A Report on the Value of Biochar and Wood Vinegar:

Practical Experience of Users in Australia and New Zealand

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AUSTRALIA NEW ZEALAND
BIOCHAR INITIATIVE Inc. ANZBI

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Thank you to all those 'ridgy-didge' biochar and wood vinegar users who gave up their time and data to assist with the survey. Your generosity of spirit and commitment is what makes this community what it is. Thanks in particular to Doug Pow, James Gaspard, Adrian Morphett, Karry Lee-Anne Fisher-Watts JP; Barry Keith Watts, Ian Stanley, Gerard Cahill and Euan Beamont for their time detailing biochar use cases. Thanks also to Annette Cowie for proofreading and editing.

Purpose

This paper discusses practical uses of biochar and the end outcomes based on the early adopters in the field. This report is not a scientific paper and instead relays practical information regarding in the field end use examples, application methods, short and some long term outcomes and importantly financial information. It is meant for people that want to hear about the uses of biochar in the field, understand different application scenarios and what the outcomes were – we are hoping that these early adopter examples will inspire others to follow. This white paper is not the end of the story, and we hope to add many more examples in later revisions – maybe yours will be one.

We'd be keen to hear your feedback, and if you have your own stories/ photos/ data of the use of biochar in field, green roof, agriculture, horticulture, cattle feed, the backyard vegie garden, Orchids or whichever the end use might be, we'd want to add them to this report for the next release. Please let us know.

Summary

Biochar and wood vinegar are emerging technologies with numerous applications in agriculture and environmental remediation[1]. Advocates and early adopters of these products are well versed in their positive attributes. Biochar, for example, has been shown generally to increase crop yields in tropical latitudes[2] [i], remediate soil[3], reduce soil greenhouse gas emissions[4,5], and sequester carbon[6] amongst many other observed benefits[1,7].

Yet it is arguably the case that not enough focus has been given in financial feasibility studies to the benefits observed by users of biochar beyond its use as a soil amendment[8]. Existing studies in high-income countries tend to focus on soil amendments in low value cereal crops, and with the exception of Joseph, et al. [9], they overlook biochar's use as an animal feed, for soil remediation and for water use efficiency.

This report begins to address this knowledge gap by providing an account of how biochar and wood vinegar users are accruing benefits or disbenefits in their farming operations. In March and April of 2019, the Australian New Zealand Biochar Initiative (ANZBI) surveyed sixteen current users of biochar and six users of Wood Vinegar.

The survey found that:

- The use of biochar as animal feed is an important emerging market in Australia. Those who feed biochar to cattle do so on a daily basis for the purpose of improved cattle health, improved cattle weight gain, methane emissions reduction and reduced feed cost.
- Biochar is being used as a soil amendment to improve the crop yields and the produce quality of higher value crops (fruits, vegetables, nuts, horticulture), but the business case remains challenging for broadacre cereal crops. These users were found frequently to produce their own biochar and to apply it on a monthly or annual basis.
- Adding small amounts of biochar and minerals to chemical fertilisers (as has now been commercialised in China) has the potential to increase yield, profitability and quality of vegetables and grains.

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[i] Though on average, not in temperate latitudes.

- Wood vinegar is being used to increase rates of seed germination, reduce fungal diseases and to improve both plant health and crop quality. Users of this product were frequently fruit and nut farmers.

Furthermore, the report includes in-depth case studies including biochar's use in a golf course, for use in an avocado orchard, for use as an animal feed and for use in a potato farming operation. These in-depth case studies exhibit circumstances under which biochar not only breaks even for the user, but is lucrative.

A review of the biochar literature examines emerging products and innovations. It highlights the importance of practices such as banded application for improved user value and the high performance of biochar fertilisers. It further remarks on the discrepancy between the literature and the commercial reality.

Finally, we make the following recommendations:

1) Work with existing users of biochar and wood vinegar to identify practices that maximise the benefits from using biochar and wood vinegar.

2) Assist innovators/early adopters in farming and waste management sector to trial fit for purpose biochars.

3) More attention must be given by users, producers, government and private sector agronomists, agricultural scientists and academics to alternative uses of biochar beyond focusing on soil amendments, particularly as an animal feed supplement, for water holding capacity (for reduced irrigation requirements), partial replacement of chemical fertilisers and environmental remediation.

4) More research and well-resourced field trials are required to understand and quantify the benefits to farmers accrued via wood vinegar application.

5) More large scale field trials are required to evaluate the applications of biochar based chemical fertilisers given their demonstrated capacity to outperform commercially available slow release fertilisers.

6) Development and large scale field trials are required of new biochar based products (e.g. extracts for fertigation or foliar sprays) that can be applied at low application rates with existing application equipment.

7) Funding is required for large scale demonstration projects where biochar is a component of a larger effort to utilise a waste resource (e.g. wood residues from clear fell operations and timber processing) to reduce nutrient runoff and increase soil health. The projects need to be well-resourced so that they do not require any significant input from farmers over and above their normal day to day activities.

1. Introduction

Since the term 'biochar' was coined in the late 1990s[10], thousands of lab and field trials have been performed, more than ten thousand papers and reports have been published and hundreds of thousands of tonnes of biochar have been produced in both private and government programmes worldwide[11]. In 2018, biochar was included by the Intergovernmental Panel on Climate Change (IPCC) as one of the negative emissions technologies (NETs) reviewed in its special report on global warming of 1.5 degrees[12]. Similarly, the beneficial properties of Wood Vinegar (also known as pyro-ligneous acid or liquid smoke) are increasingly the subject of research attention[13].

Innovations such as biochar's use as an animal feed[14] and wood vinegar's use a fungicide[13] are among the applications of biochar and wood vinegar that are proving popular with early adopters. A recent survey by the US Biochar Initiative that focused on the opinions of biochar producers notes that markets are emerging in several areas, including *"… green infrastructure for stormwater management in cities; soil water retention in turf, landscaping and urban tree plantings; biochar soil blends for horticulture; biochar seed coatings and root zone applications in field crops; remediation of mine tailings and brownfields; and replacements for activated carbon and carbon black in a variety of industrial uses"* [11].

Yet in Australia and New Zealand as in the US, the biochar and wood vinegar industries can still be considered as both nascent and niche.

Advocates for biochar note its potential to improve crop yields, crop quality, animal health and animal growth while delivering simultaneous environmental co-benefits. Critics highlight economic limitations as the explanation for the nascent market[15]. As we will demonstrate, there is a significant disconnect between the general perceptions of biochar in the published literature and its application by users. In this paper we seek to clarify the benefits that biochar and wood vinegar users are observing in practice.

Innovation and technological diffusion curves are driven by early adopters[16]. In seeking to understand the status of biochar and wood vinegar's technological diffusion, this report reveals the motivations of these early adopters.

This report seeks to address the overarching question:

What are the benefits of biochar and/or wood vinegar that users have observed in application?

In order to address this general question, the report

(i) illuminates the **perceptions** of biochar value through surveys and discussions with biochar users,
(ii) examines the **practice** of biochar use through consideration of real-life case studies, and
(iii) summarises the **potential** of biochar value through a review of key insights from the published literature and emerging innovations including those that are now being commercialised in China and the USA.

2. The Perceptions: User Surveys

Through February and March of 2019, twenty-three surveys were submitted by biochar (17) and wood vinegar users (6) and one of the authors visited and collected data verbally from a biodynamic dairy farmer. Not all users who were approached participated for a range of reasons. The survey reflects the opinions of 23 growers and graziers who use biochar or wood vinegar in agricultural operations. A copy of the survey can be found in Appendix 1.

2.1 Biochar users

A total of seventeen biochar users were surveyed.

Biochar's use as an animal feed by graziers was the main motivation for biochar use (16%). Following this was soil rehabilitation (13%) and crop yield effect (13%).

The average price for biochar as quoted by users was $1,807 per tonne, with prices ranging from $100 to $6,750 per tonne. Average acquired (or self-produced) volume was 7.6 tonnes, ranging between 2.5 kg and 25 tonnes per 'acquisition'. 'Acquired volume' includes self-made production (8 of 17 cases).

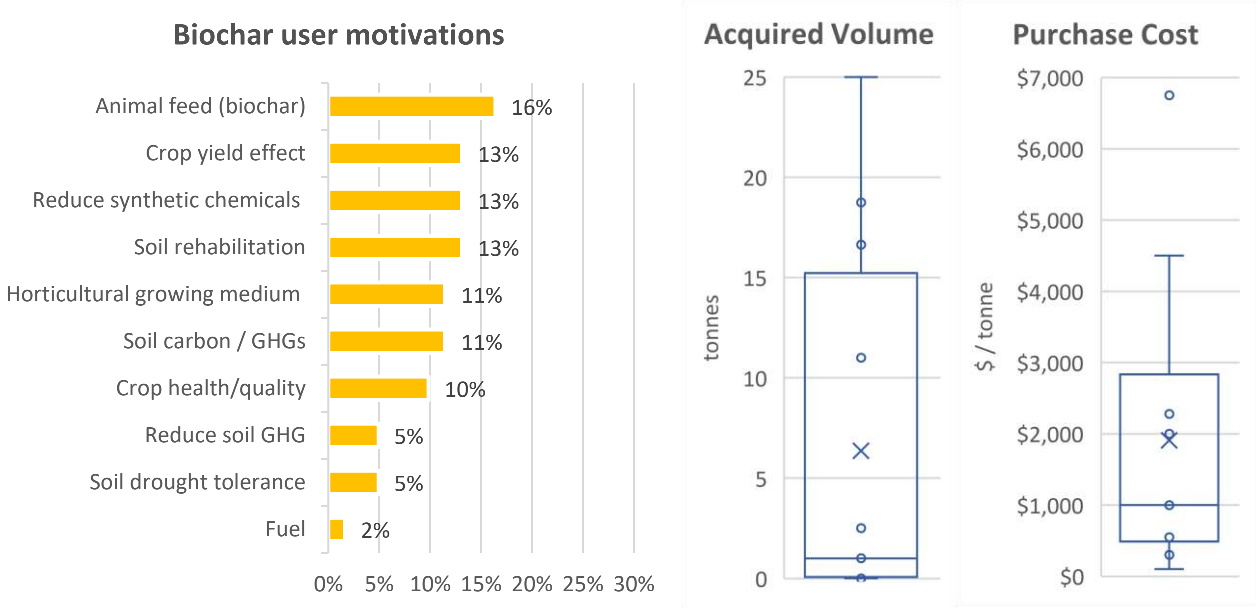

Figure 1. Biochar user motivations, acquired volumes and purchase costs.

