Horticulture Innovation Australia

# Final Report

## Closing the 'Green City Loop' – Green Organics for Urban Green Environments

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**MT13042**

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# SUMMARY

Can city green waste become a valuable media to green our urban spaces or grow vegetable seedlings to feed our expanding population? Can farm trash be made into farm profit? A collaborative project between Horticulture Innovation Australia, Brisbane City Council and The University of Queensland found that the answer is yes…provided that each new product is designed to match the needs of the grower.

Phase I of this project (HG10025, 2010-14) compared four technologies – emerging and conventional – for processing city green waste and farm trash into usable products for cross-commodity horticulture. Results suggested that plant establishment may especially benefit from biochar inputs. Thus the objective of this current project was to test the best biochars from HG10025 in turf and nursery grower trials to validate plant and profitability benefits, since faster and more reliable plant establishment equates to real profit gains for these industries. While the target audience was The Australian Turf and Nursery & Garden Industries, results are also useful for the vegetable, perennial horticulture and recycled organics industries and for waste managers. Activities to validate biochar performance were grower trials at Australian Lawn Concepts turf farm and Zoomgarden nursery. The aim was to determine the effect of biochar products on plant growth and growing media properties and whether biochar use is economical and fits into existing systems. Sir Walter buffalo and Wintergreen Couch were tested for turf industries, while tomato and capsicum were tested for nursery trials.

Outputs demonstrated that biochar products - if optimised for each industry - promise enhanced grower productivity, environmental sustainability and expanded market opportunities. The best products showed a 12-34% increase in plant productivity for three out of four varieties tested. Biochar products were economically viable if replacing media or soil additives such as peat, vermiculite and perlite. In nursery trials, products successfully replaced unsustainably harvested peat with biochar made from Brisbane city's green waste or farm trash. Outcomes were communicated via HIA's HortLink magazine, four conference presentations, three scientific articles, two field days and various demonstrations.

Outcomes identified potential markets for biochar products. For the Australian Turf Industry, products may be mixed into landscaping media or soil prior to laying turf. For industries that grow or plant nursery-raised plants – such as the Australian Nursery & Garden Industry and the Australian Vegetable Industry – products can replace media additives and accelerate plant growth. For environmental stewardship, products can replace non-sustainable media, sequester carbon and enhance soil health. Additional data was also collected with NSW DPI soil scientists from a trial running since 2011 at Mountain Blue Orchards testing biochar and compost products for blueberry production. Results showed that biochar combined with compost can boost fruit yield and soil health over the longer term.

In summary, bespoke amendments and media that deliver specific horticultural functions, are cost-effective and environmentally beneficial could be the future for recycled organics but will require industry-specific R&D to ensure they meet grower needs. Recommendations are that for consistent, positive outcomes - particularly for food crops or during sensitive stages such as plant establishment - biochars should be made from quality feedstocks and inhibitor-free. Biochars dosed with compounds and/or beneficial microbes promise even greater increases in plant productivity than biochar alone. For long-term benefits, combining biochar with compost promises enhanced yield and soil health. The ideal next step is industrial test sites that tailor products to match grower needs.

## KEYWORDS

Organic; recycling; turf; nursery; perennial; compost; biochar; market development; green waste; profitability; carbon.

# INTRODUCTION

Green organics: how best to use this resource? A University of Queensland project (HG10025, 2010-14) explored four technologies with farm and city applications to find answers. Funded by Horticulture Innovation Australia (HIA) and Brisbane City Council, the study compared each technology for its ability to produce usable products for horticulture from city green waste or farm residues. Experimental and on-farm trials targeted turf, nursery, landscape revegetation, fruit and vegetable industries. Technologies were conventional (composting[1]) and emerging (biochar[2] from pyrolysis).

**For growers** HG10025 determined that horticulture stands to gain real benefits but products must be matched to the specific needs of each industry. For example, certain biochar products significantly enhanced agronomic performance over the short term, particularly plant establishment. By contrast, the combination of biochar with compost gave longer term benefits, increasing perennial fruit yield, sequestering carbon and improving soil physicochemical properties more than each product alone. Overall, the project provided a world-first understanding of the production process from feedstock source to the farm gate and confirmed that compost and biochar production are complementary (Kochanek *et al.,* 2014, 2015a).

This project (MT13042) has taken the next step towards commercial product development by validating with growers the usefulness of products from HG10025 that most enhanced plant establishment. Urban horticulture was targeted (i.e. turf and nursery industries) because products can readily replace or enhance existing amendments or media additives, transport costs can be kept low by reusing city organics near cities and the 'green city loop' can be closed since greenlife in cities means more organics for more greenlife. Trials were also directly relevant to growers who sow nursery-raised transplants or plants, such as the Australian Vegetable Industry, fruit and ornamental tree and shrub growers, landscapers and others.

**MT13042 product selection:** During HG10025, collaborative research with chemists at the University of Western Australia revealed a plant growth promoting compound at high concentrations in certain biochars but low in others (Figure 1, Kochanek *et al.,* in prep). Concurrently, physicochemical characterisation of biochars determined ultimate and proximate properties and calorific values, degree of carbon recalcitrance, pore, surface area and density properties, surface structure, particle size distribution, as well as agronomically critical parameters, including pH, EC, neutralizing capacity, total C, total N, Colwell P, exchangeable cations (Al, Ca, K, Mg, Na) and cation exchange capacity and microelements, including heavy metals (Kochanek *et al.*, 2015b). When physicochemical properties were then modeled simultaneously with plant growth parameters, it was identified that the presence of this compound – termed 'compound ©' in this report - was at least partly responsible for the improved plant establishment observed with certain biochars (Kochanek *et al.,* in prep).

[1]Composting is a well understood technology (Vesilind *et al.*, 2002) that transforms organic matter via aerobic microbial activity into a stable end product (humus) which can be used to increase soil quality and carbon content (Rhyner *et al.*, 1995). However, the long composting cycle and variable product quality are known bottlenecks (Tian *et al.*, 2012).

[2]Biochar from pyrolysis is an emerging technology. Organic biomass is transformed under oxygen limited or zero-oxygen high temperature conditions (pyrolysis, *c.* 350 to 700°C) into biochar; a solid, charcoal-like residue consisting of recalcitrant carbon that may be sequestered for hundreds to thousands of years (Laird, 2008; Sohi *et al.,* 2010; Ahmed *et al.,* 2012; Grierson *et al.,* 2011). The emissions balance of units can be further improved if bio-oils and gases from pyrolysis are used to generate heat and power and feedstocks are recycled organics rather than purpose-grown crops (Lehmann and Joseph, 2009). In the literature, biochar is generally purported to enhance soil physical, chemical and biological properties and ecosystem health, often conferring plant growth and crop yield benefits. Just some reported mechanisms are enhanced water and nutrient retention, improved soil drainage, structure and pH and enhanced microbial communities, (Joseph *et al.,* 2010; Sohi *et al.*, 2010; Beesley *et al.*, 2011; Elad *et al.*, 2011; Lehmann *et al.*, 2011; Jeffery *et al.*, 2011). However, biochar can vary with feedstock source and pyrolysis conditions (Laird *et al.*, 2009) resulting in plant growth that can be positive, negative or neutral (Dumroese *et al.*, 2011; Quilliam *et al.*, 2012; Brockhoff *et al.*, 2010). Hence HG10025 and this project aimed to determine how biochar can consistently improve plant growth.

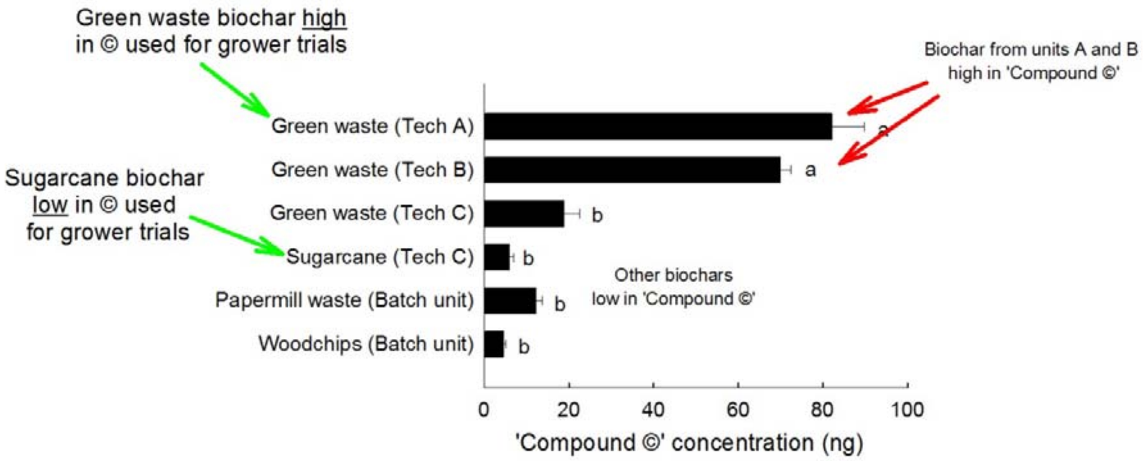


**Figure 1** The concentration of compound © in HG10025 biochars (bars are mean ± SE). Biochars selected for grower trials (green arrows) used a green waste biochar high in © and a sugarcane biochar low in ©, but with better physicochemical properties.

For example, extracts with high compound © resulted in substantially improved seed germination for two dormant species (Figure 2). Seed germination increased from 0-10% with a water control, up to 100% with pure compound © or pyrolysis extracts high in compound ©. The compound name will be published in a scientific journal; contact the project leader for more information (Dr Jitka Kochanek, email: [j.kochanek@uq.edu.au](mailto:j.kochanek@uq.edu.au)).

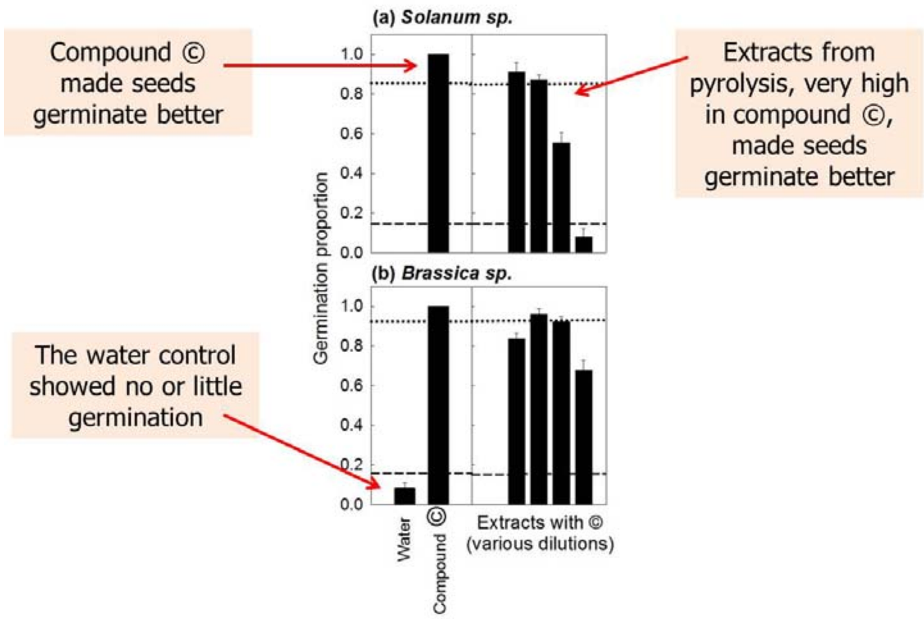


**Figure 2** The germination of seeds from two dormant lines when exposed to water (control), pure compound © or various dilutions of extracts from pyrolysis with high compound © (bars are mean ± SE). Lines indicate Dunnett's critical value, where means below the dotted line are significantly different to pure compound © and above the dashed line are significantly different to the water control.

Similarly, rapid shoot development and increased resistance to stress were observed with increased levels of compound © in growing media for lettuce, tomato and some turf varieties. For example, turf plantlet size was doubled by certain growing media with biochars containing high compound © (Fig 3).

Hence, in this project, two biochars from HG10025 were selected, *viz.* a sugarcane biochar low in compound © but with superior physicochemical properties and a green waste biochar high in compound © but with poorer properties (e.g. more saline, denser and lower water holding capacity, Kochanek *et al.*, 2014). To validate product performance with growers, trials were set up with industry leaders to determine to what extent a) plant establishment, growth and growing media properties were enhanced by the products; b) product use fits into existing systems and c) whether product purchase makes economic sense. Additional fruit yield and soil quality data was also collected from a field trial running since 2011 on a commercial blueberry farm as part of HG10025.

