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Research paper

An economic analysis of biochar production using residues from Eucalypt plantations

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A B S T R A C T

Producing biochar from organic residues is a potential method to integrate carbon sequestration and residue management costs while enhancing conventional agricultural and forestry production systems. Plantation forestry is an important industry in Tasmania, and is based on large scale plantations of *Pinus radiata* and *Eucalyptus* (*Eucalyptus globulus* and *E. nitens*). The area covered by forestry plantations in Tasmania (on State land) exceeds 100 000 ha, while plantations on private land double this number. Eucalypt plantations are managed primarily for the production of high-value pruned logs for industry; however, unpruned saw logs, peelers, poles, posts and pulp are also produced, and significant quantities of residue are produced as a byproduct. This study was an economic analysis that considered on-site biochar production system using post-harvest forestry residues, with biochar being utilized within the system, or sold as a product. The financial analysis was based on previous experimental outcomes on the use of Macadamia shell biochar in *Eucalyptus nitens* plantations, and the local operating environment in Tasmania; including current forestry procedures used for managing plantations. A number of assumptions were considered concerning a) production costs, b) savings enjoyed by traditional operations, following biochar scenario implementation, and c) biochar sales. The analysis revealed a potential annual income of over 179 k$ (2014 value) and the sensitivity analysis identified the crucial factors responsible for scenario profitability, namely biochar price and final product distribution.

1. Introduction

Forestry is a significant industry in Tasmania, with large scale plantations of radiata pine (*Pinus radiata*, D. Don) and *Eucalyptus* (*Eucalyptus globulus* and *Eucalyptus nitens*, H. Deane & Maiden) which play an increasingly important role in supplying national and international demand for timber. Propagating robust seedlings for planting in the field is an important and expensive part of plantation establishment that influences final yield.

The first Tasmanian hardwood plantations were established in the late 1930's, mainly in the North-West of the State [1]. Most of these were small *Eucalyptus* plantings within patches of native forest. Today, there are approximately 52,000 ha of softwoods and 56,000 ha of hardwoods growing on Tasmanian State forests for the supply of timber to local and interstate industries. Typical procedures to prepare the ground for plantation establishment include harvesting and clearing the slash (harvest residues) from the previous plantation, and soil cultivation and pest control (i.e. herbicides and insecticides). Clearing the harvest residues on a coupe is accomplished through a number of methods; the method chosen depending on the volume and size of residues, the soil type and quality, location of the coupe, and slope. Typically, the residue is windrowed at an inter-row distance of 15–60 m after which it is crushed and burnt [2]. Planting beds are traditionally prepared by a tractor-mounted mound cultivator, creating continuous mounds on top of which the seedlings are planted. Successful establishment during the first two years is crucial for plantation health, and productivity as well as final yield.

Producing biochar from local organic residues may provide greater levels of certainty regarding the stability of recalcitrant soil

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carbon, and increased flexibility when managing residue processing costs in conventional agricultural and forestry production systems. Biochar, however, is not widely used by farmers or foresters in Australia, mainly due to the lack of certainty concerning long-term consequences, yield gains and a lack of 'know-how' in quality assurance, transportation, logistics and cost efficiency.

Within agricultural systems, biochar has been added to soils to sequester carbon [3–5] and may maintain or improve soil functions improving desirable levels of porosity, bulk density or water holding capacity [6,7]. It has been reported to bring about positive effects on soil and plant nutrition, but also to have negative repercussions for both soil and plants [8,9]. Despite the emerging use of biochar in agriculture, very few studies have examined its utilization in forestry and other tree-based agro-systems [10]. It has been reported, that charcoal from wildfires mixed with substrates from microhabitats increase shoot-to-root ratio in silver birch (*Betula pendula*) and Scots pine (*Pinus sylvestris*) when studied in a glasshouse in north Sweden [11]. De Luca et al. [12] has also reported increased nitrification rates in the soil after application of wildfire-produced charcoal mixed with ammonium. Therefore it can be speculated that biochar deliberately applied to forestry soils may bring similar effects.

In the current commercial procedures processing of post-harvesting residues is rather connected with costs than benefits incurred by the forestry industry. Producing biochar from post-harvesting residues could serve as an alternative to on-site clearing burns while using the resultant biochar as a soil amendment could provide both agronomic benefits and financial gains. The scenario proposed in this analysis involves the use of post-harvest residues and a mobile pyrolysis unit to produce biochar, a portion of which is subsequently applied to the soil on site. The scenario proposes two other uses of the final product: use within the forestry nurseries and commercial sale into the horticultural market. A financial model was built with Excel (Microsoft®, ver. 2007) to determine if under this commercial scenario, the mobile pyrolysis of forest harvesting residue can be undertaken profitably.