2.1.1 Biochar as used by Graziers

For users feeding biochar to animals, the use of biochar is frequent (daily) and ongoing. Of the seven biochar users who fed biochar to animals, all biochars were made from wood feedstock, and all biochars were purchased from biochar producers. The distance biochar was transported from the biochar producer to the biochar user was an average of 876km ranging between 20km to 3000km. The average amount of biochar acquired on an annual basis was high, ranging between 0.2 – 18.75 metric tonnes per annum.

The char is typically crushed to 2-4 mm particles. Methods of feeding for beef cattle in feedlots include mixing with salt, combining with salt in lick blocks and mixing into feed at rates between 0.3- 3%. For application in grazing systems the biochar is mixed with a substrate such as glycerol or molasses in a ratio that can vary from 10:1 to 3:1 substrate and cows can self-administer in a pasture environment. For one dairy farm the biochar was fed only to weaners with feed supplement. The addition of biochar resulted in the cows being able to produce milk earlier and was thought to increase farm profitability by $4000 per year.

Benefits sought by users included:

- feed displacement savings and improved soil quality resulting from biochar deposited in the form of cow manure (Doug Pow, Appendix 3.3). Feeds savings amount to $305 per cow per year.
- improved cattle health
- increased cattle weight gain,
- enhanced intestinal tract health by the suppression of harmful gut bacteria
- to ‘help avoid plant poisoning’.

Benefits that were observed:

- reduced symptoms of St George disease (caused by Pimelea poisoning – Appendix 3.1)
- fuller udders on beef cattle leading to improved calf development
- reduced instance of digestive issues with early weaned calves and reduced scouring
- cattle are ‘cleaner in the coat’
- reduced death due to plant poisoning
- an increase in weight gain compared to a normal feeding program. leading to improved revenue of $400 per tonne of biochar
- *“My cattle are healthy and I have seen on average an extra 25 kg in calf-weaning weights”*
- No applied fertiliser to pasture in 2 years due to biochar infused manure. (Appendix 3.3)
- improved the overall health of the cattle, they seem more settled, shiny in the coat, seem to be eating more, higher conception rates, heavier calves and heavier cows leading to savings of $140 per cow per year (though according to this respondent, this savings figure does not consider the overall observed benefits of increased milk production benefiting calf development – Appendix 3.1)
- greater weight gains with the bulls.
- less vet visits and fewer vet bills.

While some of the anticipated and observed benefits were verified[14] and some data on weight gains had been collected by users, most of this evidence is anecdotal. Health benefits were observed in some cases (e.g. reduced instances of plant poisoning) but not in others. No negative effects were reported.

2.1.2 Biochar as used by Growers

Eleven users of biochar were growers, consisting of a broadacre cereal farmer (1), one avocado orchard (1) and smaller scale seedlings, vegetables and fruit tree growers (9). The usage is less frequent than those using biochar as animal feed, with small scale growers using biochar on a weekly basis (3 of 11 respondents) to monthly (3 of 11 respondents) and annual basis (3 of 11). Larger scale growers used biochar only once prior to planting (2 of 11).

Most of these users (8 of 11) made their own biochar. Self-made biochars were produced using 200L drum retorts, Kontiki kilns, Moki kilns or pit kilns. Post production processing activities included crushing, mixing with rock dust and fertilisers, infusion with animal urine and leaving to inoculate over days or weeks, mixing with compost and mixing into a slurry with 'other microbe biology'. One user acquired a range of biochars which had been produced from green waste which were pyrolysed with nutrients and clays to produce an enhanced biochar (biochar fertiliser). Biochar feedstocks were mostly wood based, but also included straw, poultry bedding, green waste, paper waste, bagasse and corn cobs. The finished product was then applied nearby (<25km). These users applied biochar to the root zone in plant breeding, fruit trees, small scale vegetables and in commercial forestry. Biochar quantities produced were typically small (< 200 L) but did amass to as much as 11 tonnes over a year for one plant breeder.

Three users who purchased biochar (rather than self-making) acquired it on a larger scale (2.4 – 25 metric tonnes per acquisition) and applied it once only per season. Biochar was transported between 20 - 3000 km from the producer to the user.

Application techniques included:

- using a spreader before incorporation into planting beds with rotary hoe,
- banding and incorporating to 100mm depth (Ian Stanley, Wheat) as moist powder or pellets,
- banding and incorporating to 300mm – 600mm depth (Doug Pow).
- applying in the planting hole prior to tree planting.

Benefits sought by users included:

- to raise soil organic carbon levels which are inherently low
- to improve crop yields and quality
- to reduced fire hazard (for users seeking to reduce fuel load)

Benefits/disbenefits that were observed:

- A reduction of synthetic fertiliser by around 30% (biochar compost mix used in open field and tunnel plant breeding)
- We were able to ameliorate an unidentified soil toxin (probably herbicide residue by application of biochar)
- Only one user applied biochar in broadacre cereal cropping. This user remarked that biochar costs were a constraint in its financial feasibility for use in cereals, which is reflective of the results in the literature. This trial did not result in a statistically significant increase in crop yield or any reduction in fertiliser requirement, though the trial only measured 12 months of effects (Appendix 3.4.
- Improved Avocado yield over multiple commercial crops, payback achieved after first fruiting (chapter 3, case study 2). Substantially increased initial growth rate of avocado trees with biochar.
- Improved tree survival, in a commercial eucalyptus plantation but evidence is circumstantial.

- Fertiliser saving
- A substantial increase in tomato foliage and fruiting capacity.
- Improved soil friability, improved soil moisture retention, improved plant growth
- Potted plants are more resistant to disease (macadamia)
- Great for eliminating odours from manures
- Fertiliser was reduced through application of biochar plus bacteria and fungi (D. Hamilton, NZ, Appendix 3.2).
- The grower does not need to use NPK inorganic or organic fertiliser ongoing (following biochar / bacteria / fungi mix application – D. Hamilton, NZ, Appendix 3.2)
- Broccolini yields increased from 2 (control) to 13+ stalks according to anecdotal evidence. Full extent of improved yields was not fully disclosed due to commercial in confidence, but farmer in question purchased 12 tonnes of biochar in following season. This biochar user situation considered an enhanced biochar (green waste biomass pyrolysed with straw, red clay, trace minerals, chicken manure, rock phosphate, $FeSO_4$).
- Kontiki kiln method of production is labour intensive (disbenefit) but requires very little capital.
- Doug & Helen Phillips (Triple R Biochar), the Tarragal Landcare Group and the Glenelg Hopkins Catchment Management Authority set out to investigate the beneficial use of biochar in a Southern Victorian crop of red wheat in 2015. Rates of wood biochar applied were 5 and 10 tonnes per hectare, resulting in a 21% and 29% yield increase in the first year. Their Hypothesis is that the biochar will have positive impacts over 10 years or more. The biochar application was observed anecdotally to increase yields in subsequent years of cropping. Data collection was interrupted by the untimely passing of Doug Phillips. A friend to many, Doug was an unwavering advocate of biochar who will be sorely missed by the biochar community. The group has announced its intention to re-form and, funding permitting, hopes to continue the trial in 2019 and future years.

Additional comments

- A documentation of water savings for use in horticulture would be a useful area of research or promotion for the ANZBI.

2.2 Wood vinegar users

A total of six wood vinegar users were surveyed (fig. 2).

Wood vinegar's use for crop yield effect was the main motivation for use (29%). Following this was soil drought tolerance, soil carbon enhancement and reduced reliance on synthetic chemicals (14%).

The average price for wood vinegar as quoted by users was $4.63 per litre, though prices ranged from $2 to $12 per litre. Average acquired volume was 700 L, ranging between 80 L and 3000 L per season. All volumes were acquired through producers, no wood vinegar was self-made.

