Soil Amendment with Biochar: Growth, Physiology and Fruit Yield and Quality of Young 'Fuji' Trees

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Abstract

Declining soil health in perennial fruit tree orchards is a concern due to long term lack of carbon inputs. The objective of this study was to investigate the effects of different soil amendments on the growth, physiology and fruit yield and quality of 'Fuji' apple trees on M26 rootstock in a 'replant' soil. Treatments included application of a low-temperature-derived green-waste biochar at 47 T/ha, compost application at 10 T/ha, biochar plus compost application, and control. Four years after planting tree girth, pre-dawn and midday water potentials, leaf nutrient concentrations, and fruit yield and quality were assessed.

Trunk girth of trees in the biochar plus compost treatment was significantly greater than that of controls, with those of biochar or compost only treatments being intermediate. Leaf pre-dawn (ranging from -0.13 to -0.51MPa) and midday (ranging from -1.3 to -2.4 MPa) water potentials were not significantly different between treatments as measured during the second cropping season. Leaf mineral N averages for treatments ranged between 2.27 and 2.92 % dry weight while leaf mineral P ranged between 0.17 and 0.22 % dry weight: there were no consistent significant differences between treatments. Number of fruit per cm^2 trunk cross sectional area (TCSA) ranged between 6.72-8.13 and yield efficiency (kg/cm^2 TCSA) ranged between 1.39-1.65: there were no significant differences between treatments. Fruit weight, firmness and colour were not significantly different between treatments.

Lack of a significant difference in tree water- and nutrient-relations between treatments was attributed to the site receiving excess nutrients and irrigation such that potential effects of biochar and compost on increased water and nutrient availability were not realised. The increased trunk girth of trees in the biochar plus compost treatment, were attributed in part to synergistic effect of biochar plus compost on soil microbial community or activity in the context of this replant situation. Effects of soil amendment with biochar may become evident on this site in dry seasons.

INTRODUCTION

Concern regarding the chronic decline in soil carbon under conventional orchard management, associated with herbicide application along tree rows, has become an issue in Australia. Adding carbon-rich amendments, such as composts, mulches or manures can increase soil carbon (e.g. Glover et al, 1999) but these amendments are expensive to apply and breakdown within 12-18 months (Quilty & Cattle, 2011). In contrast biochar, created by heating organic matter under reduced oxygen conditions (Sohi et al, 2010), has a residence time of hundreds to thousands of years in soils (Kuzyakov et al, 2009).

Soil amendment with some biochars (note that effects vary widely depending on initial feedstock, pyrolysis system and treatment temperature) is reported to benefit agricultural production via improved soil physical attributes and water availability, via short term fertilisation effects and/or via effects on soil microbial ecology (Chan & Xu 2009; Atkinson et al, 2010). The greatest agricultural gains from soil amendment with biochar have been on nutrient poor, acidic, tropical soils with low carbon and cation exchange capacity. In contrast, very few studies have focussed on temperate systems (Atkinson et al, 2010) and to our knowledge none on perennial horticulture production systems of pome tree physiology. Recently, Hardie et al, (2014) reported on the soil hydrology of a temperate orchard system. Therefore the objective of this study was to investigate the effects of soil amendment with biochar on growth-, water- and nutrient-relations and fruit yield and quality of young 'Fuji' apple trees.

MATERIALS AND METHODS

Site characteristics

The trial was established in November 2009 at Mountain River in the Huon Valley, Tasmania (42°57'2.91"S, 147°5'52.13"E) during replanting of an existing apple orchard. Soils were a Bleached Mottled Grey Kurosol (texture-contrast) developed on Permian Mudstone with a minor contribution from Jurassic dolerite colluvium (described in more detail in Hardie et al, 2014). Climate data from a weather station located 7 km away indicated the site had a mean annual rainfall of 744 mm, mean maximum temperature 17.1 °C, mean minimum temperature 5.8 °C, and mean annual sunshine of 5.5 hours per day.

Trial design

The site was levelled and re-mounded one week after the removal of the old trees. The trial design consisted of a randomised complete block with four treatments and five replicates. Trees were blocked on position within the tree-row and each replicate contained three trees. The four treatments were: untreated control, biochar, compost, biochar plus compost. The compost was sourced from Renew (Tasmania, Australia) and was applied at 10 T/ha as a top dressing. The biochar was sourced from Pacific Pyrolysis, Somersby, NSW (Australia). The feedstock consisted of acacia whole tree green waste which had been pyrolyzed in a continuous flow kiln at temperatures up to 550 °C for between 30 - 40 minutes. Each replicate received 15 kg biochar, equivalent to 5 kg per tree space or 47 T/ha. The biochar was spread evenly by raking across the mound and was incorporated to approximately 10 cm depth. The orchard was replanted with 'Naga-Fu No 2 Fuji' trees on M26 rootstock with a 'Royal Gala' interstem. Tree spacing within the row was 1.06 m, and 4.3 m between rows. Trees were fertilised with annual inputs of 198 kg ha^{-1} N-P-K (7:3:22) in early November and approximately 2 kg per tree of green fowl manure (4.5:1.4:1.5) in August 2010, 2011 and 2012. Depending on rainfall, trees were alternately fertigated with 12.5 kg ha^{-1} calcium nitrate (15.5:0:0) or 12.5 kg ha^{-1} potassium nitrate (13:0:45) once a week between November to February, and 12.5 kg ha^{-1} Solu-K (0:0:42.3) weekly from February up until the first week in March.