Outcomes from this work have been successfully communicated to growers, urban managers, government, researchers and the general public via four horticulture industry conference presentations, a publication in HIA's HortLink magazine, an on-line film, three peer reviewed scientific articles and various demonstrations and field days.

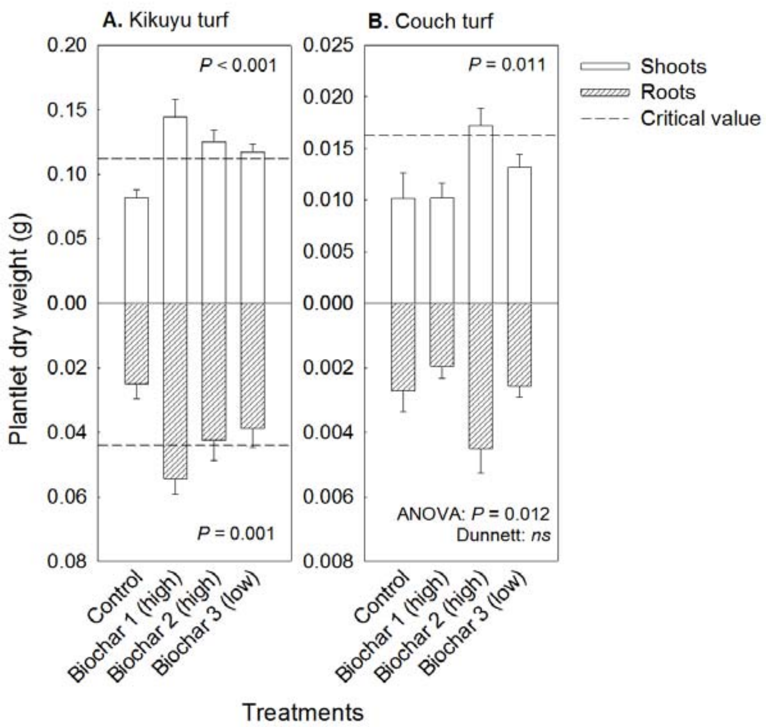


**Figure 3** Shoot and root development for Kikuyu and Couch turf lines grown from seed in media containing biochar high (Biochar 1 and 2) or low (Biochar 3) in compound © (bars are mean ± SE). Kikuyu showed the best growth with both biochars high in compound ©, while inhibitors in biochar 1 are believed to be responsible for reduced couch growth with this biochar (Kochanek *et al.*, 2014). The dashed lines indicate Dunnett's critical value, where means above the line for shoots and below the line for roots are significantly different to the control.

# METHODOLOGY

The R&D component of this project was conducted throughout 2014 as a series of grower field and demonstration trials and extension activities. The current project was heavily development and extension-based, working closely with growers in on-farm product and logistics validation. This followed on from project HG10025 which was heavily research-based, acquiring knowledge about the potential benefits of emerging versus conventional processing technologies for their efficiency and ability to convert green organics into usable products that enhance on-farm productivity.

## Product Development and Optimisation

### The Australian Turf Industry

To validate the best products from HG10025 for the Australian Turf Industry, a trial was set up at Australian Lawn Concepts on 10th April 2014 with Mr John Keleher, Turf Industry leader, Managing Director and former Turf Australia President (Fig 4). The trial tested the value of organic products to the turf consumer by determining the rate of plant establishment of a sod sown onto soil after product incorporation. Products were those biochars from HG10025 that most consistently promoted plant performance, *viz.* a green waste biochar high in compound © and a sugarcane trash biochar low in compound ©, each applied at 30 t $ha^{-1}$, assuming a 10 cm incorporation depth. The site used industry best practice, including fertiliser co-application with biochar, since this is required for optimal plant performance (Kochanek *et al.,* 2014; Housley *et al.*, 2015).


**Figure 4** Turf Industry leader, Mr John Keleher, at the Australian Lawn Concepts test site.

**Experimental design:** This randomized complete block design field trial compared Sir Walter buffalo and Wintergreen Couch bermudagrass (*Cynodon dactylon*) turf varieties. Three blocks had six randomly allocated plots per block, using a control plot (no amendment) and two treatment plots (green waste or sugarcane biochar) for each turf variety. Plots were 2.4 × 1.8 m in size, with a 1.8 m buffer between plots and along the plot periphery. Zoysia turf was planted into the buffer margins.

**Site preparation:** The site was limed, tilled with a rotary hoe, biochar applied to the surface and raked into position (Fig 5), lightly overhead irrigated to minimize dust and then each row tilled to a 10 cm incorporation depth. After this, the turf was laid on the soil surface and rolled. A pre-emergent herbicide and fertiliser were applied to the turf surface prior to all plots being overhead irrigated.

**Figure 5** Biochars on the soil surface awaiting rotary hoe incorporation during site preparation.

**Figure 6** Collecting leaf clippings at the Australian Lawn Concepts trial at 1 month after set-up.

**Measurements** characterised plant health and growth rates. Leaf biomass was collected monthly as leaf clippings by mowing each plot (Fig 6), stolons were collected from the plot periphery and plant parts were dried at 60°C and weighed (Artiola *et al.,* 2012). Soil testing was carried out prior to trial set-up across the site and in October 2014 within plots using 5 randomly collected cores per plot. Soil characteristics determined were EC, pH, total carbon and nitrogen, extractable phosphorus, cation exchange capacity and exchangeable cations and microelements. Root biomass was determined from the October coring and samples were dried and weighed as for shoot biomass. The trial was terminated in December 2014.

## The Australian Nursery & Garden Industry and Vegetable Industry

Biochar product validation for commercial nursery production began on the 10th October 2014 at Zoomgarden nursery (Burpengary, NSW) with industry leaders Mr Alistair Pritchard (CEO) and Mr. Steve McGovern (Managing Director, Fig 7). An element of environmental sustainability was introduced to the study; biochars replaced unsustainably harvested peat products in growing media. Biochars were those that most consistently promoted plant establishment in HG10025, *viz.* a green waste biochar high in compound © and a sugarcane biochar low in compound © but with superior physicochemical properties.

**Figure 7** Nursery Industry leaders, Mr Steve McGovern and Mr Alistair Pritchard (right and above), at Zoomgarden nursery.

**Experimental design:** Completely randomised block design trials at Zoomgarden's seedling propagation section (Fig 8) compared plant growth within a standard nursery propagation media without biochar against media with peat replaced by biochar at a rate of 3, 10 or 30% by volume. Nursery lines tested were commonly used by Zoomgarden, *viz.* tomato var. Oxheart (Ball Horticultural Company Australia) and capsicum var. California Wonder OP (Highsun Express Seeds). Five blocks were used per treatment.

**Figure 8** The seedling propagation sector at Zoomgarden nursery, where the trial was undertaken.

**Media preparation and plant care:** The control media used 20 L peat, 6.5 L perlite and 70 g of nutricote fertiliser. The treatment media replaced peat with 3, 10 or 30% biochar by volume, while perlite and the fertiliser were maintained as for the control media (fertiliser co-application is required with biochar for optimal plant performance, Kochanek *et al.,* 2014; Housley *et al.*, 2015). Media was mixed in a cement mixer and used to fill 122-cell trays. Dibble sticks made indents to *c.* 0.5 cm, one seed was sown per cell, the tray covered with vermiculite and trays hand-watered. Plants were overhead hand-watered daily by Zoomgarden staff (Fig 9) to industry best practice.

**Figure 9** Plants were maintained by Zoomgarden staff to industry best practice.

**Measurements** characterised plant establishment and seedling vigour at one and two weeks after germination through shoot and root length and dry weight recordings. Germination rate was not analysed because radicle protrusion could not be observed within the growing media. Media bulk density, EC, pH and moisture content were characterised and leaf samples used to quantify tomato nutrient content.

## The Australian Blueberry Industry

A long-term field trial was set up during spring 2011 at commercial blueberry farm Mountain Blue Orchards (Wollongbar, NSW) with soil scientist Justine Cox (NSW DPI) and industry leader and Managing Director, Mr Ridley Bell (Fig 10, set up as part of HG10025). The trial tested the usefulness, logistics and practicality of organic products for the perennial fruit industry, documenting crop performance, yield, soil health and carbon sequestration over consecutive seasons and years. The study aimed to determine whether biochar outperforms or complements compost in agronomic contexts, hence three biochars (two from green waste, one from sugarcane), a green waste compost and a compost and biochar combination were incorporated at 30 t $ha^{-1}$ each into the top 10 cm soil surface (Kochanek *et al.*, 2014).

**Figure 10** A long-term field trial was set up in 2011 at Mountain Blue Orchards with (from left to right) Dr Jitka Kochanek (UQ), soil scientist Justine Cox (NSW DPI) and industry leader, Mr Ridley Bell (Managing Director).

The experiment used a randomised latin square design, with four blocks of each of six treatments, creating 24 plots. Each plot was 11.7 m long with 10 blueberry bushes (variety Opi) planted per plot and three buffer plants between plots. Canopy volume was measured monthly and berry yield during winter and spring 2013 for HG10025 and in 2014 for MT13042.

The site was a red Ferrosol soil limed to pH 5.9 (originally pH 4-4.5). Soil amendments were applied to the flat mounded surface (50 cm wide) at a 30 t $ha^{-1}$ application rate and ploughed by hand into the top 10 cm mound surface. Irrigation tape, planting and mulching with woodchips occurred in early summer 2011. Until October 2012 plants were small and produced few fruits. After October 2012 the plant canopy began to expand and plants produced their first berry harvest in winter to spring 2013 (Kochanek *et al.,* 2014) and second harvest in 2014 (this study). For yield measurements, berries were sorted into firsts (large, marketable fruit) and seconds, with total and individual berry fresh weight recorded.

Soil physicochemical, biological and carbon sequestration properties were measured over multiple years and seasons, with sampling at 0, 3, 12, 18, 24 (Kochanek *et al.,* 2014) and 36 months (this study). Soil characteristics determined were EC, pH, total carbon and nitrogen, extractable phosphorus, nitrate ($NO_3$), ammonium ($NH_4^+$), cation exchange capacity and exchangeable cations. The yield and soil results from the second harvest (2014) are presented in this report.

### Statistical Analysis

Statistical analysis was carried out using MINITAB, Version 16 (Minitab Inc., State College, PA, USA). General linear model analysis of variance (ANOVA) was used to compare the effects of species, biochar type and/or biochar application rates and their interactions on plant or soil parameters. Mean separation was performed by least significant difference (LSD) at the 5% level of significance. A one-way ANOVA was used for single factor analyses, with a post hoc Dunnett's test identifying means different to the control with a 5% significance level. Transformation is indicated in Table or Figure captions where transformation before analysis improved the homogeneity of variance, otherwise data are presented untransformed.

## Biochar Safety and Certification

A preliminary analysis of biochar safety was conducted. Polycyclic aromatic hydrocarbon (PAH) levels were quantified at the University of Queensland, National Research Centre for Environmental Toxicology, by PhD Candidate Jennifer Braunig, Dr Daniel Drage and Prof Jochen Mueller. Methods for the extraction of PAHs from biochar:

**Reagents and standards:** Acetone, n-hexane, dichloromethane (DCM) and toluene were purchased from Merck (Darmstadt, Germany). Surrogate standards $d_{12}$-naphthalene, $d_{10}$-acenaphthylene, $d_{10}$-phenanthrene, $d_{10}$-fluoranthene, $d_{12}$-benzo[*a*]anthracene, $d_{12}$-chrysene, $d_{12}$-benzo[*b*]fluoranthene, $d_{12}$-benzo[*a*]pyrene, $d_{12}$-ideno[1,2,3-*cd*]pyrene and $d_{12}$-benzo[*ghi*]perylene at concentrations of 2.5ppm (4 mg/ml for $d_{10}$-phenanthrene) were purchased from Cambridge Isotope Laboratories (Tewksbury, MA, USA). PAH mix solutions containing naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo[*a*]anthracene, chrysene, benzo[*b*]fluoranthene, benzo[*k*]fluoranthene, benzo[*a*]pyrene, indeno[1,2,3-*cd*]pyrene, dibenzo[*a,h*]anthracene, benzo[*ghi*]perylene at 2000 ppm was purchased from AccuStandard (New Haven, CT, USA).

**Sample preparation and extraction:** Biochar samples were ground to a fine powder using a mortar and pestle. The samples were thoroughly mixed and 0.5 g of each biochar was placed into a glass centrifuge vial and spiked with 20 µl deuterated PAH standard. A volume of 10 ml acetone:n-hexane (1:1) was added to each sample, vortexed for 1 minute and subsequently sonicated for 30 minutes. The extraction solutions were centrifuged for 20 minutes and the supernatant was collected in a 100 mL round bottomed flask. Ultrasonication extraction was repeated twice for each sample and the extracts combined. Toluene (0.5 ml) was added to each sample as a keeper and the extraction solvent volume was carefully reduced to 1 ml using a rotary vacuum evaporator (Büchi, Switzerland).