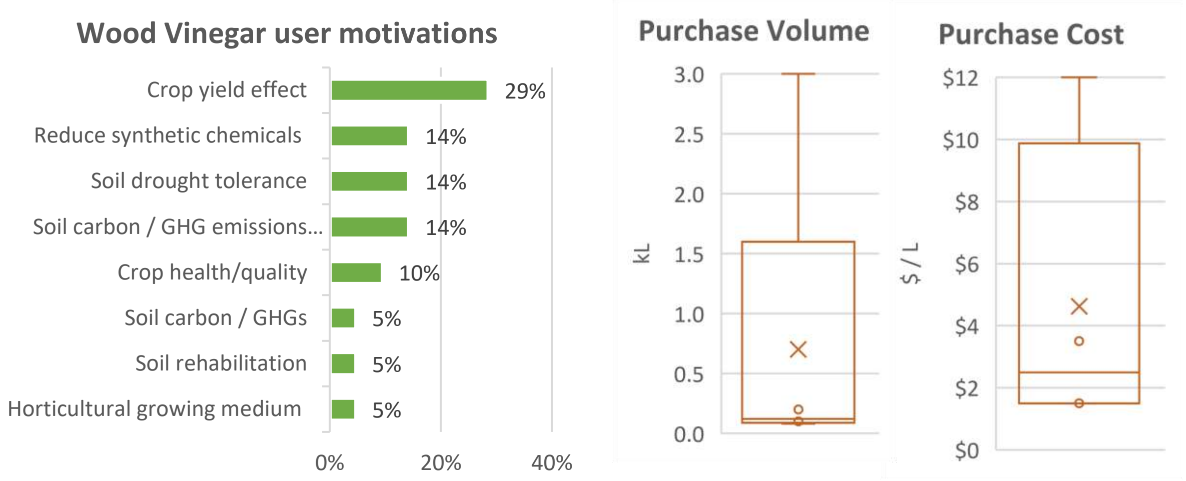

Figure 2. Wood vinegar user motivations, acquired volumes (per acquisition) and purchase costs.

Users of wood vinegar were generally targeting higher value crops, including nut plantations (3), orchids (1) and vegetables (1) with only one user applying to cereals (1) for the purpose of improved seed germination.

Use frequency ranged from weekly to annually. Application was achieved through foliar spray to established plants in 4 of 6 cases or was mixed in with seed using a grain auger prior to planting in 2 of 6 cases. Mixing methods varied depending on benefits sought. One user seeking improved yields through foliar application applied at a rate of 2mL vinegar per litre of water. Another seeking improved germination of seeds applied 20L of wood vinegar per metric tonne of seed prior to sowing. Another user who was using wood vinegar as a fungicide applied at a rate of equal parts vinegar to water.

Benefits sought by users included:

- Reduced pest and disease pressure resulting in healthier trees
- Growth promotion and pest control
- Reduced fungal disease
- Reduced Pinks fungal (Macadamia)
- An increase in germination rate and crop health for lupins and wheat

Benefits that were observed:

- Reduced pest pressure and less fungal pressure (Macadamia)

- Higher quality produce – *"my reject nut has fallen from high 2% to low 2% and crack-outs are 1% better"* (Macadamia)
- No harm to any beneficial insects but suppression of pests & husk spot observed (Macadamia)
- Good for cleaning husk spot from trees three days before adding Trichoderma for husk spot control (Macadamia).
- Trees were much healthier, and more resistant to disease (Macadamia)
- Reduced use of chemical fungicide (Macadamia)
- Plant more resistant to disease, greater strike rate on new planting (Macadamia)
- Quicker root establishment after repotting, reduced incidence of bugs and disease problems (orchids)
- Healthier plants (orchids)
- Reduction of insect damage (sucker insects and mildew / fungal diseases)
- Did not have to cut limbs off trees (because of elimination of Pinks fungal in Macadamia)
- 20% increase in germination rate for Lupins. No change in germination rate for Wheat. Treated seed areas showed increased vigour through the growing period.

Comments:

"A standardised declaration of the concentration of pyro-ligneous acid should be clearly given on the label. There are different brands available and without this information it is difficult to know the correct dosing rate."

"Wood vinegar has good potential to eliminate black layering on turf grass (bowling greens and golf greens) @10mL per Litre. Further testing in this area would be productive."

3. The Practice: Case studies of use

For all case studies, the benefits can only be attributed to the individual biochar and the circumstances under which it was used. To the greatest extent possible, detail has been provided about biochar feedstock, temperature and enhancements.

Case study 1: Beef biochar

	User net benefit (NPV[ii])	User net benefit (NPV) per tonne of biochar	User cost	Payback
Beef biochar - Doug Pow 60 cows, 0.3kg biochar per day, 1 year	$12,000 (per 60 cows)	$1,700	$1,000 (per 60 cows)	< 1 year

Western Australian Grazier and Grower Doug Pow believes biochar should not be an addition to a 'business as usual situation'.

"The whole farming system should be re-examined with a very good dose of lateral thinking and completely re-engineered around the biochar. The more costs a production system can eliminate the more it can afford to spend on biochar and accrue the cumulative benefits."

This lateral thinking is certainly evident in Doug Pow's use of biochar in avocado plantations and as a cattle feedstock.

Since 2011, Doug has acquired 150 tonnes of biochar from a silicon manufacturer who sells charcoal fines as a by-product (SIMCOA Bunbury, WA). A proximate and ultimate analysis of the jarrah wood biochar is detailed in Appendix 3.3.

Biochar was applied once prior to planting avocados, and biochar was mixed with molasses and fed to beef cattle.

The biochar – molasses mix was trialled as a substitute to a regime of hay feeding, in conjunction with pasture fed grass. The results indicate that the biochar-molasses mix increased profitability for a herd of 60 cows by $12,230[14], where biochar was fed at a rate of 0.33 kg per cow per day mixed with 0.1 kg of molasses achieving similar animal weight outcomes to the control. In aggregate this amounts to more than 7 tonnes of biochar per annum. Based on this estimate, each tonne of biochar is creating approximately $1,700 of net benefits to the farmer. In the gut of the cattle and in the resulting dung, the biochar absorbed high levels of nutrients, particularly N and P.

Between the months of mid-April until mid-October, a dung beetle emerges. The dung beetles (*Bubas bison*) process the cowpats quickly and bury it deep into the soil profile, usually 600 mm underground, along with the biochar that was ingested by the cow. This ingenious approach harnesses the natural functions of both the cattle and the beetles to transport a nutrient enriched biochar to the pasture soil, creating user value at both stages. The recalcitrant C structure of the Biochar was unchanged after having passed through the gut of the animal and after being sequestered by the beetles.

[ii] Net Present Value

Case Study 2: Avocados

	User net benefit (NPV[iii])	User net benefit (NPV) per tonne of biochar	User cost[iv]	Payback
Avocados - Doug Pow 7 years of effects, 1 hectare (400 trees)	$20,000 (per hectare)	$400	$5,040 (per hectare)	4 years (first fruiting)

Avocados originate from Central and South America, having evolved in volcanic andosols. In Manjimup, WA, this crop faces several challenges not found it its original setting. Adjusting to this differing climate and soil type requires irrigation and substantial additions of fertiliser. Another issue is infestation of *Phytophthora cinnamomi*, a soil borne fungus which rots the root system and reduces fruit yield and quality.

Doug Pow, who has been growing avocados in WA for decades, applied biochar as part of a trial to emulate the properties the volcanic andosols have from which the crop originates. The jarrah wood biochar (Appendix 3.3)was mixed in to the topsoil at rates of 5, 10 and 20% by volume to varying depths, and was also added to the surface mixed with mulch.

By the end of the first year, it was clear that the trees with biochar application mixed in the topsoil were outperforming the control. Those trees where biochar was applied only to the mulch did not exhibit improved performance compared with the control.

Control **With biochar (10%)**

Figure 3. *Control and biochar amended plants*

By the end of 2017, the trees had fruited. The average yield of the 36 plants amended with biochar was 150% higher (average of 89 fruit per tree) than that of the control trees (average of 34 fruit per tree). Average height was increased from 154 cm to 194 cm. Leaves demonstrated increased photosynthetic capacity and tissue sampling indicated that macronutrients where highest in the 10% application rate. No increase in arbuscular mycorrhizal fungi was detected.

[iii] Net Present Value

[iv] This includes the cost of biochar at $100 per metric tonne

Pow reports that the cost for biochar per tree was $72 and the increased revenues associated with the biochar per tree amounted to $84 in the first fruiting (55 additional fruit per tree on average – fig. 4), repaying the initial outlay. The second fruiting led to 28 additional fruit, equivalent to $42 in additional revenue per tree. If a similar yield surplus continues for 3 years and assuming avocado prices remain at similar levels, then the discounted net benefit (NPV) over a hectare would amount to $20,000[v], or approximately $400 per tonne of biochar.

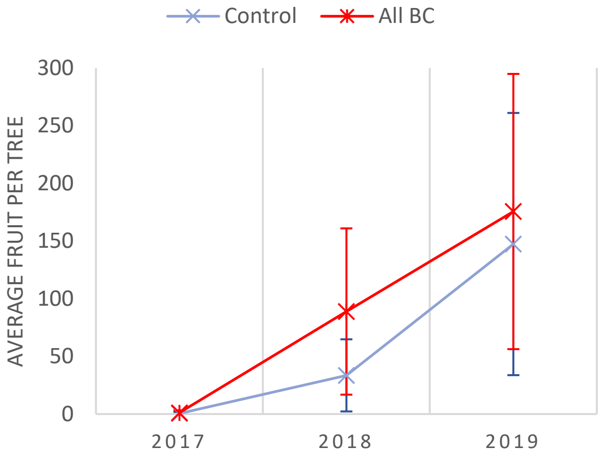

Figure 4. Average avocado fruit yield with (All BC) and without (Control) biochar application

The biochar was sourced from SIMCOA, a silicon producer who uses charcoal as a reductant. The charcoal fines are then sold as secondary products, including as biochar, allowing the company to sell the char at a significantly reduced price of $100 per metric tonne relative to general market prices.

Surrounding farmers who noted the difference in growth of Doug's avocados purchased more than 400 tonnes of biochar to replicate the practice.

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[v] Assuming 400 trees per hectare at a 7% discount rate, with trees first fruiting in the fourth year. Affects associated with 10% application rate.

Case study 3: Potatoes

	User net benefit	User net benefit (NPV) per tonne of biochar	User cost	Payback
Potatoes - Ballarat biochar trial 20% fertiliser substitution	$ 8,000 (Per hectare)	$ 53,400	$ 160 (Per hectare)	< 1 yr.