Tree and fruit assessments

Trunk girth was measured at 4 cm above the graft union in July 2013. At planting, there were no significant differences in mean trunk girths across all treatments (6.1 ± 0.2 cm). Flowers/fruitlets were removed from trees during the first two seasons as per normal commercial practice, and trees were cropped for the first time in the 2011/12 season. Fruit was harvested in April of each year at normal commercial harvest times. All fruit from the centre tree in each plot were counted and weighed and the number of fruit per cm^2 TCSA, and yield efficiency (kg/cm^2 TCSA) calculated. From each replicate, samples of 25 randomly selected fruit were individually weighed and evaluated for fruit firmness (flesh pressure), total soluble solids (TSS), background colour, red blush intensity, percentage blush coverage (TSS and colour not reported). Fruit flesh firmness was measured on pared flesh with a Guss Fruit Texture Analyser fitted with an 11 mm penetrometer probe.

Monthly measurements of mid-day leaf (1300 h) water potential and pre-dawn (0500 h) leaf water potential were undertaken on biochar treated and control trees from November 2012 to April 2013. Detached leaves were placed immediately into plastic bags and kept in the dark until measurements were made using a 4.0 MPa model 615 pressure chamber (PMS Instruments Co., Albany, OR, USA). Leaves were collected and processed for leaf nutrient analysis. Leaves were dried to constant weight at 65 °C and nutrient concentrations determined on dried and ground material by the commercial laboratory CSBP, Western Australia.

Data analysis

Trunk girth data was subjected to repeated measures analysis of variance (ANOVA) using the trunk girth measured in November 2009 as a covariate to test for treatment differences. Repeated measures ANOVA was also used to test for treatment differences in foliar chemistry and water potentials. One-way ANOVA was used to test for treatment effects on number of fruit per cm^2 TCSA and yield efficiency. Individual fruit weight, fruit firmness, and background colour, red blush intensity, percentage blush coverage were analysed by ANOVA. The block and soil amendment treatments were the main plot factors. The assumptions of ANOVA such as homogeneity of variance and the Gaussian distribution were evaluated by the use of quantile-quantile plots and residual plots for all variables. A critical value of $P = 0.05$ was used and Fischer's protected Least Significant Difference (LSD) post hoc tests were used to determine significant differences among treatment means.

RESULTS

Four years after soil amendment with biochar, compost or a combination of the two, trunk girth of trees in the biochar plus compost amended treatment was significantly greater than that of controls, with those of the biochar and compost only treatments being intermediate (Fig. 1). Leaf mineral N ranged between 2.27 and 2.92 % dry weight while leaf mineral P ranged between 0.17 and 0.22 % dry weight: there were no consistent significant differences between treatments. Leaf pre-dawn (ranging from -0.13 to -0.51 MPa) and midday water potentials (ranging from -1.3 to -2.4 MPa) were not significantly different between treatments. Number of fruit per cm^2 trunk cross sectional area (TCSA) ranged between 6.72-8.13, yield efficiency (kg/cm^2 TCSA) ranged between 1.39-1.65: there were no significant differences between treatments. Fruit weight, firmness (Table 1) and colour (results not shown) were not significantly different between treatments.

DISCUSSION

Multiple lines of evidence suggest that biochar applied at 47 T/ha, compost applied at 10 T/ha or biochar plus compost treatment had no significant effect on either soil water availability or nutrient uptake. In particular, the soil amendment treatments had negligible effects on soil water availability (Hardie et al, 2014), pre-dawn and midday tree water potentials, foliar nutrition, and fruit yield and quality. In contrast, Baronti et al, (2014) found that two seasonal soil applications of biochar obtained from orchard pruning waste feedstock reduced water stress during droughts in a field trial of Grape vine (*Vitis Vinifera*) . The lack of a significant effect of biochar on foliar nutrition of the 'Fuji' trees was unexpected given the significant levels of N, K and S that are retained in low-temperature-derived (<550°C) biochars (Joseph et al, 2010) that often translate to elevated plant nutrient uptake (Atkinson et al, 2010) and previous pot trials using the same biochar which demonstrated elevated Ca, B and S in M26 rootstocks grown in biochar-amended soils (Street et al unpub.). The lack of any significant difference in fruit yield and quality observed in the soil amendment treatments can perhaps be attributed to the high level of irrigation and fertiliser inputs applied under the commercial conditions at the site. These inputs would have most likely ensured non-limiting conditions throughout the trial period such that any potential benefits from increased water or nutrient availability associated with biochar application were not apparent.