**Sample cleanup:** Samples were cleaned using an aluminium oxide (3g, 6% deactivated, Sigma Aldrich) and silica gel (2 g, 3% deactivated, Sigma Aldrich) glass column. The columns were conditioned with 20 ml DCM and 20 ml n-hexane prior to sample loading. Samples were eluted with 25 ml DCM:n-hexane (1:1), 0.5 ml toluene was added as a keeper and the solvent volume reduced to 1.5 ml under a gentle nitrogen stream. These solutions were transferred to amber glass vials, reduced further to 1 ml and stored at 4°C until analysis.

**PAH determination by GC-MS:** Samples were analysed using a Thermo DFS high resolution mass spectrometer (HRMS) coupled to a Thermo TRACE 1310 gas chromatograph (GC). 1.6 µL of each sample was injected in splitless mode at 250 °C, with helium as the carrier gas at a constant flow of 1 mL/min. Separation was achieved using a DB5-ms column (30 m x 0.25 mm x 0.25 µm, J&W Scientific). The HRMS was operated in electron impact (EI) positive mode applying an electron energy of 70eV. The source and transfer line temperatures were 250 °C and 280 °C respectively. Resolution was set to ≥10,000 (10% valley definition). The instrument was operated in multiple ion detection (MID) mode. The full MID parameters from the lead author of this report are available upon request.

# OUTPUTS

## Product Development and Optimisation

### The Australian Turf Industry

**<u>Grower summary</u> from scientific outputs**

Turf trials at Australian Lawn Concepts concluded that biochar has real potential as a product for landscaping if mixed into growing media or soil prior to laying turf. "We have seen promising results in this early work that has potential to deliver real benefits to turf growers," said Mr John Keleher, Managing Director and former Turf Australia President. In this study, biochar additions increased Wintergreen Couch leaf biomass by 34% above the control over a 6-month period. Importantly, the largest boost to plant growth was in spring, with 68% more leaf clippings collected from the best biochar plots in October relative to the control. For Sir Walter Buffalo, results were inconclusive and more work is needed. Biochar initially slowed growth during winter, then showed a non-significant trend towards increased growth in spring. Improvements to turf media with biochar additions have been attributed to higher aggregate stability, higher soil macronutrient content (Ghosh *et al.,* 2012) and higher water and nutrient retention capacity (Brockhoff *et al.,* 2010; Artiola *et al.,* 2012) compared to media without biochar. In this study, the biochar that most enhanced plant growth contained high rates of compound ©, hence the effect of this compound on turf growth without biochar should be explored. Industry optimisation will be needed for consistent outcomes, and biochars should be made from quality feedstock and be inhibitor-free. The next step is testing the usefulness of biochar for the grower on-farm and optimising products specifically for the Turf Industry.

**Figure 11** Biochar shows real potential for turf landscaping media but requires industry optimisation. Dr Jitka Kochanek collects data from the test site in June 2014.

**Scientific outputs - plant establishment and growth**

**Method summary:** Grower trials at Australian Lawn Concepts (Fig 11) tested the value of biochar products to the consumer by determining the rate of growth of a sod sown onto soil after product incorporation. Sir Walter buffalo and Wintergreen Couch bermudagrass (*Cynodon dactylon*) turf varieties were used and a sugarcane biochar low in compound © but with superior physicochemical properties and a green waste biochar high in compound © were compared to plots without amendments (control). **Results** showed that each turf variety behaved differently (Table 1). Soil chemical and leaf nutrient analyses will be modelled against plant growth outcomes in subsequent publications.

For **Wintergreen Couch** (Fig 12, Table 2) biochar consistently improved plant growth above the control:

- Both biochars enhanced growth, but particularly the green waste biochar high in compound ©, which resulting in a 34% increase in total leaf biomass above the control.
- The largest improvement in turf growth rate with the best biochar was in spring. For example, 68% more leaf clippings were collected from the green waste biochar plots in October relative to the control.
- Stolon growth and root biomass were not significantly different across treatments (data not shown, Fig 13, 14).

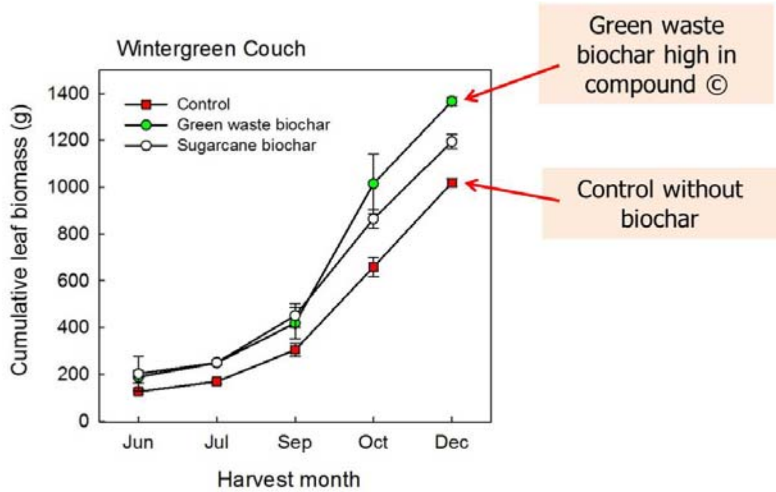


**Figure 12** The cumulative average leaf biomass for Wintergreen Couch (per plot, ± SE) for five harvests over a 6 month period. While both biochars improved turf performance, the green waste biochar high in compound © was most effective, particularly during spring (September and October). Refer to Table 2 for statistical results.

**Figure 13** Mr Chris George (horticulturalist, UQ) collecting cores for soil and root analysis in spring.

For **Sir Walter Buffalo,** biochar initially slowed growth during winter, then showed a non-significant trend towards increased growth in spring (Fig 14, Table 2). The results are inconclusive and more work is needed.

- Plant-inhibiting chemicals may have initially reduced growth, but been leached by overhead sprinkler irrigation for later growth (Kochanek *et al.*, 2014; Artiola *et al.*, 2012; Graber *et al.*, 2010).
- Leaf clipping biomass was reduced by 37% in biochar plots relative to the control (Fig 14; Table 2). In winter, there was also a trend towards reduced stolon biomass by *c.* 20% in biochar-treated plots relative to the control (non-significant, Fig 14).
- In spring, there was a trend towards increased stolon biomass by *c.* 20% in biochar-treated plots relative to the control (non-significant, Fig 14).
- Root biomass was not significantly different across treatments (data not shown).

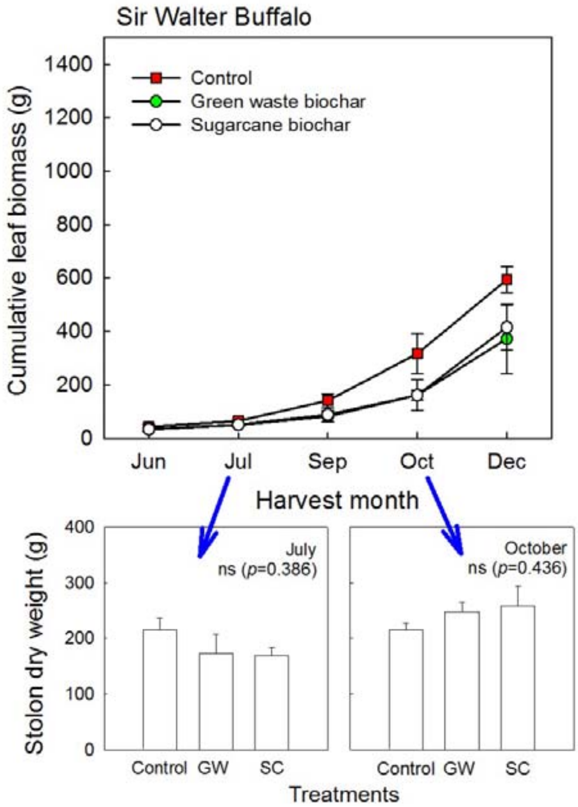


**Figure 14** The cumulative average leaf biomass for Sir Walter Buffalo (per plot, ± SE) for five harvests over a 6 month period (top graph) and the stolon biomass collected from the plot periphery (lower graphs, bars are mean ± SE). Treatments are sugarcane biochar (SC), green waste biochar (GW) and plots without amendments (Control). Biochars initially reduced turf growth, then showed a non-significant trend towards increased growth in spring. Refer to Table 2 for statistical results.

Variation in turf growth to biochar has been observed by other researchers, for example, greenhouse pot experiments with a loamy sand soil sown with bermudagrass (*Cynodon dactylon*) seeds showed 25% higher grass clipping yields when amended with 2% biochar compared to 0% or 4% biochar (Artiola *et al.*, 2012), while for creeping bentgrass (*Agrostis stolonifera* L.) biochar amendments at <10% char into sand had no effect on plant growth, while >10% reduced rooting depth compared to sand alone (Brockhoff *et al.*, 2010). Industry optimisation will be needed for consistent outcomes, most likely achievable if biochar manufacturers use quality feedstocks and inhibitors are removed prior to product sale.

**Table 1** General linear model analysis of variance and means for leaf clipping biomass testing the effect of a green waste biochar high in ©, sugarcane biochar low in © and a control without biochar (Treatment) across five clipping collection times (Harvest) on Wintergreen Couch and Sir Walter Buffalo turf (Species).

| | Leaf biomass | Degrees of Freedom |
|---|---|---|
| Block | * | 2 |
| Treatment | ns ($p$=0.4) | 2 |
| Harvest | *** | 4 |
| Species | *** | 1 |
| Treatment × Harvest | ns ($p$=0.9) | 8 |
| **Treatment × Species** | ** | **2** |
| Harvest × Species | * | 4 |
| Treatment × Harvest× Species | ns ($p$=1.0) | 8 |

Within each column, nonsignificant differences and significant differences at $P \leq 0.05$, 0.01 and 0.001 are indicated by ns, *, ** and ***, respectively. Values are the mean of three replicates of leaf biomass collected monthly as clippings (one replicate per block, three blocks). Data were $\log_{10}$ transformed prior to analysis to improve homogeneity of variance. Residual degrees of freedom = 58.

**Table 2** General linear model analysis of variance and means for leaf clipping biomass for Wintergreen Couch or Sir Walter Buffalo turf testing the effect of a green waste biochar high in ©, sugarcane biochar low in © and a control without biochar (Treatment) across five clipping collection times (Harvest).

| | Couch | Buffalo | DF |
|---|---|---|---|
| Block | ** | ** | 2 |
| **Treatment** | * | * | **2** |
| Harvest | *** | *** | 4 |
| Treatment × Harvest | ns ($p$=0.7) | ns ($p$=0.9) | 8 |

Within each column, nonsignificant differences and significant differences at $P \leq 0.05$, 0.01 and 0.001 are indicated by ns, *, ** and ***, respectively. Values are the mean of three replicates of leaf biomass collected monthly as clippings (one replicate per block, three blocks). Data were $\log_{10}$ transformed prior to analysis. Residual degrees of freedom = 28.

**Figure 15** Dr Jitka Kochanek collecting stolons from the plot periphery for drying and weighing.

## The Australian Nursery & Garden Industry and Vegetable Industry

### Grower summary from scientific outputs

Trials at Zoomgarden nursery concluded that biochar has real potential as a media component for container plant production. The best products accelerated vegetable seedling growth without compromising quality, fit within existing infrastructure, were economically viable and environmentally sustainable – replacing unsustainably harvested peat with products made from Brisbane city's green waste or farm trash. "NGIA believes that there are opportunities for the introduction into the industry of renewable growing media components derived from organic plant material, as demonstrated by this project," said Mr Robert Prince, CEO of the Australian Nursery & Garden Industry.

In this study, tomato and capsicum seedling size was increased by 12 and 20%, respectively, by the best biochar-containing media above the control. Quality was maintained; seedlings had larger leaves but were not spindly or deformed. More work is needed to determine whether compound ©, biochar or their combination is responsible for improvements in plant growth because the biochar abundant in compound © most consistently improved plant growth, despite having inferior physicochemical properties. While the sugarcane biochar had similar physicochemical properties to peat, the green waste biochar was more dense, saline and held less water. Other researchers have observed positive plant growth outcomes with biochar additions to media for container plants (e.g. *Calathea rotundifola*, Tian *et al.*, 2012; *Alnus viridis, Pinus contorta*, Robertson *et al.*, 2012), however, this study is the first to identify compound © as a possible contributor to improved plant growth with biochar additions.