The red ferrosols north of Ballarat are renowned for potato production. In late 2013, a biochar field trial was performed on a Ballarat farm considering whether a wheat straw enhanced biochar could improve Nadine seed potato yields while partially substituting for the standard NPK fertiliser regime.

Biochar was made using a mixture of wheat straw and poultry litter (hardwood sawdust and manure) feedstock (approx. 70%) mixed with crushed basalt, wheat straw ash and Lucerne micronutrients (10%) and clay material (20%). This underwent pyrolysis at approximately 450°C, following which the biochar was conditioned with phosphoric acid to reduce the pH to 6.8. This was subsequently left to dry in the open air until moisture levels reached 8% of dry weight. This acid activated mineral enhanced biochar was then mixed with a chemical fertiliser that had 7% N, 14% P and 14% K in different ratios (NPK + 2.5%, 5%,10%, 20%, 40%). These mixtures were left to react with the NPK in bags for 2 weeks to produce a biochar compound fertiliser. All of the treatments were applied at 778kg/ha which, if there was a 20% addition of biochar, would mean biochar is applied at a rate of 145.6kg/ha.

The pyrolysis of the mixture of minerals and different feedstocks and then reaction with an acid results in a biochar that has the ability to bind both cations and anions that exist in the chemical fertiliser. This results in the much slower release of nutrients and the reduction in the loss of nutrients due to leaching and volatilisation[17]. The biochar itself has water soluble and other organic compounds that are the same as those found in wood vinegar as well as other compounds that are similar to humic acids. The research to date indicates that infusing the biochar pores and surfaces with chemicals and minerals can outperform commercially available slow release fertilisers, and outperform non-enhanced biochar products[18] making them economic prospects for use in cereal agriculture[19].

The treatments were applied through the cooperating grower's commercial equipment which was banded approximately 50mm in 2 rows below and to each side of the potato seed. The trial was subsequently harvested using the cooperating grower's harvesting equipment.

When it came to harvest in the fourth month, it was found that the biochar application increased the total yield per hectare of potatoes from 38.8 tonnes to 58.1 tonnes, a 53 % increase.

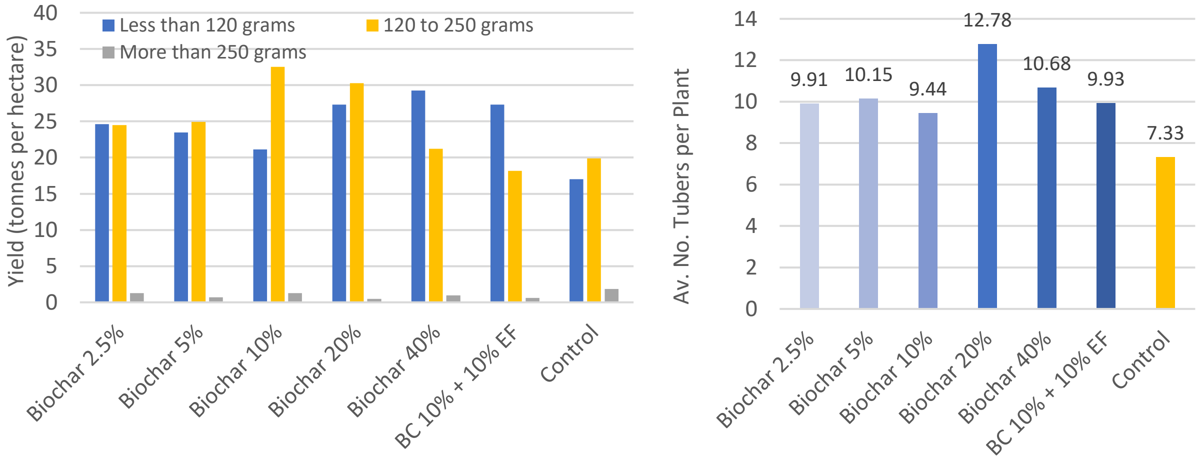

***Figure 5. LHS:** Potato yield per hectare given differing biochar fertiliser substitution rates given varying seed potato sizes. 'BC' - biochar, 'EF' - Extra Fertiliser*
***RHS:** Average number of tubers per plant.*

Of the treatments considered, the 20% biochar substitution delivered both the highest yield and highest tuber productivity per plant (fig. 5). However, the yield of seed potatoes that had the required weight for sale (<120g) had the highest yield at 40% replacement.

The resulting yield increase of 53% crop yield led in to an increase in farmer net benefits by $8,000 per hectare, at a biochar cost of $160 per hectare. A limitation of this study was the small number of replicates, and an absence of soil or plant tissue analysis.

While these results exhibit the high performance and potential of biochar fertilisers, they also highlight the need for more research to confirm biochar fertiliser performance and to improve understanding of the underlying mechanisms.

Case study 4: Golf courses

	User net benefit (NPV[vi])	User net benefit (NPV) per tonne of biochar	User cost	Payback	Years of effects
Golf course - Biochar Now[vii] Average golf course	$2,055,000	$22,600	$200,000	< 1 year	10 yr.
Golf course - Biochar Now Capital lease – average golf course	$1,674,000	$18,500	0	0 years	10 yr.

Colorado based company *Biochar Now* first began selling biochar to golf courses in California[viii] four years ago.

Infestations of beetle in Colorado forests have produced voluminous amounts of unused wood biomass which is the feedstock of the biochar product. *Biochar Now*'s biochar making process focuses on producing high temperature, high carbon chars using modernised slow pyrolysis ring kilns over 8-10 hours, contrasting with other regional producers who focus on fast pyrolysis. Emissions (PM2.5, NO_x, CO) from these kilns are very low.

The company's pyrolysis units do not capture oils or gases, focusing on high C content biochar. The product was recently tested by a potential client, and the *Biochar Now* product exhibited 20% higher carbon than its nearest competitor.

US$10 million has been invested to get *Biochar Now* to its current point, with US$1 million in sales per annum now being achieved. James estimates a minimum biochar sale price of $1 per pound ($2.20 / kg), indicating a maximum current annual production of 450 metric tonnes, though prices can be as high as $3 per pound ($6.61 / kg) depending on the grade of the biochar product and the scale of the order.

James explicitly states that the results and performance of biochar in Californian golf courses can only be associated with the 'Biochar Now' biochar.

Southern California has sandy coarse textured soils, in which biochar has been shown to retain soil moisture[20]. It is not uncommon in the Southern Californian summers to experience 110°F (43°C) days in popular residential and tourist destinations such as Coachella valley and Palm Springs which is home to 150 golf courses. These golf courses can consume 1 million gallons of water per day at an annual expense of between $0.5 – $1 million in water irrigation bills. Climate change and increasing severity of droughts is expected to exacerbate these costs.

Biochar Now biochar is applied raw at a rate of approximately 2% at the root zone. Initially, there were some dust challenges associated with biochar handling. To solve this, the company developed a pelletized product. The golf course (with biochar) is then watered at normal rates for a week, then watering is cut

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[vi] NPV – Net present value.

[vii] Assuming highest cost / lowest effect (the least financially feasible scenario) of 30% water irrigation cost savings and high cost biochar application for average sized golf course of $200,000. The lowest cost / highest effect (65% irrigation savings cost and $100,000 application cost) results in net benefits greater by an order of magnitude, but the lower bound has been considered only to maintain conservative estimates of user value. The 10 year effect is also a conservative estimate, with biochar expected to continue delivering cost savings for the duration of its physical persistence, which is effectively in perpetuity. Assuming ongoing effects doubles the estimate of financial value.

[viii] This US case study is outside of the Australia & New Zealand scope, but an exception was made to include it to demonstrate a novel biochar use that has many applications in both Australia and New Zealand.

back thereafter. The biochar holds moisture to six times its dry weight, and the biochar is able to reduce both water and fertiliser use by 50%. 1.6% of biochar in root zone doubles turf grass growth.

The raw char sells to golf courses at a rate of \$2000 - \$6000 per metric tonne of char. To apply biochar to these golf courses using *Biochar Now's* raw product costs \$100k - \$200k. While expensive, this reduces irrigation bills by \$300k - \$500k with a payback of approximately 6 months.

Initially the upfront cost of the biochar was a barrier for clients. The solution was a financing arrangement (capital lease), where golf courses amended with biochar paid the standard amount of water expense, and any water cost saving went to the financial institution over one to two years. After this period, the arrangement ended, and the golf course received the ongoing savings. This arrangement was able to show 30-40% interest (IRR), and so was of great appeal to financiers. The char lasts indefinitely (half-life of 17,000 years according to lab trials), with consistent effects over time without issues of erosion or char translocation within the soil profile.

Despite the focus on carbon purity, revenues from carbon credits remain elusive. James estimates that it would cost \$0.5 million to do the requisite paperwork to claim \$0.75 million in revenues. At current carbon prices, the company would be lucky to obtain \$10 per tonne CO_2e in the voluntary market.

However, the methodology framework for biochar is improving rapidly, with researchers seeking to address concerns relating to modelling nitrous oxide soil emissions. Within the next few years it is anticipated that issuance of these credits will become simpler for biochar producers.

Other lines of business.

Biochar Now has tested in 13 major markets, including for improved hemp production and other specialty agriculture, applications in building materials (asphalt, plastics, cement), environmental remediation and algal bloom reduction. *Biochar Now* is targeting 'bottomless markets'.

James estimates that they have \$100 million backlog in orders from the hemp production industry, where he estimates his larger grade product can increase revenues by \$100,000 per hectare due to improved crop yields. In light of this, customers happily outlay \$2,000-\$4,000 per hectare for biochar.

