findings are similar to those that have recently been published for metal-containing biochar produced from plants grown on contaminated soils (Evangelou et al., 2014). The cultivation of macroalgae at coal-fired power stations could provide a sustainable and local source of biomass to support the rehabilitation of adjacent mines. However, while a growing literature base attests to the positive effects of biochar on the health of a range of soils, some studies nevertheless show that under certain conditions biochar amelioration can be detrimental to soil health and the growth of plants (Jeffery et al., 2011; Mukherjee and Lal, 2014). The large-scale application of biochar is therefore limited by a lack of a mechanistic understanding of how different types of biochar perform in different types of soil and it is difficult to predict which combinations of biochar and soil will yield positive outcomes for soil health and plant growth. It is therefore important to assess whether the high-ash biochars produced from algal biomass cultivated in bioremediation ponds are effective in a range of soils.

We have previously described the *in situ* cultivation of *Oedogonium* in waste water from a coal-fired power station (Roberts et al., 2015) and the use of biochar produced from this biomass as an ameliorant to enhance the production of edible crops (Roberts et al., 2015a). Here, we add to this existing literature by producing biochar from *Oedogonium* that has been cultivated in waste water at Tarong power station (Queensland, Australia) and test it as a soil ameliorant to assist in the rehabilitation of two soils (a red-basalt ferrosol and a saline-sodic sodosol) from soil stockpiles at the adjacent Meandu coal mine (also Queensland, Australia). First, we produce biochar from *Oedogonium* that was cultivated in waste water at Tarong power station and characterize its physico-chemical properties. Second, we test the leaching of metals from the high-ash biochar in the two soils taken from Meandu coal mine. Finally, we compare the germination and growth of a native Australian plant (Kangaroo grass, *Themeda australis*) in the two soils with and without the *Oedogonium* biochar through outdoor pot experiments.

2. Methods

2.1. Biomass and biochar production

The cultivation of *Oedogonium* at Tarong power station has previously been described and detailed methods regarding the production of *Oedogonium* can be found there (Roberts et al., 2015). Briefly, *Oedogonium* was grown at Tarong in June 2013 (26°46′51″S, 151°54′45″E). Tarong has a 46,000 mega liter (ML) Ash Dam (AD) containing Ash Water (AW) that is used to dispose of residual ash from coal combustion (Roberts et al., 2015). *Oedogonium* was collected from Tarong AD and cultured in 15,000 L ponds containing AW that was pumped from the AD. Flue gas was piped into the ponds to maintain pH between 8.4 and 8.6. The *Oedogonium* biomass was harvested twice weekly and sun dried. Biochar was produced from a pooled sample of biomass from four successive harvests in June 2013. We have previously shown that a pyrolysis temperature of 750 °C delivers a biochar that has a negligible rate of leaching of metals (Roberts et al., 2015) and that this biochar can be applied to soils to enhance the growth of crops without transferring metals to the soils or plants (Roberts et al., 2015a). A pyrolysis temperature of 750 °C also yields an algal biochar in which >85% of the total C is found in the stable polycyclic aromatic carbon (SPAC) fraction that is anticipated to be recalcitrant across at least centennial time scales (McBeath et al., 2015). To make the biochar for this study, dried *Oedogonium* was placed in a mesh bag and put into a muffle furnace that was purged with N_2 gas at a flow rate of $4\ L\ min^{-1}$. The biomass was heated to 750 °C and left in the furnace for 60 min then cooled to room temperature under continued N_2 flow.

The elemental profile (C, H, O, N, and S) of the biomass and biochar were analysed using an elemental analyser (OEA Laboratory Ltd, United Kingdom). The metal concentrations in the biomass and biochar samples were measured following acid digest. First, 100 mg of the biomass or biochar was placed in a Teflon digestion vessel with 3.0 ml distilled HNO_3 and 1.0 ml H_2O_2. The solution was digested for 2 h then heated in a microwave to 180 °C for 10 min, and diluted with Milli-Q water. The concentrations of Al, As, Cd, Co, Cr, Cu, Hg, Fe, Mn, Mo, Ni, Pb, Se, V and Zn were measured with a Bruker 820-MS Inductively Coupled Plasma Mass Spectrometer (ICP-MS), and Ca, K, Mg and Na with a Varian Liberty series II Inductively Coupled Plasma Optical Emissions Spectrometer (ICP-OES). An external calibration strategy was used. Collisional Reaction Interface (CRI) was used for As (H_2), while ^{82}Se isotope was used for Se quantification to eliminate polyatomic interferences. A 1% HCl solution was spiked with 1 ppb As and Se and measured three times

Download English Version:

https://daneshyari.com/en/article/7481680

Download Persian Version:

https://daneshyari.com/article/7481680

Daneshyari.com