Consistent with the many studies reporting elevated plant growth in response to soil amendment with biochar plus fertiliser application, elevated tree girth was observed in the compost plus biochar treatment, with the combined treatment being significantly higher than control treatment, four years after soil amendment with biochar. We speculate that this could be due to restricted growth in the control treatment caused by 'replant disorder', thought to be caused by altered soil microbiology (Utkhede & Smith, 1992). All soil amendment treatments resulted in significantly altered soil microbial communities, relative to the control, at this site (Gentile et al, unpub).

We conclude that, whilst biochar plus compost amendment had little effect on tree water- or nutrient-relations in a temperate pome-fruit orchard context with high water and nutrient inputs, greater trunk girth in a replant situation could be advantageous for filling the tree allocated space earlier, resulting in greater carbohydrate reserves and potential benefits during dry seasons. It is possible that the effects of soil amendment with biochar could lead to significantly improved outcomes in terms of tree health and fruit quality in orchards where soils are not as well managed for carbon content or in regions where unfavourable summer heat-waves are becoming the norm such as mainland Australian growing regions.

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Table

Table 1: Fruit weight and fruit flesh firmness of 'Fuji' apple harvested in 2013 under different soil amendment treatments ± 1 standard error.

	Fruit weight (g)	Fruit firmness (kg)
Control	196.1 (2.4)	8.490 (0.063)
Biochar	202.0 (3.0)	8.095 (0.066)
Compost	211.1 (2.8)	8.062 (0.068)
Biochar plus compost	211.4 (2.9)	8.332 (0.068)

Figure

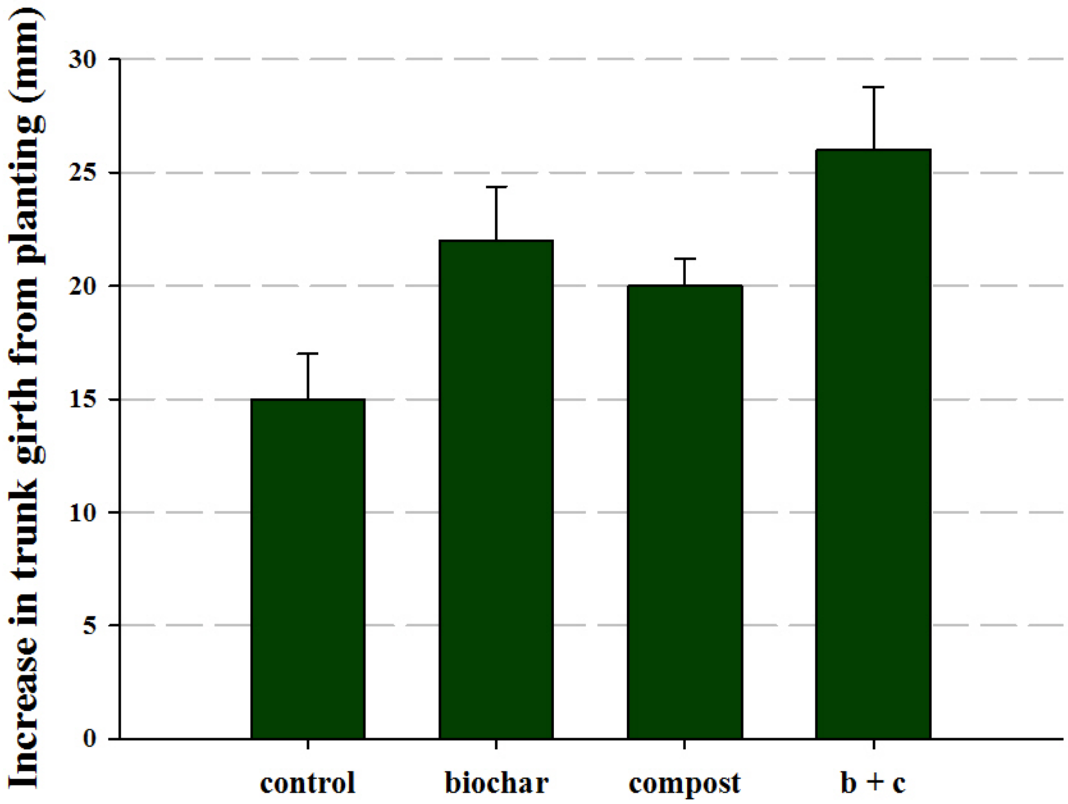

Fig. 1: Effects of biochar and compost soil amendment treatment on trunk girth of young 'Fuji' apple trees measured on 15 June 2013, four years after planting into a 'replant' situation. Error bars are standard error of the mean.