Case study 5: Saline Soil Remediation

Biochar has demonstrated a capacity to reduce salt effects on plants in saline soils [21,22]. A preliminary investigation of the potential of a biochar permeable reactive buffer to provide medium to long-term remediation of salt-affected soil was undertaken at a small property owned by Karry Fisher Watts and Barry Watts at Brookton WA. The property has been established as a native food farm and sandalwood plantation. Permeable biochar wells (PBW) were established to reduce the impact of salt on tree growth, improve water penetrability and improve soil health. Anecdotally, the use of the PBW led to rapid plant growth with little or no apparent impact of salinity despite the original saline status of the soil. Tree growth appeared to be greater than at comparable sites elsewhere. A range of Sustainable Nature Farming Amendments and the addition of Molasses Water and Wood Vinegar were investigated to lay the foundation for further innovative long-term experiments (Appendix 2, Table 1).

Figure 6. LHS - *Charwell installation.* ***RHS*** - *Photo of the trial site: 10 months after installing charwells*

The test site in question was located on a 1.8 ha property (*Treōwstede,* Brookton WA) that has a history of salinity. *S*everal species of salt-tolerant plants were planted, and the affected land was covered with straw to reduce evaporation during the dry season. The soil is loam over clay with fine gravel sediments. The property is subject to a failed sub-surface agricultural ditch that was designed to leach saline sub-surface waters. The drain was made using a corrugated PVC pipe, which was laid on a blue metal base and covered by a geotextile, covered with another layer of blue metal, and top-dressed with a soil cover. The depth has been suggested to be approximately 800mm.

Initially (according to neighbours), this system helped remove sub-surface water to a depth of approximately 1 metre below the surface from both the Treōwstede site and further upcountry. Water leaked into the drain and was pumped via a solar pump into an area west of the project area. However, within 4 years of the system being installed the pump stopped. It was claimed that the system had drained the water from the affected area. Unfortunately, this type of sub-surface agricultural drain can become blocked with fine sediment and it was not maintained after it was installed. Consequently, the land at the bottom of site had returned to its natural state, habitually ponding with water. It can take several days for the water to drain after heavy water flows. Then, when the area dries, the soil develops a layer of salt on the surface

Five treatments with jarrah wood biochar (Appendix 3.3, Table 2) were applied in 5 trenches (fig. 6) (Treatments 1-5) and one trench was untreated (Treatment 6). Treatment 1 was a mixture of Biochar, Straw, Lactic Acid Bacteria, Wood vinegar, Molasses water, Worm Juice and Fermented Urine. Treatment

2 was a mixture of Biochar and Straw. Treatment 3 was a mixture of Biochar, Straw, Lactic Acid Bacteria, Wood vinegar and Molasses water. Treatment 4 was a mixture of Biochar, Straw, Lactic Acid Bacteria, Worm juice and Molasses water. Treatment 5 was a mixture of Biochar, Straw, Lactic Acid Bacteria, Fermented Urine and molasses water. The details of the treatments are given in Appendix 2, Table 1.

Each trench was 800mm deep, 150mm wide and 10 meters long. Each treatment was replicated three times in a random pattern. Each trench was one meter from a growing tree. Each trench had 4 layers: 150mm top soil cover, 100mm of biochar, 200mm of wheat straw and 100mm biochar. Different mixtures of liquids and microbes were added to the biochar and the straw.

Trees were planted in front of each of the treatments. These included *Eucalyptus erythrocorys*, *Eucalyptus preissiana*, *Eucalyptus pleurocarpa*, *Grevillea olivacea*, *Hakea petiolaris*, *Eucalyptus kruseana*, *Grevillea* Robyn Gordon, and Frost Kill *Hakea baxteri.* The charwells reduced the ponding of water in the lower sections of Treōwstede. The addition of the soil amendments appeared to help the plant growth and provide resilience against soil borne disease. No soil health problems have been observed since the addition of WV/MW as part of the ongoing plant maintenance program. Accelerated plant growth and resistance to insect attack has been noted.

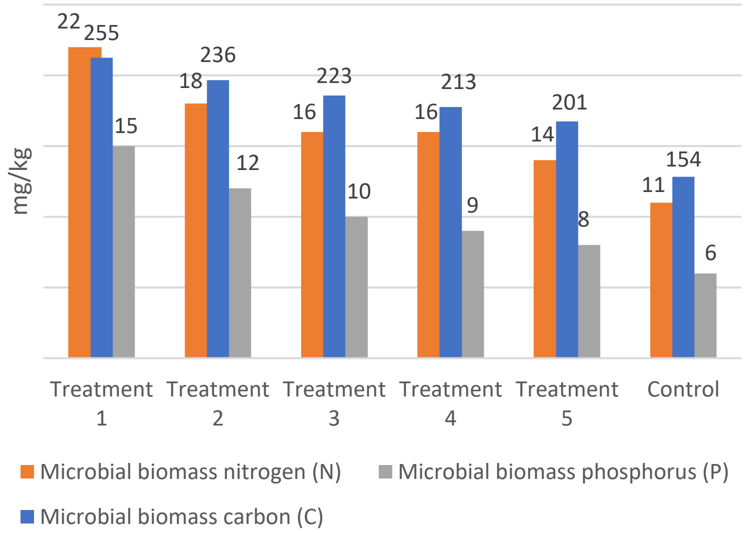

Figure 7. *Increase in microbial C, N and P as a result of various treatments.*

Trees in all treatments were observed as being healthy and not salt-affected relative to the control. There were no differences in measured soil characteristics among trenches before treatments were imposed (Appendix 2, Table 2). After the treatments had been established for one year, soil salinity levels were significantly reduced, there were differences in soil pH, and carbon and nitrogen increased in the treated soil compared with the untreated area (Appendix 2, Table 2 & 3). As depicted in fig. 7, Microbial biomass C, N and P were significantly increased with soil amendments compared with the untreated area (Appendix 2, Table 4).

While this trial did not consider the business case of biochar or wood vinegar's use, it does highlight the need for further research into biochar's applications to avoid salt affects in tree planting. Since the trial, the project manager observed that the impact of the biochar wells has been 'unbelievable', with salinity 'no longer an issue', with the property being completely transformed (Fisher-Watts, pers. comm., 22 May 2019).

Case study 6: Cucumbers

	Net benefit / row	*BC[ix] / row*	*Net benefit / kg of BC*
Treatment 1	$188	7 kg	$26.86
Treatment 2	$498	13 kg	$38.31
Treatment 4	$366	7 kg	$52.29

A cucumber farm located near Geraldton has a subsoil dominated by highly leached sand with poor nutrient retention capacity. In 2016, a collaborative trial with Energy Farmers Australia (EFA) was established (fig. 8) to examine the application of poultry litter biochar to soil in a cucumber horticultural system considering the effect on nutrient availability, plant health and yield.

Figure 8. LHS *- Poultry litter biochar applied in rows in 2016,* ***RHS*** *– Cucumber harvesting*

Energy Farmers Australia had been producing biochar from poultry litter in the expectation that the product (table 1) might have the potential to reduce nutrient runoff, as well as improving nutrient uptake.

	pH (H_20)	**pH ($CaCl_2$)**	**EC (mS/cm)**	**Total C**	**CN Ratio**	**Total N**	**P %**	**K %**
2016 Poultry Litter BC	9	8.5	7.7	38.8	10.6	3.7	2.53	2.8

Table 1*. Chemical analysis of poultry litter biochar.*

The trial aim was to assess the effects of a high and low rate of biochar application with a high and low rate of starter fertiliser (T1,T2, T4,T5) with separate treatments considering biochar only (T3, T6) as shown in table 2.

The farmer applied his base fertilisers by hand and the biochar was applied shortly after with a small fertiliser spreader. Both fertiliser and biochar were then incorporated into the soil by a rotary hoe. To prevent edge effect, biochar was spread only on the inside three rows of each house.

[ix] BC – Poultry litter biochar

	CPM		NP		PLB		Total Cost
kg/row	$/row	kg/row	$/row	$/row	kg/row	$/row	**$/row**
Control 1	9	7	5	7.8			**15**
T1	9	7	5	7.8	7	5	**20**
T2	9	7	5	7.8	13	10	**25**
T3					13	10	**10**
T4	1	1	2	3.12	7	5	**9**
T5	1	1	2	3.12	13	10	**14**
T6					33	25	**25**
Control 2	9	7	5	7.8		0	**15**

Table 2. *2016 Treatments and cost of treatments. CPM - Compound Poultry Manure, NP – Nitrophoska, PLB – Poultry Litter Biochar. Costs based on: $1000/t NP and $750/t for PLB & CPM*

Cucumbers were planted by the farmer and managed as part of their normal farming operation. During the harvest period, cucumbers were picked and weights recorded for each treatment. In the 2016 season the biochar was laid down on the 10th of March with the cucumber seedlings planted on the 6th of May. In the 2017 season no additional biochar was applied. However, the farmer did apply 5kg of CPM (starter fertiliser) across the whole farm as a base. In this season the cucumber seedlings were planted on the 28th of April. Recording sheets were installed at the end of each row and a set of scales supplied. Cucumber weights for each row were recorded during picking. It was assumed by researchers that by adding biochar to the soil, fertiliser efficiency use would be increased by holding nutrients in the soil profile and improving soil and crop health. Fig. 9 indicates that Treatment T1, T2 and T4 outperform the average control.