2. Material and methods

2.1. Area and feedstock

It is estimated that an average area of 2000 ha of forestry plantation is harvested and replanted annually in Tasmanian State forests. Annually, the quantity of post-harvest organic residues, specifically slash and litter, vary between 10 and 70 t ha^{-} (Sadanandan Nambiar, Chief Scientist CSIRO, personal communication, project meeting 2011). For modelling purposes an average value of 30 t of woody residues per hectare was assumed. Typically, the water mass fraction of freshly cut wood is approximately 30%, and after being air-dried on site for several months, this is likely to decrease to ca. 12% [13,14]. It is at this approximate water mass fraction (12%) wood residues are considered suitable for either burning on-site or, for conventional kiln combustion to produce energy and other products [15].

2.2. Pyrolyser

There are various mobile pyrolysers available on the market. In this analysis the CharMaker MPP20 mobile pyrolysis plant from the Earth Systems® (VIC, Australia) was considered as the most suitable for the proposed scenario. The unit is designed around a standard 20 foot shipping container and can be easily transported on a truck or trailer. Processing up to 4 tonnes of wood material (moisture content up to 35%) per batch, the unit can produce approximately 1 tonne of biochar after 4 h operation. The unit is intended to operate on large pieces of material (up to 2 m length) in order to by-pass the need for on-site chipping of large volumes of woody matter. The CharMaker MPP20 is equipped with primary heating and emission control (after-burner) systems and supplied by diesel oil during start-up. The unit can operate unattended and has the potential to sequester several kilo-tonnes of carbon dioxide equivalent (CO_2e) per annum through char production [16].

2.3. Agronomic assumptions

A Field trial was established on the 18th Oct 2011 in Florentine valley, South-West Tasmania (42°38′S, 146°27′E; Forestry Tasmania coupe FO031Z). Six rates of biochar (0–20 t ha^{-1}) were combined with 3 rates of fertiliser (0, 50 and 100% of the full commercial fertiliser dose) to produce a factorial combination of 18 different treatments. The agronomic assumptions used within the model were based on the results of plant growth and chemical changes in the soil and leaf material in response to fertiliser and biochar application rates. The assumptions were also based on results of a pot trial with *E. nitens* seedlings performed within a wider biochar project [17]. Plantation soil type, location and size were also used to emulate the parameters associated with a typical plantation site in Tasmania and these were included in the set of model specifications. The influence of biochar on chemical fertility in-field was compared to di-ammonium phosphate (Impact Fertiliser®) applied at a rate of 200 g per seedling. Soil in the field experiment was classed as a brown dermosol (Australian Soil Classification System). The nutritional analysis of soil and leaf tissue of growing trees was performed on 4 occasions during the first 14 months following planting.

2.4. Biochar

The model scenario presumed the use of biochar produced from an *E. nitens* residue feedstock, however due to availability, the agronomic assumptions were based on data using macadamia shell biochar and its effect on eucalypt productivity. While macadamia and *E. nitens* biochars are both wood-based products it is important to emphasize that the effects of their application to soil will most likely vary.

The macadamia shell char was made in South Africa in the Mpumalanga province, Alkmaar. The feedstock was provided by Golden Macadamias Pty Ltd. and collected from 3 to 30 years old orchards of *Macadamia integrifolia* (Maiden & Betche) in 2008. The char was made at the HTT (highest temperature treatment) of 480 °C and residence time was 180 min. The char was stored and then shipped to Australia in 1.2 m^2 bags made of polypropylene fabric. After arrival in Freemantle WA, it was stored in the same bags until April 2011, when it was shipped to Tasmania in plastic bins and stored before application in eucalypt plantation trial in September 2011. Relative to other biochars described in the literature, analyses have characterized the macadamia shell biochar used in this study as high in potassium and sodium, moderately high in carbon content and low in nitrogen (N) and phosphorus (P) [18–21]. Further characteristics of the applied biochar are presented in Table 1.

2.5. Model building

The model consisted of several formulae (Table 2) and used projected values to calculate total annual benefit. The total benefit calculated by the model was based on three main components: 1) a cost/benefit analysis of production that included standard operating costs and savings that accounted for fertilisation, site cleaning/preparation after plantation harvesting, and weed control during plant establishment; 2) cost/benefits arising directly from biochar production and application, this calculated with respect to