Biochar products were economically viable, being cost-comparable to media additives such as peat, vermiculite and perlite. However, industry optimisation will be needed for consistent outcomes, for example, by ensuring biochars are made from high quality feedstocks and are inhibitor-free, particularly for food crops and during plant establishment. Dosing such biochar products with plant promoting compounds or microbes is one potential future for recycled organics, promising faster plant turn-over and improved productivity.

### Scientific outputs - plant growth and media quality

**Method summary:** Trials replaced peat in propagation media with biochar products at a rate of 0, 3, 10 or 30% (Fig 16). A sugarcane biochar low in compound © but with superior physicochemical properties and a green waste biochar high in compound © were compared to a peat containing propagation media without biochar (control). Plant establishment and seedling vigour at one and two weeks after germination were quantified for tomato var. Oxheart and capsicum var. California Wonder OP. Media quality was determined for each mix, *viz.* bulk density, EC, pH and moisture content.

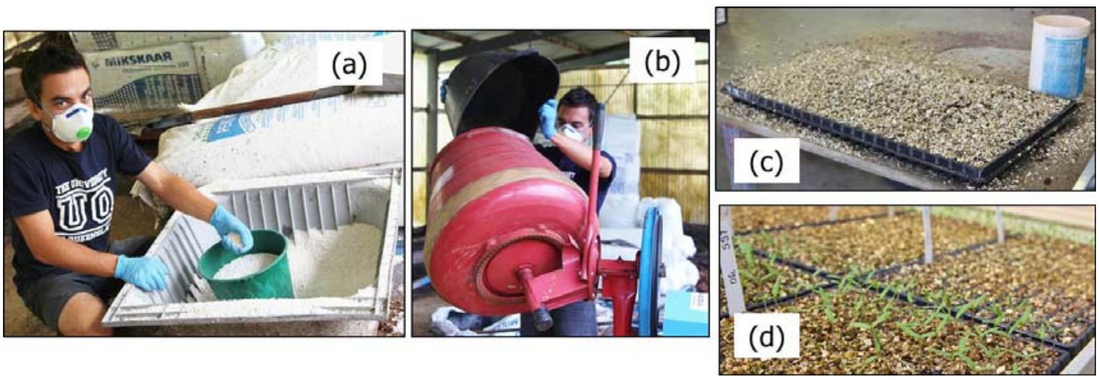


**Figure 16** Mr Chris George prepares propagation media using peat, perlite and nutricote fertiliser and biochars to replace peat at 0, 3, 10 or 30% by volume (a). Each media was mixed in a cement mixer (b) and used to fill 122-cell trays (c, d).

**Results** showed that both nursery lines benefitted from biochar, but each line behaved uniquely (Table 3). For both species, the greatest benefits were observed at 2 weeks after germination (Table 4).

For **tomato, biochar high in compound © significantly improved plant growth** at two weeks after germination (Table 4, Fig 17a, 18):

- Tomato is known to be highly responsive to compound © (Kochanek *et al.*, 2014, in prep);
- The green waste biochar high in compound © resulted in larger seedlings than the control, irrespective of the application rate (Table 4). The largest seedlings, from the 30% biochar media, were 12% larger than the control (Fig 17).
- The sugarcane biochar, low in compound © but with better physicochemical properties, did not significantly improve plant growth above the control (Fig 17);
- Seedlings from the best biochar media were of high quality, having larger leaves (Fig 17b) but a non-elongated hypocotyl (Fig 17c; Table 4), thus desirable, non-spindly and rapid growth.
- More work* is needed to determine whether compound ©, biochar or their combination is responsible for improvements in plant growth.

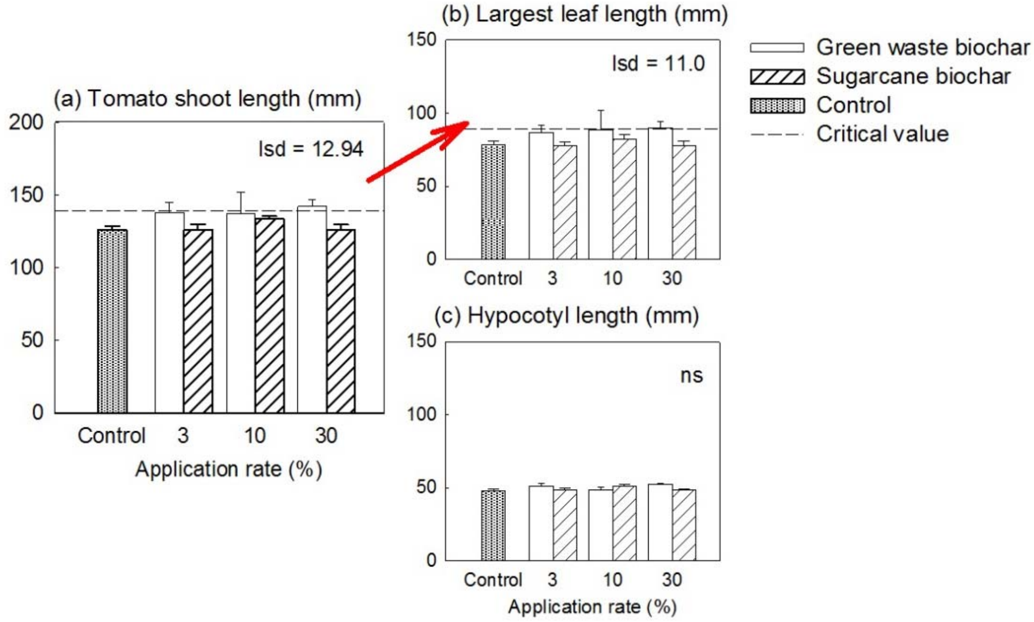


**Figure 17** Tomato seedling size at two weeks after germination for (a) the shoot, (b) the largest fully open leaf and (c) the hypocotyl. Bars show the mean ± SE and values above the critical line are significantly different to the control. Refer to Table 4 for statistical results.


**Figure 18** Tomato seedlings growing in media containing 3, 10 or 30% green waste biochar resulted in *c.* 12% longer seedlings than from media without biochar.

*Note: Tomato seedling size and quality was most improved by the media that was also saline and would normally reduce crop growth, *viz.* 30% green waste biochar mix (Fig 21). Literature cites that high compound © can overcome plant stress, hence its abundance in this biochar may be responsible. More work is needed to determine the usefulness of compound © for horticulture.

For **capsicum, both biochars significantly improved plant growth** at two weeks after germination at the lowest application rate (Table 4, Fig 19a, 20):

- Media containing 3% biochar resulted in *c.* 20% larger seedlings than from the control media, irrespective of the biochar used.
- Seedlings from the best biochar media were of high quality, having larger leaves (Fig 19b) and a non-elongated hypocotyl (Fig 19c; Table 4), hence desirable, non-spindly and rapid growth.
- Capsicum may be unresponsive to compound © or require higher doses to enhance plant growth than was available in the green waste biochar. More work is needed.

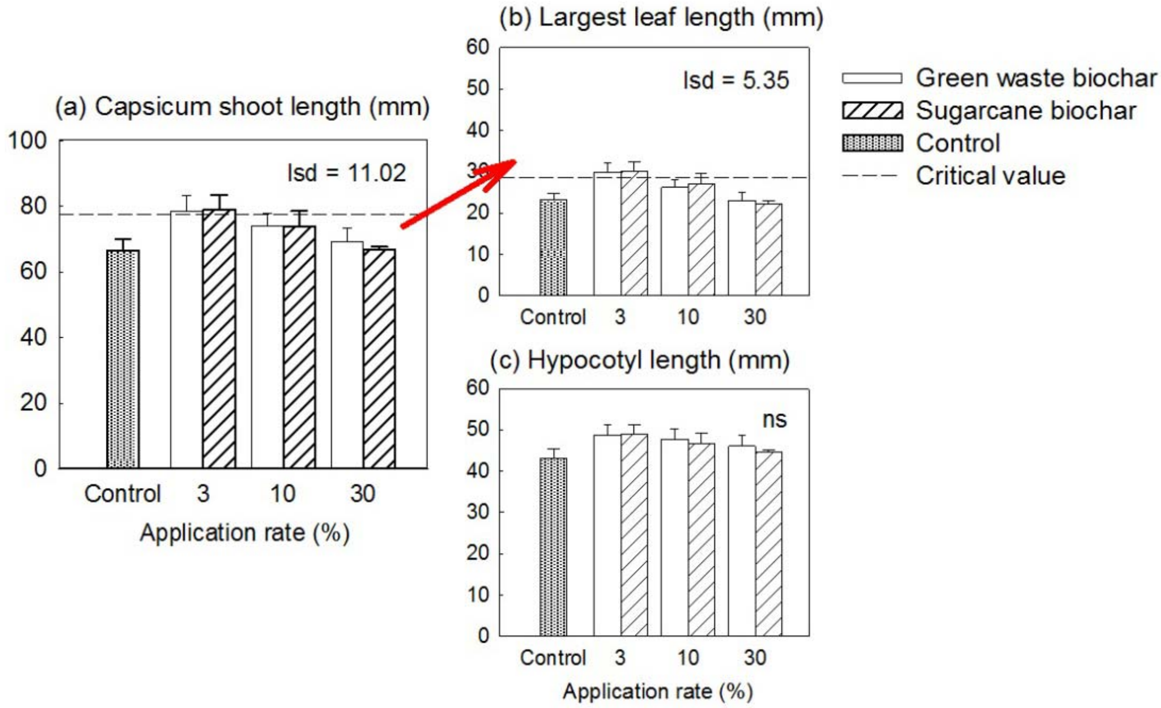


**Figure 19** Capsicum seedling size at two weeks after germination for (a) the shoot, (b) the largest fully open leaf and (c) the hypocotyl. Bars show the mean ± SE and values above the critical line are significantly different to the control. Refer to Table 4 for statistical results.

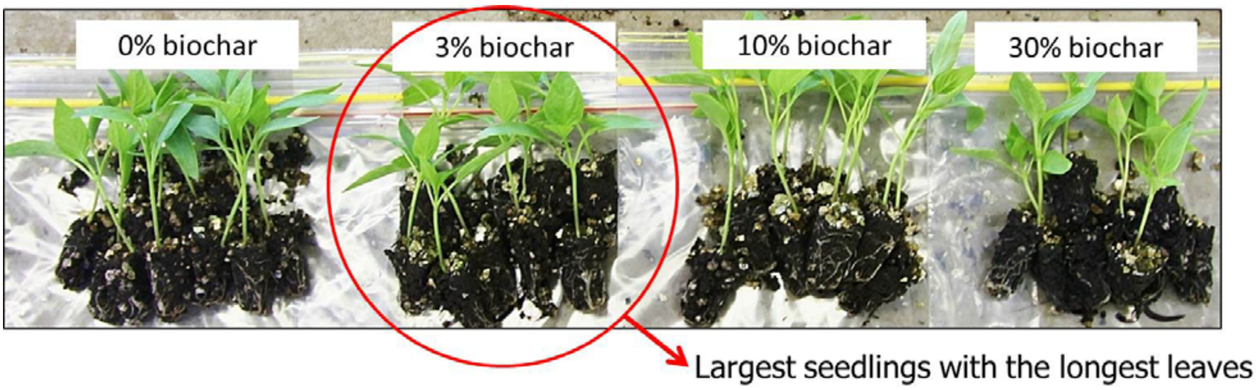


**Figure 20** Capsicum seedlings were the largest from propagation media where biochars replaced peat at 3%. Seedlings shown are at two weeks after germination and growing in media with peat replaced by 0, 3, 10 or 30% green waste biochar.

Biochar has previously been trialed as a substitute for peat, having the advantage of high water and nutrient retention but not readily decomposing like peat moss in media for turf, landscaping and container production (Tian *et al.*, 2012; Brockhoff *et al.*, 2010; Vaughn *et al.*, 2013). In this study, **media quality** assessement showed that:

- The **sugarcane biochar** had similar physicochemical properties to peat (Fig 21). Media containing sugarcane biochar had a similar EC, bulk density and water holding capacity to peat, regardless of the application rate (i.e. 3, 10 and 30% replacement).
- The **green waste biochar** significantly:
  - Increased salinity as application rates increased. At 30% biochar, the $EC_e$ of media was 4.9 dS $m^{-1}$, which would normally have negative impacts on most crops (Hazelton and Murphy, 2007; Handreck and Black, 2010). Hence feedstock used to make biochar should be non-saline (the green waste feedstock had an $EC_e$ of 11.3 dS $m^{-1}$, Kochanek *et al.*, 2015a).
  - Increased bulk density as application rates increased. However, even at the highest rate of 30% biochar, bulk density was still low at 0.16 g $cm^{-3}$ and should not adversely affect plant growth (0.3-0.6 g $cm^{-3}$ is recommended for standard potting media; Handreck and Black, 2010). Other researchers have found that replacing peat with biochar at rates >50% increased bulk density to undesirable levels and reduced plant performance relative to peat alone (Tian *et al.*, 2012).
  - Decreased water holding capacity as application rates increased. However, even at the highest rate of 30% biochar, WHC was still high at 81%.