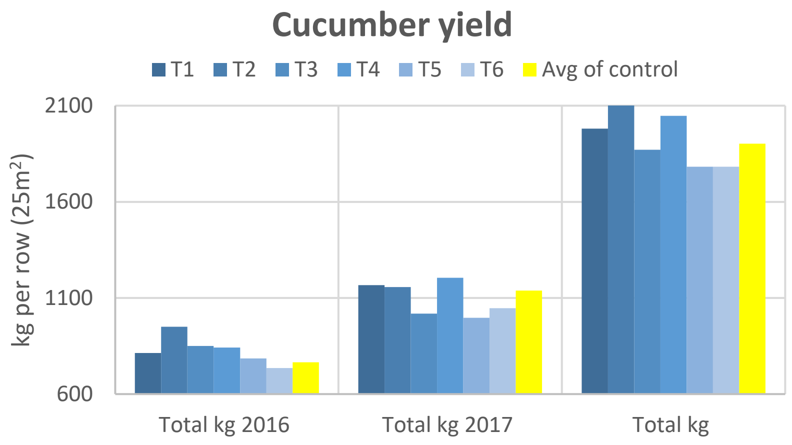

Figure 9. *Cucumber yield (kg per row) depicting 2016 yield (LHS), 2017 yield (centre) and combined yield (RHS)*

Treatment 4 was the highest performer at 1205 kg per row. This treatment was a low rate of biochar application with a low rate of fertiliser and was the cheapest treatment. The researchers suggested that this may be indicative of improved fertiliser use efficiency. Treatments 1 and 2 both performed well at 1167 kg and 1156 kg respectively. Both these treatments had a blend of biochar and fertiliser, again supporting the theory that using biochar with fertilisers improves the efficiency of fertiliser use.
T1, T2 and T4 all created significant net user financial value of $27, $38 and $52 per kg of biochar respectively (fig. 9).

Both T3 (1019kg) and T6 (1047Kg) underperformed control with T5 being the lowest at 997kg per row. Both T3 and T6 had high rates of biochar application and no fertiliser applied in the first year. The researchers suggested that there may be additional factors leading to this result such as the biochar absorbing nutrients from the soil.

Case study 7: Biochar as a feedstock additive in a feedlot scenario

	User net benefit (NPV[x])	User net benefit (NPV) per tonne of biochar	User cost (per head)	Payback
Feedlot beef cattle (per head of cattle over 2 months)	$36	$4,800	$3.57	< 1 year

Biochar has demonstrated a capacity to increase cattle weight[7]. In order to explore this potential further in an Australian context, a feed lot beef cattle agriculturalist in northern New South Wales established a trial to examine the effect biochar may have on weight gain.

A jarrah wood biochar from SIMCOA (detailed in Appendix 3.3, Table 2) was transported 3000 km from Western Australia to New South Wales at a total cost of $500 per tonne.

Figure 10: *Feed lot complex of the beef biochar scenario*

The trial was performed in two feed lot pens which hold approximately 140 head of young cattle each (fig. 10). The first of these is the control pen, in which the cattle were fed a standard milled grain feed mix and wheat straw as a fibre source. The standard (control) feed consisted of a mix of barley (75%), canola meal (6-10%), soya meal (4-6%) amongst other salts and additives.

The second pen was the experimental treatment in which the cattle were fed the same milled grain feed mix, but 1% biochar was added to the mix, offset by a 1% reduction in barley grain. These cattle have the same wheat straw as a fibre source. All cattle had unhindered access to the grain feed mix and wheat straw hay for the duration of the trial period. On average, 11 kg of feed was consumed per head of cattle per day, implying 0.1 kg of biochar consumed daily per head in the experimental treatment, and implying a total consumption of 1 tonne of biochar over the two month period by the 140 head of cattle.

The biochar blend feed mix was introduced to the experimental pen two weeks before the actual trial to ensure the cattle accepted the change in grain feed mix. At the commencement of the trial, eighteen

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[x] NPV – Net present value.

young cattle that had been previously fed a grass and hay ration were introduced to both the control pen and the experimental pen.

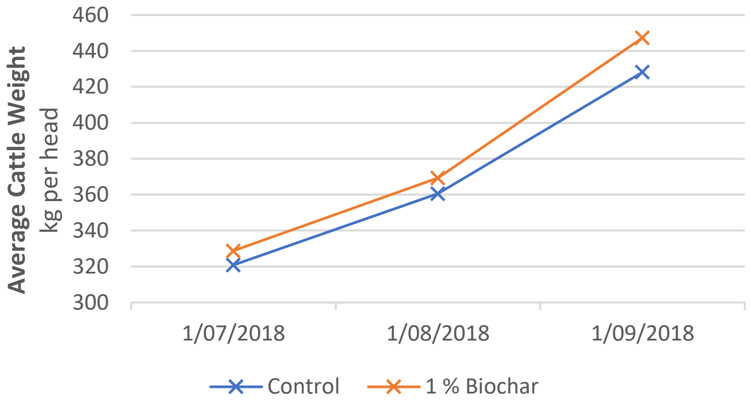

Figure 11: *Biochar 1% supplement influence on average weight per head of cattle.*

Over the two month trial period, the biochar treatment cattle gained 118.56 kg on average compared to the standard feed ration cattle who gained 107.35 kg, an improvement of 10.4% (fig. 11).

It was observed in the experimental treatment that 5-6 animals (of the 140) were not eating the biochar - grain mix, approximately twice the number of cattle that rejected the control mix. One possible reason for this, as posited by the researchers, was that the biochar mix had a reduced odour compared to the standard mix which typically has a strong grain aroma, explaining its reduced attractiveness to the cattle.

The cost of biochar consumed per head amounted to $0.055 per day, or $3.55 per head of cattle over the two month trial period. In aggregate, the 140 head of cattle consumed one metric tonne of biochar over two months.

At a live weight sale price of $3.50 per kg of animal weight, the amount of net benefit / net value created over 140 head of cattle was $4,988[xi] per tonne of biochar.

Information on this case study is partial, with insights into animal health only examining weight gain, and this weight gain data (as made available for this report) did not detail whether the higher biochar treatment average was statistically significant. Nevertheless, this result is reflective of the survey responses of beef cattle agriculturalists who use biochar as a feed supplement, and the value creation in this case study is certainly significant enough to warrant further research attention.

[xi] $5488 in total revenue less the cost of biochar ($500 per tonne)

Case study 8: Zucchini

	User net benefit (NPV per hectare[xii])	User net benefit (NPV) per tonne of biochar	User cost (per tonne)	Payback
Zucchini (13.25 tonnes of biochar per hectare)	$ 2,400	$ 730	$ 1,000	< 1 year

Earth Systems Bioenergy, in association with Hu Organics, was engaged by Territory Natural Resource Management (Territory NRM) in 2013 to conduct preliminary pilot trials to investigate the potential benefits of applying biochar for horticultural production in the Northern Territory (NT) considering the effects of biochar on crop yield and on soil characteristics.

The project was conducted at an organic farm in Lambells Lagoon in the Litchfield Municipality approximately 56 km south-east of Darwin in the Northern Territory. Soils in the trial area were dominated by kandosols and sandy loams (Appendix 3.6, Table 2).

The trials were conducted during the late dry season over a period of four months (July to November 2013). A site of approximately 2 hectares was selected, consisting of three separate trial plots in which zucchinis were planted.

The biochar used in this trial (Appendix 3.6, Table 1) was produced and supplied by Earth Systems in July 2013 using the CharMaker MPP20 mobile pyrolysis plant to convert waste wood into biochar. The feedstock source in the trials for biochar production was pine sourced from North Eastern Victoria. After processing and packaging, the biochar was transported to the Project site in early August 2013. Below is an overview of the pyrolysis process and the biochar feedstock used in the trials.

Figure 12: *Loading and unloading the CharMaker MPP20*

The MPP20 technology can be used to make biochar or standard charcoal and is ideal in situations where transport or economic issues make resource recovery difficult, wood processing costs are expensive, or a process is needed for biomass treatment without smoke emissions such as operation in an urban environment. The CharMaker MPP20 is capable of producing approximately 0.6 - 1.2 tonnes of biochar per batch (dry basis) from 4 - 10 tonnes of woody waste (dependent on wood density), with an average batch time of 3 to 6 hours. Assuming a density of between 0.15 to 0.3 m^3 per tonne, a batch will produce about 3m^3 of biochar product. Depending on site requirements and hours of operation, the technology can generate between 2 to 5 batches per day.

[xii] NPV – Net present value.

The species utilised as biochar feedstock was predominantly Pinus radiata (Radiata pine) sourced from plantations near Myrtleford in Victoria. Once processed, the biochar was packaged in ten 400 kg bulk bags and moistened before transportation. Two (2) of the ten (10) bulk bags contained biochar produced from untreated pine of mixed origin which was sourced from the waste transfer station in Wangaratta.

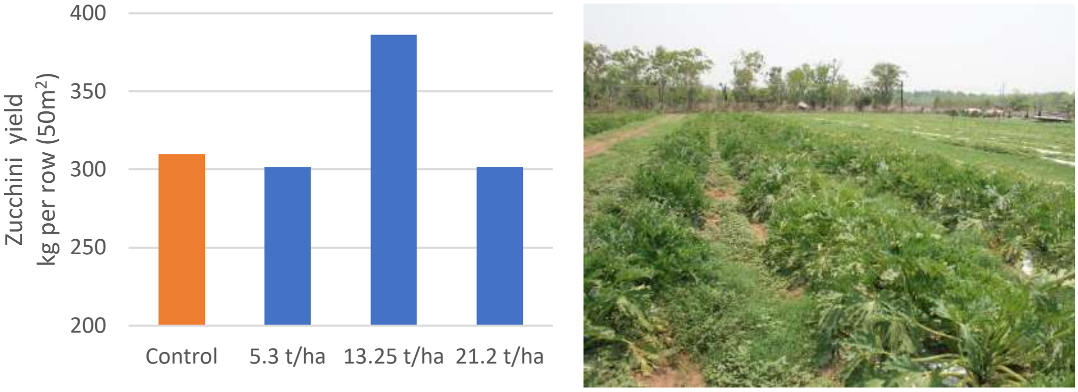

Figure 13: LHS *Zucchini yield (kg per row) resulting from application of Green Man Char.* ***RHS****: Zucchini trial (2013).*

Control fertiliser consisted of pelletised poultry manure (8000 kg per ha); guano (180 kg/ha); potassium sulphate (250 kg per ha); stabilized boron humate granules (20 kg per ha); micronized lime (200 kg per ha); crushed rock dust (400 kg per ha); microbial input post emergence and plant inoculation of VAM. Char was applied in 0.5m wide strips with a spreader in rows 100 metres in length, then was harrowed into the soil to 15cm of depth along with the control fertiliser at application rates of 5.3 tonnes per hectare (approx. 0.25 kg per plant), 13.25 tonnes per hectare (approx. 0.65 kg per plant) and 21.2 tonnes per hectare (approx. 1 kg per plant). Biochar was moistened prior to application. the irrigation schedule involves irrigating the plots for 45 mins at 10am daily and 45 min after 3 pm daily.

As depicted in fig. 13, the 13.25 tonne per hectare application scenario had the greatest overall yield surplus of 25% relative to control. Interestingly, both the lower (5.3 tonnes per hectare) and higher (21.2 tonnes per hectare) application rates resulted in zucchini yields very similar to control.

At an application rate of 13.25 tonnes per hectare, the Green Man Char product created $730 of financial value per tonne of biochar for the user. In addition to increased yield, the opinion of the farmer was that the produce was greatly improved in terms of health, size and appearance.

Other user scenarios of Green Man Char

Green Man Char has also been supplied in large quantities to a melon grower in the NT for use on their dry and low carbon soils. Since an initial 2016 trial, 'truck-sized' quantities have been applied year-on-year to all areas of the farm in question. The initial trial site is still performing well given the longevity of the biochar in the soil. The soil at this trial exhibited an increase in Cation Exchange Capacity, soil pH and C:N ratio (Appendix 3.6, Figure 1, Figure 2, Figure 3).

Char and nutrients being applied in an NT melon crop

Green Man Char has supplied biochar in a coarse grade for green roofs on educational and commercial facilities in inner city areas. On these roofs, 30% coarse biochar was mixed with coir fibre, scoria and nutrients. This has resulted in improved water holding capacity and plant available water (PAW) in the growth medium. Green roofs amended with biochar performed better than roofs without biochar in summer due to the improved water holding capacity of the material.

The char product is additionally used in grass pasture for race horses, in banded application in horticulture using a direct drill seeder, as a potting medium in a commercial nursery and as a commercial landscaping soil amendment for use in garden beds, tree establishment and flower planting.

4. The Potential: a review of the literature

We reviewed a number of biochar feasibility studies focused on high and middle-high income countries as defined by the World Bank [23] to compare the practice of biochar use with the scenarios in the published literature by examining the following:

- Net biochar user benefit per tonne of biochar (Net Present Value per tonne)
- Biochar yield spread (biochar yield effect per tonne per hectare)

By selecting papers based on high and middle-high income country status we identified 20 papers with 49 relevant scenarios[8,24-38]. Most of these scenarios resulted in financially infeasible outcomes (39), where no net benefit was created for the user.

Of the ten financially viable scenarios, the most financially feasible was a study of Doug Pow's beef cattle biochar system in Joseph, et al. [14] (fig. 14). This scenario is particularly significant in that it is a singular example of a published financial feasibility study considering biochar's use as an animal feed.

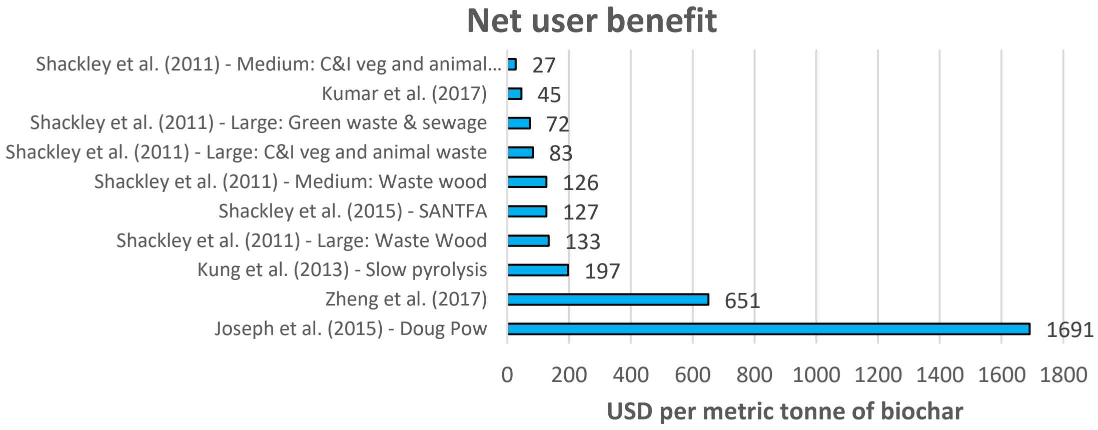

Figure 14. *Net user benefit (Net present value) in US dollars per tonne of biochar*

The second highest value creation scenario was Zheng, et al. [19], which considered a biochar fertiliser in a maize crop. Biochar fertiliser was applied at the rate equivalent to the required nitrogen fertiliser level, simultaneously displacing the cost of commercial fertiliser, as well as increasing crop yield relative to the control scenario.

All other financially feasible scenarios relied on pyrolysis unit co-production capabilities (with the exception[xiii] of Kumar, et al. [39]) capable of producing electricity or biofuels, but were not financially feasible when considering biochar value creation alone. This is reflective of many biochar users surveyed in Western Australia who obtained charcoal from a Silicon producer (SIMCOA). The silicon producer uses charcoal as a reducing agent to create molten silica, and the fines from this charcoal are sold as biochar, amongst other products. This enables the producer to sell the biochar product at a negligible price (between $100 and $300 per tonne).

[xiii] Kumar et al. (2018) is an Israeli based study of a high-value crop (sweet pepper). While this biochar has a modest biochar yield spread (1.35%), the high value of the crop enables net value creation for the user.

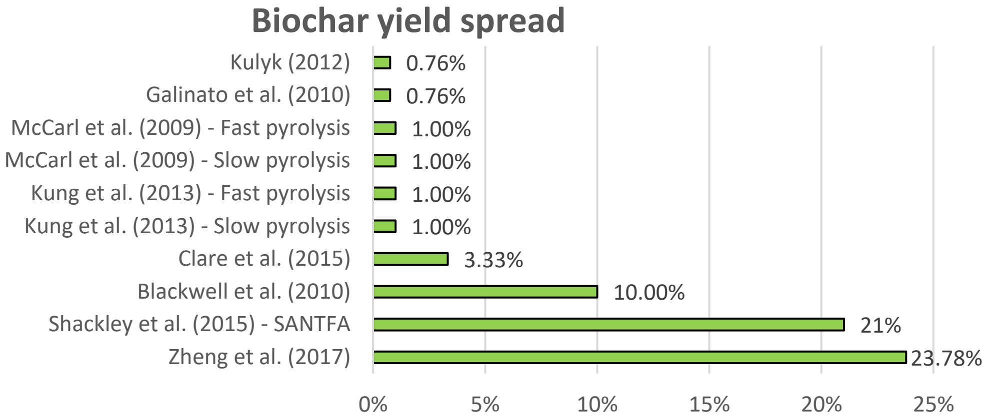

Figure 15. *Biochar yield spread (yield growth as a percentage per tonne of biochar per hectare) in studies considering high and middle-high income countries*

Biochar yield spreads (fig. 15) are a measure of product performance of biochar applied for crop yield improvement, here defined as the crop yield effect of one metric tonne of biochar applied to one hectare of cropland[xiv]. A consideration of the biochar yield spreads that underpin financial feasibility studies highlight three important results[8,19,34].

Zheng, et al. [19], as discussed previously, considers a biochar fertiliser product which attains a yield spread of 23.8% in Chinese maize, implying a yield effect an order of magnitude greater than a comparable standard biochar field trial of Zhang, et al. [18], and far greater than global yield averages in temperate latitudes[2,40] which are typically higher-income countries. As previously noted, this biochar fertiliser outperforms slow release fertilisers, mirroring results of studies both in China[41,42] and Australia[43].

Shackley, et al. [8] considers multiple case studies, one of which relates to a study performed by the South Australian No-Till Farmers Association (SANTFA). Here they apply biochar in banded rows, concentrating biochar particles at the wheat rhizosphere to achieve a 21% yield spread[xv]. Blackwell, et al. [34] similarly evaluates a scenario where biochar makes use of banded application to achieve a 10% yield spread in West Australian wheat.

Liquid biochar products have been tested in China with promising results [44]. Companies in the USA are now selling liquid biochar products. These liquids can be added to fertigation systems. Considerably more product development and testing is required to determine the costs and benefits of these products.

4.1 Comparing the literature and the user experience

This partial examination of the literature in higher income countries highlights a few key points for consideration for both academics and users:

(i) Biochar financial feasibility studies have focused almost exclusively on biochar's use as a soil amendment. As we have demonstrated in fig. 14, biochar's use as an animal feed has been shown not only to be financially feasible,[14] amongst the higher income studies considered, it is the most valuable use of biochar from the user's perspective. Furthermore, this study[14]

[xiv] If one tonne of biochar is applied across one hectare and crop yield increases 1%, then the biochar yield spread is 1%.