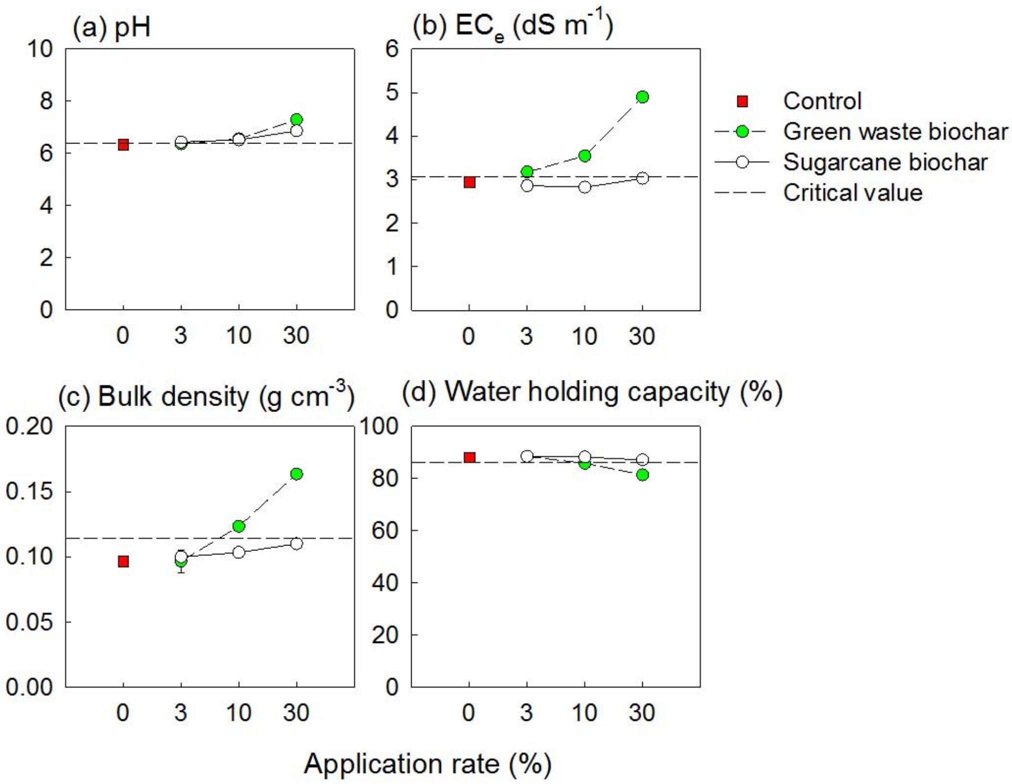


**Figure 21** Physicochemical properties of propagation media containing a sugarcane or green waste biochar peat replacement at 3, 10 or 30% or 0% biochar (control). Points show mean ± SE for media (a) pH, (b) salinity, (c) bulk density and (d) water holding capacity. Dashed lines are Dunnett's critical difference; means above the line, or below for water holding capacity, are significantly different to the control ($F_{6,14}$=301 (pH), 617 (EC), 33 (BD), 35 (WHC); $p$<0.001 for all treatments).

- Both biochars significantly increased pH from 6.3 for the control media up to 7.2 and 6.9 for the green waste and sugarcane biochars, respectively, at 30% application rates. These values exceed the recommended pH for growing media of 4.5-6.5 (ideal is 5.5-6.0; Handreck and Black, 2010).
- Air-filled porosity was significantly reduced by the green waste biochar at 10% application rate to 9.5%, compared to 12% in the control media. The other media were similar to the control, ranging from 10-13.8% (data not shown, $F_{6,14}=8.06$, $p=0.001$). All values fall within recommended levels for potting mixes (7-50%; Handreck and Black, 2010).

Overall, we recommend a biochar incorporation rate of 3-10% (v/v) media replacement to optimise plant growth and physicochemical properties since higher rates, such as 30 to 50%, tend to reduce plant performance (Kochanek *et al.*, 2014; Tian *et al.*, 2012). If biochars are made from clean feedstocks and are free from inhibitors (Kochanek *et al.*, 2014; Artiola *et al.*, 2012; Graber *et al.*, 2010), higher application rates may provide *better plant growth, but this will require grower validation.

**Table 3** General linear model analysis of variance and means for **capsicum versus tomato** (Species) seedling length at two weeks after germination testing the effect of a green waste biochar high in © or sugarcane biochar low in © (Biochar type) incorporated into media at four rates (Rate = 0, 3, 10, 30%).

| | Leaf | Hypocotyl | Shoot | DF |
|---|---|---|---|---|
| Block | ns (*p*=0.2) | ns (*p*=0.3) | ns (*p*=0.13) | 4 |
| **Biochar type** | ***** | **ns (*p*=0.7)** | ***** | **1** |
| Species | *** | ** | *** | 1 |
| Rate | * | *p*=0.054 | * | 3 |
| **Biochar type × Species** | ****** | **ns (*p*=0.4)** | ***** | **1** |
| Biochar type × Rate | ns (*p*=0.7) | ns (*p*=0.4) | ns (*p*=0.4) | 3 |
| Species × Rate | ns (*p*=0.2) | ns (*p*=0.4) | ns (*p*=0.2) | 3 |
| Type × Species × Rate | ns (*p*=1.0) | ns (*p*=0.6) | ns (*p*=0.9) | 3 |

Within each column, nonsignificant differences and significant differences at $P \leq 0.05$, 0.01 and 0.001 are indicated by ns, *, ** and ***, respectively. Values are the mean of three replicates of leaf biomass collected monthly as clippings (one replicate per block, three blocks). Data were not transformed prior to analysis. Residual degrees of freedom = 51.

**Table 4** General linear model analysis of variance and means for **capsicum or tomato** seedling length at two weeks after germination testing the effect of a green waste biochar high in © or sugarcane biochar low in © (Biochar type) incorporated into media at four rates (Rate = 0, 3, 10, 30%).

| | Capsicum | | | Tomato | | | |
|---|---|---|---|---|---|---|---|
| | True leaf | Hypocotyl | Shoot | True leaf | Hypocotyl | Shoot | DF |
| Block | ns (*p*=0.3) | ns (*p*=0.2) | ns (*p*=0.2) | ns (*p*=0.5) | ns (*p*=0.15) | ns (*p*=0.7) | 4 |
| Biochar type | ns (*p*=0.6) | ns (*p*=0.7) | ns (*p*=0.7) | ***** | **ns (*p*=0.14)** | ***** | **1** |
| Rate | ****** | **ns (*p*=0.07)** | ***** | ns (*p*=0.4) | ns (*p*=0.4) | ns (*p*=0.3) | 3 |
| Type × Rate | ns (*p*=0.9) | ns (*p*=0.5) | ns (*p*=0.7) | ns (*p*=0.9) | ns (*p*=0.7) | ns (*p*=0.8) | 3 |

Within each column, nonsignificant differences and significant differences at $P \leq 0.05$, 0.01 and 0.001 are indicated by ns, *, ** and ***, respectively. Values are the mean of three replicates of leaf biomass collected monthly as clippings (one replicate per block, three blocks). Data were not transformed prior to analysis. Residual degrees of freedom for tomato was 19 and for capsicum was 28.

*Note: Researchers have found that ethylene emissions from fresh biochar can influence plant growth negatively (Fulton *et al.*, 2013), while others absorb ethylene to enhance growth (Di Lonardo *et al.*, 2013). Fulton *et al.* (2013) recommended that biochars should be aged for 3 months prior to use to ensure ethylene is degassed (oxidized). Biochars in this study were >2 years old, so ethylene was unlikely to play a role in plant growth outcomes.

## Economic Viability

As the cost of commonly used amendments escalate or growers look to more environmentally friendly products, biochar could replace or be used alongside conventional media additives (Dumroese *et al.*, 2011). This study determined that biochar products were economically viable if compared to media additives such as peat, vermiculite and perlite (Table 5). For example, in this study biochar cost $0.07-0.40 per litre, while peat cost $0.13-0.26, vermiculate *c.* $0.27 and perlite $0.24-0.32. Sales of biochar have been tripling annually since 2008 for wholesale and consumer markets in the United States (Cernansky, 2015) and commercial biochar products are now available in Australia for $500-1000 per tonne or $250 $m^{-3}$ (bulk orders, factory door price, Kochanek *et al.*, 2014). The up-scaling of biochar facilities would further reduce biochar product cost.

**Table 5** Comparing the cost of biochar to common growing media additives ($ per litre).

| | Cost ($ per L) | |
|---|---|---|
| Product | Minimum | Maximum |
| Sugarcane biochar | 0.07 | 0.14 |
| Green waste biochar | 0.20 | 0.40 |
| Peat | 0.13 | 0.26 |
| Vermiculite | 0.27 | - |
| Perlite | 0.24 | 0.32 |

Wholesale prices were supplied by Garden City Plastics in Oct 2014. Density was 140 g $L^{-1}$ for the sugarcane biochar (*c.* 7 L $kg^{-1}$) and 400 g $L^{-1}$ for the green waste biochar (*c.* 2.5 L $kg^{-1}$). The maximum and minimum cost for biochars is based on their current cost of $1000 per tonne and expected price in the near future of $500 per tonne, respectively (Kochanek *et al.*, 2014).

Other studies have demonstrated that biochar may successfully substitute peat (for tomato and marigold, Vaughn *et al.*, 2013) and vermiculite (for reforestation and ecosystem restoration, Dumroese *et al.*, 2011), exhibiting desirable characteristics for container production. Biochar is also purported to improve plant drought tolerance (*Artiola *et al.*, 2012) and Table 6 shows that on a weight basis, biochar may be as or more economically viable as common wetting agents. More work is needed to validate biochar as a wetting agent and determine its economic viability for this use (beyond study scope). Biochar is also showing promise for cleaning up polluted water and is cheaper than activated charcoal, currently used for this function (Cernansky, 2015; Beck *et al.*, 2011).

**Table 6** Comparing the cost of biochar to common wetting agents ($ per tonne).

| | Cost ($ per tonne) | |
|---|---|---|
| Product | Minimum | Maximum |
| Biochar | 500 | 1000 |
| Earthcare water crystals | 10400 | - |
| Hydraflo | 2700 | 4250 |
| MoisturAid | 3411 | - |

Wholesale prices were supplied by Garden City Plastics in Oct 2014. The current cost of biochar is $1000 per tonne, expected to drop to $500 per tonne (Kochanek *et al.*, 2014).

The potential for environmental benefits of biochar products adds even greater potential value, such as for 'green product' labeling and carbon credits. For example, replacing media additives which have environmental costs - such as peat moss and vermiculite – with products made from locally available organics is an environmental bonus. There is also the option to use heat from pyrolysis for other applications. By contrast, vermiculite must be heated to 900°C, while peat mining involves the draining and destruction of wetlands, and both are often shipped long distances (Fulton *et al.*, 2013).

*In a one month drought experiment, 100% of bermudagrass plants grown from seed survived in a 4% biochar amended media, while 50% survived in media with 2% biochar and all plants were killed in media without biochar (Artiola *et al.*, 2012).

## The Australian Blueberry Industry

### Grower summary:

Compost and biochar, applied together, were a winning combination for blueberry yields and soil health over the long term. The synergistic use of compost and biochar has been suggested for field applications to improve soil physical, nutrient and water retention attributes (Liu *et al.*, 2012), add a stabilised carbon source for synergistic carbon sequestration (Schulz and Glaser, 2012) and to adsorb contaminants (Beesley and Dickinson, 2010; Karami *et al.*, 2011). In this study, the biochar and compost combination increased yield more than other treatments in both years, although the first fruit harvest in 2013 revealed a significant 58% increase in fruit yield, while in 2014 the non-significant increase was 12% relative to the control. Soil health was most consistently improved by the compost and biochar combination across years and, in 2014, cation exchange capacity was increased by 34% and soil carbon content by 25% above the control. This suggests that the soils in the compost and biochar combination are healthier, with better structure, buffering capacity and ability to retain nutrients than in control plots and agrees with meta-analyses, which have correlated crop yield increases in soil most consistently with CEC and soil carbon improvements (Crane-Droesch *et al.*, 2013).

Biochar without compost either did not enhance or slightly reduced fruit yield (by up to 10%) during the 2014 harvest, suggesting that biochar without compost may not benefit crop production in this soil type over the long term (also observed by researchers on other soils, e.g. Quilliam *et al.*, 2012, Schmidt *et al.*, 2014). Conversely, adding biochar to compost appeared to accelerate compost benefits; for example, in 2013 compost reduced yield by 12% but increased yield by 8% in 2014 relative to the control, while its combination with biochar increased yield in both years (58 and 12% in 2013 and 2014, respectively). Multivariate analysis will simultaneously model soil, yield and plant growth parameters to determine possible reasons for the observed effects for a journal publication.

The study concluded that the combination of biochar and compost products show potential to provide a complementary and beneficial effect for fruit yield and soil health over the long term. Economic analyses for such systems are needed, being beyond the scope of this study.

**Figure 22** Soil scientist Justine Cox (NSW DPI) during the 2014 fruit harvest, with pickers collecting blueberries from the commercial crop in the background. Inset is a bush bearing fruit.

**Methods:** A commercial blueberry field trial was set up in 2011 with soil scientist Justine Cox and Managing Director, Mr Ridley Bell. The study tested three biochars (two from green waste, one from sugarcane), a green waste compost and a compost and biochar combination, incorporated at 30 t $ha^{-1}$ each into the top 10 cm soil surface (Kochanek *et al.*, 2014, 2015a). Berry yields were measured in 2013 (HG10025) and 2014 (Fig 22). Soil characteristics determined in 2014 were EC, pH, total carbon and nitrogen, extractable phosphorus, nitrate ($NO_3^-$), ammonium ($NH_4^+$), cation exchange capacity and exchangeable cations.

**Results:** The combination of biochar and compost products continued to work best, demonstrating a complementary effect of biochar and compost co-application consistent with project HG10025. Overall, the positive effects on yield were less dramatic and non-significant, while soil health continued to be consistently improved by this combination.

**Fruit yield in 2014:** There was a non-significant trend towards the biochar and compost combination enhancing fruit yield more than other treatments (Fig 23). Key observations:

- Fruit yield per plant increased by *c.* 12% above the control by the biochar and compost combination (Fig 23(ii)). In 2013, yield was improved by 58% by this treatment.
- The compost treatment performed almost as well as the biochar and compost combination in 2014, increasing fruit yield per plant by 8.3% above the control (Fig 23(ii)). In 2013, the compost treatment reduced fruit yield by 12% relative to the control.
- Rhizosphere soil samples will describe the microbial population in the biochar and compost combination relative to the control (Fig 24).
- Biochar without compost did not enhance fruit yield over the longer term. In 2014, fruit yield was either similar to the control or reduced by up to *c.* 10% with biochar incorporation, particularly for Technology C biochars.

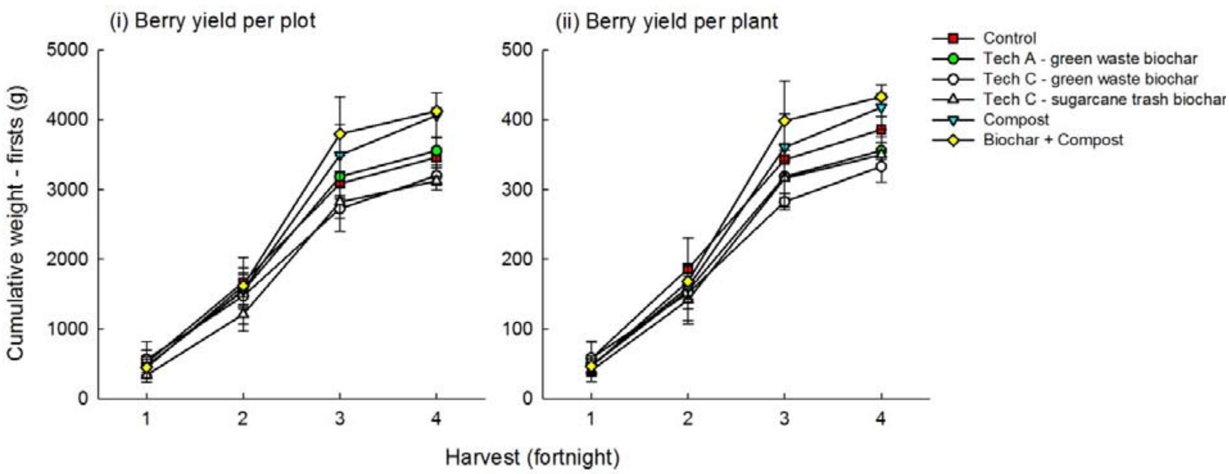


**Figure 23** The cumulative fruit yields of marketable blueberry fruit (firsts, mean ± SE) collected during the second harvest in 2014, showing the average yield (i) per plot, where plant death was not accounted for or (ii) per plant, where plant death was accounted for (Treatment and Treatment×Harvest $p$>0.5).

**Figure 24** The rhizosphere soil was sampled in early 2014 to compare microbial populations across treatments (awaiting analysis).

**Soil characteristics in 2014:** The biochar and compost combination most consistently enhanced soil health, as in 2013. Key observations:

- **Cation exchange capacity** was significantly increased by the biochar and compost combination and the compost treatment by 34% relative to the control (Fig 25a), increasing the soil CEC from 'low' to 'moderate' (Hazelton and Murphy, 2007). For the grower, increased CEC means healthier soils. Such soils can, for example, better hold and exchange cations such as potassium, calcium and magnesium, maintain a desirable pH, retain available nutrients and maintain good structure (Hazelton and Murphy, 2007).
- **Soil carbon content increased** significantly with the biochar and compost combination and one biochar (green waste, Tech A) by *c.* 25% above the control (Fig 25b), consistent with 2013 results. Soil carbon was *c.* 5.7% for these treatments (down from *c.* 6.5% in 2013) but only 4.6% for the control (down from 5% in 2013). Maintaining high organic soil carbon promises improved soil structure and stability for the grower (Hazelton and Murphy, 2007). Similarly, soil carbon content was doubled in the 2014 turf trial by both the sugarcane and green waste biochars, from 0.6% for the control to 1.2% with biochar additions ($F_{2,3}$ = 13.7, $p$=0.03), while CEC, N, P and K were not significantly different across treatments.

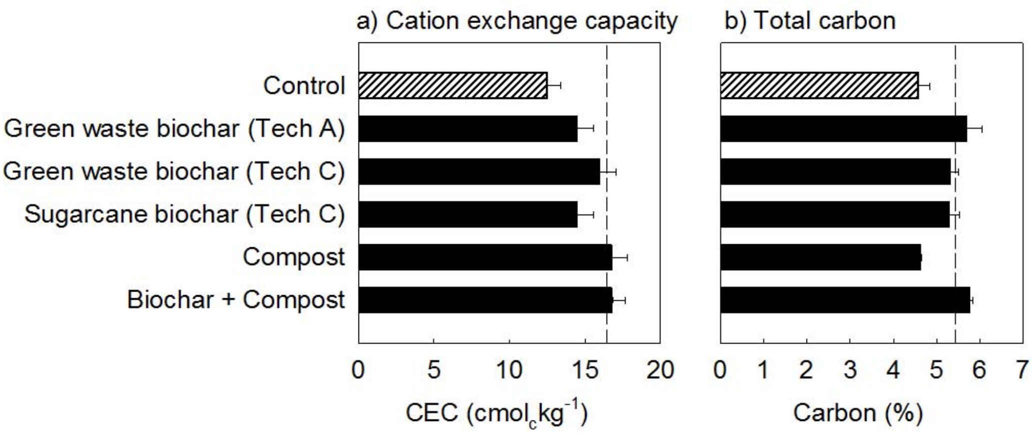


**Figure 25** Soil characteristics from the blueberry field trial in late 2014. Bars show means ± SE for (a) cation exchange capacity and (b) total carbon for each treatment. Dashed lines are Dunnett's critical difference; means to the right of the line are significantly different to the control (CEC $F_{5,18}$=2.72, $p$=0.05; carbon $F_{5,18}$=5.39, $p$=0.003).

- **Nitrate and ammonium were not retained** by treated soils above control values (data not shown), consistent with 2013 results. Thus organic products will not necessarily retain nitrates and ammonium for plant growth or prevent their leaching into waterways (Yao *et al.*, 2012).
- **Other nutrients were not retained** in soils above control values (data not shown). Leaf analyses will determine plant nutrient status across treatments (Fig 26, awaiting analysis).

**Figure 26** Leaves were collected in late 2014 for nutrient determination (awaiting analysis). From left, horticulturalist Chris George (UQ) and soil scientists Justine Cox and Michael Davy (NSW DPI).

## Biochar Safety and Certification

In this study, a preliminary analysis of biochar safety was conducted for potential biochar users. Polycyclic aromatic hydrocarbon (PAH) levels were quantified at the University of Queensland, National Research Centre for Environmental Toxicology, by PhD Candidate Jennifer Braunig, Dr Daniel Drage and Prof Jochen Mueller. PAHs were determined because their formation during pyrolysis is likely and high concentrations can adversely affect human and environmental health (Fabbri *et al.*, 2013). Since May 2013, the International Biochar Initiative (IBI) has provided biochar manufacturers with the option to certify that their biochars meet quality standards and are safe for application to soil (http://www.biochar-international.org/characterizationstandard, accessed March 2015). The IBI quality standards recommend PAH concentrations of <6-300 mg $kg^{-1}$, where values above the maximum would not be acceptable for use as a soil amendment or fertiliser (based on the sum of 16 US EPA PAHs, *viz.* those on the US Environmental Protection Agency priority list; IBI, 2014). Standards for European Biochar Certification recommend <4 mg $kg^{-1}$ PAHs for premium biochars and <12 mg $kg^{-1}$ for basic biochars (EBC, 2012; Hilber *et al.*, 2012). Preliminary results from this study have so far shown **low PAH concentrations that would classify these biochars as 'premium' and safe for soil application by the European Biochar Certification program** (EBC, 2012; Hilber *et al.*, 2012), the total PAH concentration being 0.1 to 1.2 mg $kg^{-1}$ (Σ 16 EPA PAH) for biochars made by Technologies A and B (green waste biochar, 0.4-1.2 mg $kg^{-1}$; woodchip, 0.1 mg $kg^{-1}$; papermill waste, 0.2 mg $kg^{-1}$). These values are comparable, for example, to PAH quantities in fresh spent mushroom compost (0.5 mg $kg^{-1}$ PAHs, Garcia-Delgado *et al.*, 2013). Furthermore, the four PAHs with human health impacts, benzo[a]pyrene, dibenz[a,h]anthracene, benzo[b]fluoranthene, and benzo[k]fluoranthene (Li *et al.*, 2015), were in negligible concentrations, making up <10% of the PAH profile (sum of these PAHs in biochar from green waste was 0.04-0.08 mg $kg^{-1}$; woodchip, 0.001 mg $kg^{-1}$; papermill waste, 0.01 mg $kg^{-1}$). Recoveries were poor for Technology C biochars, so are not yet available. These results will be released as a journal publication once the dataset is complete.

## Communication and Extension

**Extension** communicated R&D outcomes to growers, city waste managers, government and the general public. The project was communicated via:

**1. On-line Information**
R&D outcomes were published in the **HIA Hortlink magazine** autumn 2015 edition. An on-line **video** documented project outcomes via interviews with grower (Mr John Keleher, Turf Australia), government (Ms. Christine Blanchard, BCC Waste Minimization Manager) and research (Dr Jitka Kochanek, UQ) stakeholders.

**2. Public demonstration:** MT13042 was demonstrated to the city public by Dr Kochanek via a nursery display and poster at Brisbane City Council's Green Heart Fair in October 2014 (Fig 27; http://www.citysmart.com.au/greenheartfair).

**Figure 27** The Green City Loop project was demonstrated at Brisbane City Council's Green Heart Fair by Dr Jitka Kochanek, with (left) Ms. Lyn Comiskey, BCC Program Officer for Waste Education (photo: Brisbane City Council) and (right) industry leader, Mr Alistair Pritchard, CEO of Zoomgarden nursery (photo: Mark Kochanek). There was a strong emphasis on promoting the benefits of plants and green environments in our cities using the 'closed green loop' scenario i.e. uncontaminated green organics will enhance city green space, which will in turn benefit society through improved urban health and wellbeing (Nursery and Garden Industry, 2012; Turf Producers Australia, 2012).

**3. Conference presentation 1**
Dr Kochanek presented HG10025 and MT13042 as an oral paper at **The 29th International Horticultural Congress**, *Sustaining Lives, Livelihoods and Landscapes,* Brisbane**,** 17-22 August 2014. The presentation was extremely well received and Dr Kochanek answered many questions from the audience.

**4. Conference presentation 2**
Dr Kochanek presented MT13042 as a poster at the *Blue Sky Thinking, Real Green Living*, **Nursery and Garden Industry Conference** Darling Harbour, 10-13$^{th}$ March 2014. Dr Kochanek attended the conference, field day and events and made valuable contacts within NGIA, NGIQ and HIA.

**5. Conference presentation 3**
Dr Kochanek prepared an oral paper and handouts about HG10025 and MT13042 for the **2014 Annual Arboriculture Conference** at the Novotel Twin Waters on the Sunshine Coast, 4 - 8 April 2014. Ms. Christine Blanchard (Waste Minimisation Manager, BCC) presented the paper.

**6. Conference presentation 4**

Soil scientist Justine Cox and Dr Kochanek prepared a poster titled "Biochar and compost combination superior to single ameliorant inputs in a blueberry orchard soil" for the National Soil Science Conference, MCG, Melbourne, Victoria, 23-27 November 2014. The poster was presented by Ms. Cox.

**7. Field day 1 – growers and scientists**

Soil scientist Justine Cox and Dr Kochanek ran a field day for *c.* 40 delegates from **The 29th International Horticultural Congress** on 23rd August 2014 to view the long-term field trial at Mountain Blue Orchards (Fig 28, 29).

**Figure 28** The long term field trial at Mountain Blue Orchards was demonstrated to delegates from the International Horticultural Congress with Justine Cox (NSW DPI) and Ridley Bell (Managing Director). Terrible weather didn't hold back the keen horticulturalists!

**Figure 29** Soil scientist Justine Cox (left) and industry leader Ridley Bell (right) speaking about the Mountain Blue Orchard trial to Horticultural Congress delegates, with Philip Wilk, NSW DPI Blueberry Industry Development Officer.

**8. Field day 2 – growers, government and industry**
Dr Kochanek and Ms Blanchard organised a field day and oral paper for growers, city waste managers, Queensland Government and waste recycling industry delegates at the Australian Lawn Concepts grower trial/demonstration site in July 2014 (Fig 30). Queensland Government delegates were highly impressed by HG10025 and MT13042 project outcomes and grower, industry, government and research collaboration. They were keen to work with the team towards new legislation to make organic waste recycling facilities with novel technologies (such as pyrolysis) possible in Queensland.

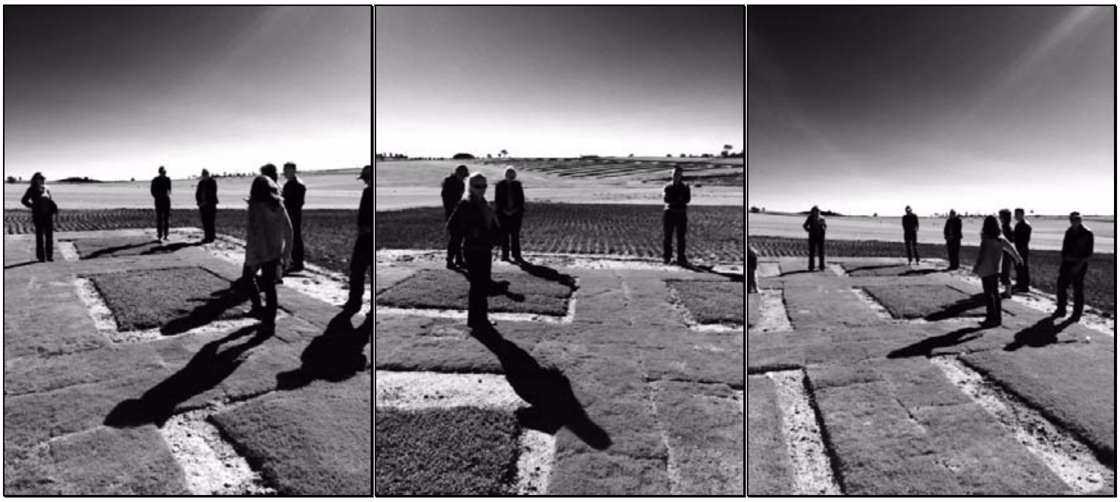

**Figure 30** Dr Kochanek presenting the Australian Lawn Concepts grower trial to growers, city waste managers and delegates from the Queensland Government and waste recycling industry (Photos: Mr John Keleher).

**9. Project communication to Urban Waste Managers**
An oral paper was presented to the Brisbane City Council Waste Management team in Nov 2014 to communicate outcomes from HG10025 and MT13042. The audience numbered about 50 and feedback was strong encouragement to continue this work into future projects.

**10. Paper accepted for publication in Acta Horticulturae**
Kochanek J, Cox J, Kochanek MA, Swift R, Flematti GR. 2015. A systematic approach to recycling organics for horticulture: comparing emerging and conventional technologies. *Acta Horticulturae*. **In print.**

**11. Paper submitted**
Kochanek J, Kochanek MA, Flematti GR, Swift R. 2015. Properties of biochars prepared principally from one feedstock using three pyrolysis technologies. **In Review.**

**12. Cost benefit analysis for biochar use in horticulture.** Submitted to HIA in July 2014.

**13. Two strategy meetings** were held in January 2014 and March 2015 with government (BCC), grower (TPA and NGIA) and research (UQ) stakeholders.

# OUTCOMES

All outcomes were achieved during this project, specifically:

**1. New market opportunities were demonstrated within Horticulture for productivity-enhancing and economically viable products made from green organics.**

(i) The benefits and shortcomings of products from green organics were validated with industry leaders from The Australian Turf and Nursery & Garden Industries (also applicable for the vegetable industry). An additional outcome was continuation of a long-term grower trial for the Perennial Fruit Industries.

- **Turf** grower trials concluded that biochar has real potential as a product for landscaping if mixed into growing media or soil prior to laying turf. Industry optimisation will be needed for consistent outcomes.
- **Nursery** grower trials concluded that biochar has real potential for the Australian Nursery & Garden and Vegetable Industries, provided products are optimized for grower needs. Trials at Zoomgarden nursery confirmed that the best products accelerated vegetable seedling growth without compromising quality, fit within existing infrastructure, were economically viable and environmentally sustainable – replacing unsustainably harvested peat with products made from Brisbane city's green waste or farm trash.
- Biochar products were **economically viable if used to replace media additives**, being cost-comparable to commonly used products such as peat, vermiculite and perlite. The up-scaling of biochar facilities would further reduce product cost.
- Long term trials in a commercial blueberry orchard concluded that the combination of biochar and compost products show potential to provide a complementary and beneficial effect for fruit yield and soil health (consistent with project HG10025). Economic analysis for such systems in needed (beyond scope).

(ii) For long term benefits and market expansion, future industrial test sites will ideally tailor products to enhance grower productivity and expand market opportunities for horticulture. Both urban and perennial horticulture have been shown to be potential markets:

a) Biochars for markets such as turf and nursery production

- High value, industry-optimised biochars dosed with plant promoting compounds and/or microbes is one promising future scenario for recycled organics,
- Products should be made from high quality feedstock (particularly for food crops) and inhibitor-free to ensure consistent growth outcomes across varieties and lines.

b) Perennial horticulture

- Complementary production and combination of biochar and compost products may be optimal for longer-term horticulture, such as for fruit and ornamental tree and shrub markets, to boost fruit yield, plant performance and soil health.
- Trials are needed to test application methods to minimize costs. For example, pre-placing biochar and compost products into growing media during container production may minimize the cost of product use without compromising in-ground plant growth benefits.

(iii) Just some examples of potential economic, social and environmental impacts from new recycled organic products, as demonstrated in HG10025 and this project:

- Climate change adaption: Green organics have potential to enhance climate change adaption of nursery, turf, vegetable and perennial production systems through, for example, improved plant performance (e.g. rapid and more reliable plant establishment) and improved resistance to abiotic (e.g. drought) and biotic stress (e.g. fungal pathogens).
- Climate change mitigation: Products from green organics, such as biochar and compost, can sequester carbon for hundreds to thousands of years (Sohi *et al.*, 2010, Laird, 2008), enhance plant growth to capture more carbon and reduces emission from landfill (Rhyner *et al.*, 1995).
- Sector innovation and new market opportunities: The potential for improved productivity for the nursery, turf, vegetable and perennial industries were demonstrated with the best organic products.
- Potential spill-over benefits for society from new products, for example:
    - Improved human and environmental health via improved soil and water quality,
    - Climate change mitigation via biochar and compost carbon sequestration,
    - Reduced emissions from landfill and less land required for landfill sites,
    - Greenlife to improve health of residents, increase house prices (NGIA, 2012; TPA, 2012).

**2. Outcomes were communicated widely to growers, city waste managers, researchers and the general public, concomitantly providing publicity for each sector:**

- On-line multimedia:
    - HIA Hortlink magazine, autumn 2015 edition,
    - On-line video with grower, local government and research stakeholders.
- Public demonstration to urban residents (poster and grower display).
- Industry and scientific conference presentations:
    - Oral paper at The 29th International Horticultural Congress (August),
    - Poster at the Australian Nursery & Garden Industry Conference (March),
    - Oral paper at the Annual Arboriculture Conference (April),
    - Poster at the National Soil Science Conference (Nov).
- Other industry and government communication:
    - Field day at Mountain Blue Orchards, International Horticulture Congress delegates (Aug),
    - Field day and oral paper at Australian Lawn Concepts for growers, city waste managers, Queensland Government and waste recycling industry delegates (July),
    - Oral paper to the Brisbane City Council Waste Management team (Nov),
    - Two strategy meetings with industry, government and researchers (Jan 14, Mar 15).
- Other publications:
    - Paper accepted for publication in *Acta Horticulturae*,
    - Paper submitted to peer-reviewed scientific journal *Bioresource Technology*,
    - Conference proceedings of the Australian Society of Soil Science.

**3. Due to extensive collaboration and communication, new linkages were made between the Australian Turf and Nursery Industries, HIA, BCC and UQ.**

**4. Industry demonstration sites, meetings and presentations were a vehicle towards State and Local government support for future market development. For example:**

- The project was presented to growers, city waste managers, Queensland Government and waste recycling industry delegates at the Australian Lawn Concepts demonstration site. Queensland Government were keen to work towards new legislation for organic waste recycling facilities with novel technologies (such as pyrolysis) in Queensland.
- An oral paper presented to the Brisbane City Council Waste Management team received strong encouragement to continue this work.
- Dr Kochanek supported Brisbane City Council waste recycling initiatives, for example, by presenting the project and grower demonstrations at the public educating 'Green Heart Fair'.

# EVALUATION AND DISCUSSION

The project was a success and all outcomes were achieved.

## Scientific Summary

In this study, grower validation trials with leaders from the Australian Turf and Nursery & Garden Industries tested two biochars that consistently enhanced plant growth in project HG10025. During HG10025, a plant growth promoting compound was found at high concentrations in certain biochars but low in others and is termed 'compound ©' in this report. To begin to understand the potential effectiveness of biochar and this compound for horticulture, two biochars from HG10025 were selected for grower trials – one biochar was low in compound © but exhibited superior physicochemical properties and one biochar high in compound © but with poorer qualities (more saline, higher bulk density, lower water holding capacity).

Results showed that crops grown in soil or media with high compound © biochar generally performed better than the low compound © biochar or media without biochar (control). Wintergreen Couch for turf and tomato for nursery production showed a particularly impressive 34% and 12% improvement in plant performance, respectively, with the high compound © biochar relative to the control (Fig 31). Capsicum seedling development was enhanced by both biochars by about 20% above the control. Buffalo turf growth was inconclusive as biochar initially reduced plant performance relative to the control, possibly as a result of inhibitors described in HG10025. However, stolons harvested in spring showed a non-significant trend towards biochar increasing stolon biomass by up to 20% above the control. These results are promising and warrant further investigation in future research. More work is needed to determine whether compound ©, biochar or their combination is responsible for improvements in plant growth.

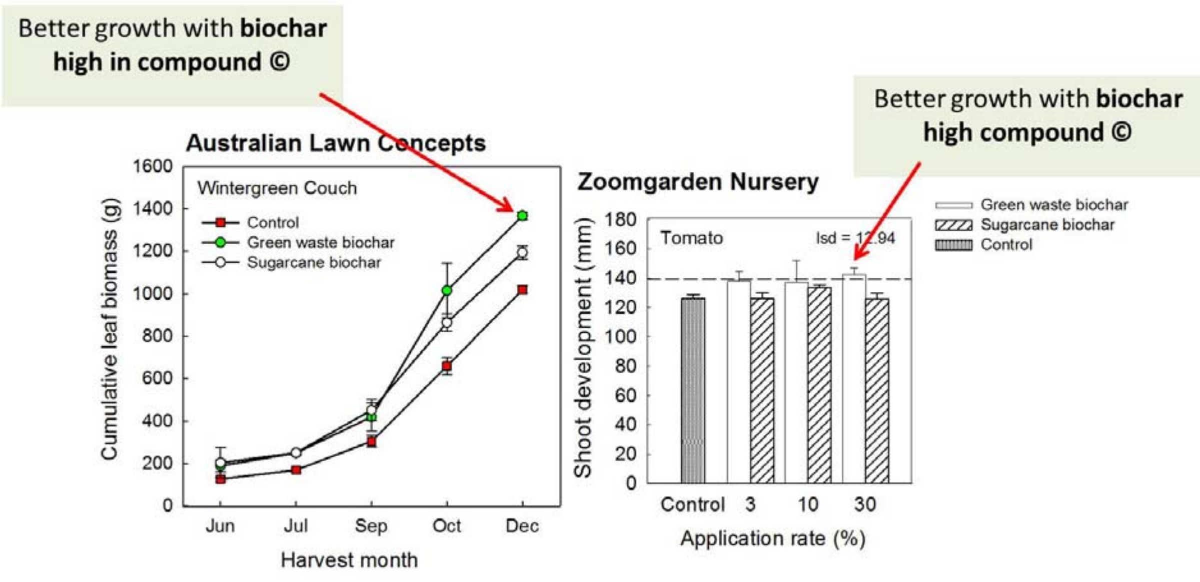


**Figure 31** Grower trials confirmed that biochar high in compound © most consistently improved plant performance for turf (left) and tomato seedlings (right), consistent with project HG10025. Points or bars denote the mean (± SE) and, for tomato, the dashed line indicates Dunnett's critical value, where means above the line are significantly different to the control.

A combination of biochar and compost products worked best in long term perennial fruit production, demonstrating a complementary effect of biochar and compost co-application, consistent with HG10025 results. The biochar and compost combination significantly enhanced soil health by increasing cation exchange capacity and carbon content above the control and there was a trend towards the highest fruit yields being from the biochar and compost combination plots (non-significant).

## Outcomes Summary

1. New market opportunities were demonstrated for novel products from green organics:

- Urban horticulture are potential markets, *viz.* the Australian Turf and Nursery & Garden Industries,
- Industries that sow nursery-raised transplants or plants, such as the Australian Vegetable Industry, are potential markets,
- For nursery-raised seedlings, the best biochar products increased plant growth by 12-20%,
- For one turf variety the best biochar products increased plant growth by 34%. Results were inconclusive for the second variety,
- Biochar products were economically viable if replacing media or soil additives, such as peat,
- Products can be environmentally beneficial if replacing unsustainable products, such as peat,
- Industry optimisation of novel products is needed for consistent outcomes,
- Products should be made from high quality feedstocks and inhibitor-free,
- Biochars dosed with plant promoting compounds or microbes promise new, high value products.

- Perennial horticulture are potential markets, *viz.* fruit and ornamental tree and shrub producers,
- The best products boosted fruit yield, plant performance and soil health over 3 years,
- A combination of biochar and compost products were optimal, better than each product on its own,
- Mixing products into media during container production may be one way to minimise the cost of products, but benefits need to be validated,
- Economic analysis for perennial horticulture is needed.

2. Project impacts are expected to be wide-reaching due to extensive communication of outcomes.

Communication to growers, government, waste managers, researchers and the public was via:
- On-line multimedia, *viz.* HIA Hortlink magazine and an on-line video,
- A public demonstration to urban residents, including a grower display,
- Four conference presentations, *viz.* two oral papers and two posters,
- Two field days, *viz.* Mountain Blue Orchards and Australian Lawn Concepts grower trials,
- Two industry and government oral presentations,
- Two project strategy meetings with industry, government and researchers,
- Three peer-reviewed scientific publications,
- Two additional scientific publications are in preparation.

Towards Commercialisation:

Overall, this study has demonstrated that novel products made from recycled organics promise enhanced grower productivity, environmental sustainability and expanded market opportunities for horticulture if optimised for each specific industry. Towards commercialization:

- Industry optimisation of novel products is needed for consistent outcomes,
- Products should be made from quality feedstocks and inhibitor-free, particularly if used for plant establishment benefits and food crops,
- Biochars dosed with plant promoting compounds and/or microbes promise new, high value products for shorter-term benefits, such as nursery-raised transplant or plant establishment,
- Complementary production and combination of biochar and compost products may be optimal for longer-term horticulture, such as for fruit and ornamental tree and shrub production,
- The ideal next step is industrial test sites that will tailor products to match grower needs.

# RECOMMENDATIONS

## Recommendations to Industry/Growers

**Potential uses/markets** for biochar products in horticulture identified by this study:

- The Australian Turf Industry
  - For landscaping, if mixed into growing media or soil prior to laying turf.
- The Australian Nursery & Garden Industry
  - To accelerate plant growth and replace unsustainable media additives, such as peat.
- Industries that sow nursery-raised transplants/plants, such as the Australian Vegetable Industry
  - To accelerate growth,
  - Enhanced survival of transplanted crops requires validation.
- Perennial horticulture, such as fruit and ornamental tree and shrub production
  - If combined with compost, to boost fruit yield, plant performance and/or soil health over the longer term.
- Environmental stewardship
  - To replace non-sustainable additives with products made from recycled organics (e.g. peat),
  - To sequester carbon and enhance soil health.

**Economics** of biochar for horticulture:

- Biochar products are economically viable if replacing media or soil additives -
  - Biochar is currently cost-comparable to peat, vermiculite and perlite,
  - The up-scaling of biochar facilities promises to further reduce cost into the future.
- Economic analysis for perennial horticulture is needed.

**Future opportunities**:

- A new compound for better plant growth:
  - A plant promoting compound was identified in biochars (termed compound © in this report);
  - Biochars containing high amounts of compound © generally improved plant growth more than those with low amounts,
  - Compound © may become a stand-alone product for horticulture into the future,
  - Research is needed to determine whether compound ©, biochar or their combination is responsible for improvements in plant growth.
- High value biochar products for short-term use:
  - Clean biochars dosed with plant promoting compounds and/or microbes promise improved productivity,
  - Some potential uses are for accelerated turf and nursery plant production, hence productivity gains.
- Long-term benefits with biochar and compost co-application:
  - The combination was better than each product alone over the long term,
  - May accelerate compost benefits,
  - May benefit fruit, ornamental tree and shrub production, needs to be validated for turf production (biochar was tested alone).

**Future challenges and recommendations:**

- Biochar is an emerging technology and requires industry-specific optimization.
- The ideal next step is industrial test sites that tailor products to match grower needs.
- For consistent, positive outcomes of biochar:
  - Quality feedstocks must be used - e.g. no or low soil, salt and heavy metal contamination,
  - Biochars should be inhibitor-free,
  - Particularly vital during sensitive stages such as seed germination and plant establishment

and for food crops.

- Broad-acre application poses cost and logistical issues, particularly for regularly tilled systems:
  - For example, direct application to soils for vegetable production is not recommended,
  - Instead, products may be mixed into media at the nursery prior to sowing in-field.
- Growers are encouraged to test biochars in small on-farm trials prior to wide-scale use.
- Preliminary analyses of toxin concentrations have so far classified biochars in this study as 'premium' and safe for soil application (PAH levels, European Biochar Certification program, EBC, 2012). Results will be released as a publication and made available to growers once complete.

## Recommendations to Investment Decision Makers

**Opportunities** for future R&D:

**A new compound for better plant growth**

- In HG10025 a plant promoting compound was identified in biochars (termed compound ©):
  - In literature, this compound is known to accelerate germination and growth in many plants,
  - Benefits have not been validated for horticulture.
- This study demonstrated:
  - Biochars containing high amounts of compound © generally improved plant growth more than those with low amounts.
- Key future R&D opportunities:
  - This compound could become a stand-alone product for horticulture into the future,
  - Research is needed to determine whether compound ©, biochar or their combination is responsible for improvements in plant growth,
  - Improved germination and accelerated plant growth with compound © need to be validated for key lines for industries such as The Australian Nursery & Garden Industry and Vegetable Industry.

**Biochar dosed with plant promoting compounds/microbes**

- This study demonstrated:
  - A 12-34% increase in plant productivity with biochar for three out of four varieties tested.
- Key future R&D opportunities:
  - Dosing biochars with compounds and/or beneficial microbes promises even greater increases in productivity than with biochar alone,
  - Optimisation for each industry is recommended, for example:
    - Germination promoting compounds added for nursery seedling production,
    - Fertilisers and microbes may be added to biochars for turf production,
  - Promising high-value future products from recycled organics,
  - Requires R&D and economic analyses to ensure viability.

**Biochar and compost co-application** for long-term benefits

- This study demonstrated:
  - The combination of biochar and compost was better than each product alone over 3 years,
- Ideally the long-term trial would be continued to ascertain benefits over 5 years.
- Key future R&D opportunities:
  - Determine whether biochar speeds up the composting process at industrial test sites,
  - Validate whether biochar accelerates the benefits of compost on-farm at other sites,
  - Potential to benefit fruit, ornamental tree, shrub and turf production needs to be validated and products optimized for each industry.

**Other future R&D opportunities:**

- For industries that sow nursery-grown plants, such as vegetable transplants (Vegetable Industry):
  - Determine if new products identified in this study improve in-field survival.
- For the Australian Turf Industry, determine if:
  - Plant growth is enhanced more by compost and biochar combination than biochar alone,
  - Products in this study accelerate turf erosion control and improve water runoff quality.
- For perennial horticulture determine if:
  - Compost and biochar added to potting media during nursery propagation convey similar plant growth benefits as direct application to the soil,
  - Compost and biochar co-application are economically viable, comparing nursery media versus on-farm soil application.

## Recommendations to Government / Policy Makers

**Potential new markets in horticulture** for biochar and compost products (identified in this study)

- The Australian Turf Industry (biochar).
- The Australian Nursery & Garden Industry (biochar).
- Industries such as the Australian Vegetable Industry, that sow nursery-raised transplants/plants (biochar).
- Perennial horticulture (biochar + compost).
- Industries that market environmental stewardship, for example:
    - To replace non-sustainable products with those made from recycled organics (e.g. biochar to replace peat or vermiculite),
    - To sequester carbon and enhance soil health (biochar + compost).

**Economics** of biochar for horticulture

- At current biochar pricing, *viz.* $500-1000 per tonne (dry weight):
    - Products are economically viable if replacing media or soil additives,
    - Cost-comparable to peat, vermiculite and perlite.
- Economic analysis for perennial/broad acre horticulture is needed.
- Up-scaling of biochar facilities:
    - Promises to reduce costs for growers, further expanding market opportunities,
    - For example, biochar use in broad-acre horticulture may become economically viable.

**Future challenges and recommendations**

- Biochar is an emerging technology and requires industry-specific optimisation.
- The ideal next step is industrial test sites that tailor products to match grower needs:
    - Operators should work closely with growers and researchers to create products that each horticultural system/industry needs.
- For food crops and high value commodities, such as turf and nursery crops:
    - Quality feedstocks must be used, e.g. no or low soil, salt and heavy metal contamination,
    - Biochars must be inhibitor-free,
    - Toxicological analyses should be performed when new production methods or feedstocks are trialed (e.g. polycyclic aromatic hydrocarbons).
- Compost and biochar production is complementary:
    - Biomass that readily decomposes is ideal for compost production, while woody feedstocks are best for biochar production,
    - Applied together, these products promise to enhance yield, plant performance, soil quality and carbon sequestration over the long term for perennial crops,
    - Biochar may accelerate compost benefits.
- Future R&D opportunities are in 'Recommendations to Investment Decision Makers'.

# SCIENTIFIC REFEREED PUBLICATIONS

Journal article

Kochanek, J., Kochanek, M.A., Flematti, G.R., Swift, R., 2015. Properties of biochars prepared principally from one feedstock using three pyrolysis technologies **In Review.**

Chapter in a book or Paper in conference proceedings

Kochanek, J., Cox, J., Kochanek, M.A., Swift, R., Flematti, G.R., 2015. A systematic approach to recycling organics for horticulture: comparing emerging and conventional technologies. *Acta Horticulturae* **In Print.**

Cox, J., Kochanek, J., 2014. Biochar and compost combination superior to single ameliorant inputs in a blueberry orchard soil. In: Patti, A., Tang, C., Wong, V. (Eds.), Proceedings of the Soil Science Australia National Soil Science Conference: Securing Australia's soils - for profitable industries and healthy landscapes. Melbourne. Australian Society of Soil Science Inc. ISBN: 978-0-09586-595-2-9.

Journal articles in preparation

Kochanek, J., Long, R.L., Flematti, G.R., In prep. Unfolding the chemical mechanisms behind biphasic biochar. *Target journal: New Phytologist*.

Cox, J., and Kochanek, J., In prep. Biochar and compost combinations are superior to single ameliorant inputs in a blueberry orchard soil. *Journal undecided.*

## INTELLECTUAL PROPERTY/COMMERCIALISATION

'No commercial IP generated'

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