[xv] Note that this scenario does not actually consider revenues associated with increased yields in the publication in question, merely presenting field trial results.

overlooks the financial benefits of the secondary use of biochar infused manures, animal health improvements, reduced enteric methane emissions, and increased animal growth. These functionalities have all been exhibited in early research[7], but clearly require more investigation.

The *Biochar Now* case study further highlights the need for more research into biochar's use to improve water use efficiency, its applications in environmental remediation and for incorporation in construction materials.

(ii) Biochar financial feasibility studies in higher-income countries such as Australia have tended to focus on lower value cereals such as wheat. Even with high biochar performance as in Blackwell, et al. [34], the business case for these broadacre low-value crops remains challenging[xvi]. It is unsurprising that all but one biochar user in the survey has applied biochar in cereal cropping, and this user redirected biochar research efforts after finding insufficient biochar yield effect to justify further expenditure in this target crop. Such biochar users will need much higher biochar performance as with the biochar fertiliser in Zheng, et al. [19] or much lower biochar costs, as in the SIMCOA char[14] where biochar was a by-product of another economic activity and could be sold at negligible cost. Conversely, user responses indicate that biochar applied in higher value crops such as fruits, vegetables, nuts and horticulture are all potentially financially feasible through improvements in yield.

(iii) Biochar yield spreads[xvii] can be improved through banded application, as in Blackwell, et al. [34] and Shackley, et al. [8]. Almost all publications considering biochar's use in high income countries assume uniform mixing into the topsoil which increases costs unnecessarily by an order of magnitude. In practice, this is avoided.

(iv) Biochar fertilisers (biochars which have undergone pre-pyrolysis or post-pyrolysis treatment[17]) have been shown to outperform commercial slow release fertilisers in early research. If the early results of high performance can be broadly affirmed, this opens the potential for use in broadacre cereals and disruption of the existing slow release fertiliser market.

(v) There has been insufficient attention given to the financial value of applications of Wood vinegar as a fungicide, for improved germination and improved crop quality. While there is research verifying the capabilities relating to the properties of wood vinegar as a fungicide[13] and as a germination agent, more research is required to assess the financial value being created for users.

[xvi] Although developments such as biochar fertilisers may offer an alternative pathway.

[xvii] The yield potential of a given biochar product defined as the percentage increase in crop yield per hectare attributable to a single metric tonne of biochar.

5. Conclusion

This study sought to address the question: "What are the benefits of biochar and/or wood vinegar that users have observed in application?"

In the introduction, we noted that biochar and wood vinegar's use remains niche. However, early adopters in Australia, New Zealand and the US are using biochar in ways that create substantial net benefit, and do not reflect the practices assumed in the published literature.

In order to address the general question, this study sought to

(i) *Illuminate the* ***perceptions*** *of biochar and wood vinegar benefits through surveys and discussions with biochar users.*

Users who fed biochar to animals commonly valued biochar in its measured or perceived ability to improve animal health and weight. Such users purchased high volumes of biochar in bulk from biochar producers. Biochar was fed to animals on a daily or ongoing basis. Feed cost savings and weight gain were documented by some. Other users observed additional benefits of improved animal health and reduced veterinary expenses.

Users who applied biochar as a soil medium generally made use of it in horticulture and in higher value crops such as nuts, fruits and vegetables. Most of these users (more than 75%) made their own biochar using small kilns. Production volumes were typically small (< 200 kg) for these users but could aggregate to relatively large amounts over a year (up to 11 metric tonnes). Users who applied biochar on a larger scale in broadacre or plantation crops did not make it themselves, obtaining it from biochar producers. These larger scale users applied banded application techniques to achieve higher yield effects with smaller amounts of biochar. Application in broadacre cereal was found to be financially infeasible, however application in avocados was found to be financially feasible to the extent that neighbouring growers observed and adopted the practice.

Users of wood vinegar sought benefits in increased seed germination, reduced fungal diseases and improved plant health and crop quality. Users of this product were frequently fruit and nut farmers. Benefits observed included reduced diseases, improved seed germination rates and improved crop quality.

(ii) *Examine the* ***practice*** *of biochar and wood vinegar use through consideration of recent case studies*

The case studies considered highlighted the importance of alternative biochar uses beyond application to soil. Biochar's use as an animal feed in Western Australia and biochar's use as a water efficiency medium in a Californian golf course created more financial value for biochar users than any other scenario found in the literature.

The use of biochar in an avocado orchard similarly created net benefit for the user through multiple years of surplus fruit yield, demonstrating the financial benefit of targeting higher value crops. The char was sourced from a business which produced charcoal fines as a waste product and as such was far cheaper than typical market prices.

A field trial and feasibility study of a biochar fertiliser's use in a Ballarat potato farm demonstrated the immense potential of these alternative biochar products, highlighting the need for further research into their applications.

(iii) *Summarise the* ***potential*** *of biochar and wood vinegar value through a review of key insights from the published literature and emerging innovations.*

Two innovations in the literature were shown to significantly increase value for the user in terms of net benefit and biochar yield spread. These were banded application techniques and biochar fertilisers.

The literature typically assumes a uniform mixing into the topsoil across a hectare, whereas in practice it is almost always the case that application is banded. Directly applying biochar at the plant root zone can reduce the amount of biochar used by an order of magnitude while achieving similar effects[8,34].

In the limited number of studies performed examining biochar fertilisers, these products have demonstrated a capacity to outperform slow release fertilisers[19,41-43,45], substituting fertiliser costs and delivering an additional yield surplus.

The literature was generally shown to focus heavily on biochar's application to cereal crops, mostly overlooking higher value crops and alternative biochar uses. This contrasts substantially with use in practice, which consists almost exclusively of high value cropping and alternative biochar uses such as a feed additive for cattle.

Finally, most financially feasible studies in the literature are not feasible because of user benefits associated with biochar application but are feasible as a result of other economic activities. Examples include where biochar is a waste product (charcoal fines) emerging from silicon production, or where bioenergy or biofuels are the primary revenue streams and biochar is sold as a secondary by-product. This enables producers to sell the biochar at a negligible price, increasing the number of circumstances where biochar can create net benefit. Such an approach is reflected in the biochar product sold for $100 per metric tonne by SIMCOA to Avocado farmers and Cattle Graziers in Western Australia.

5.1 Recommendations

1) **Work with existing users of biochar and wood vinegar to identify practices that maximise the benefits from using biochar and wood vinegar.**

There is considerable expertise amongst scientists and engineers to assist producers and users of biochar and wood vinegar either reduce their application rates and/or increase crop yields. Mechanisms and funding need to be established for this assistance to be available.

2) **Assist innovators/early adopters in farming and waste management sector to trial fit for purpose biochars.**

There is now a large data base of information related to both the production and use of biochar and wood vinegar. ANZBI members who have specific experience are encourage to work with early adopters to adapt existing biochar and wood vinegar products to meet their specific needs and to carry out extensive field trials.

3) **More attention must be given by users, producers, government and private sector agronomists, agricultural scientists and academics to alternative uses of biochar beyond focusing on soil amendments, particularly as an animal feed supplement, for water holding capacity (for reduced**

irrigation requirements), partial replacement of chemical fertilisers and environmental remediation.

Biochar's use as an animal feed has been shown to be popular amongst respondents. Not only does it have the potential to generate animal health benefits and reduced feed costs, the nutrient enriched char having passed through the animal may be used subsequently as a soil amendment creating multiple stages of value creation for the user. Biochar producers targeting these markets can likely expect larger volumes of sales, ongoing sales and users who are prepared to pay more for biochar.

Biochar's use for water saving as demonstrated in the *Biochar Now* case study resulted in very high financial benefits to the user assuming the most pessimistic numbers reported, with irrigation savings expected to be received effectively in perpetuity. Additional uses such as environmental remediation and biochar's use as a component in construction materials requires further attention. With droughts and increasing temperatures anticipated as a result of a changing climate[46], such applications are likely to become more relevant. As one user requested of the ANZBI for future research: *"A documentation of water savings for use in horticulture would be a useful area of research or promotion for the ANZBI."*

4) **More research and well-resourced field trials are required to understand and quantify the benefits to farmers accrued via wood vinegar application.**

The survey revealed that wood vinegar users are observing numerous benefits because of wood vinegar application, including reduced fungal disease and improved produce quality where a foliar spray is applied.

While there are publications documenting the benefits of wood vinegar as a fungicide and as a stimulant for germination[13], the amount of literature considering wood vinegar's application is relatively modest in contrast to the number of biochar publications. No financial feasibility or economic studies have been performed in the published literature, though users are measuring improved produce quality.

5) **More large scale field trials are required to evaluate the applications of biochar based chemical fertilisers given their demonstrated capacity to outperform commercially available slow release fertilisers.**

Field trial results from China[19,41,42,45] and more recently Australia[43] demonstrate biochar fertiliser's capacity to outperform commercially available slow release fertilisers. These results are further confirmed in the potato farming case study in Ballarat and a Broccolini farmer's use of an enhanced biochar. These products offer the dual benefit to users of substituting existing fertiliser costs while increasing crop yields. While more research is required to continue confirmation of the benefits of biochar fertilisers, the high relative performance of these alternative biochar products and their subsequent potential for user value creation suggest they have the capacity to overcome the economic constraints that are currently faced by biochar's use in cereal agriculture, and to deliver considerable benefits to higher value crops such as the potato case study detailed in section 3.

6) **Development and large scale field trials are required of new biochar based products (e.g. extracts for fertigation or foliar sprays) that can be applied at low application rates with existing application equipment.**

Although small trials have been carried out in China with foliar spray and liquid fertilisers are sold commercially[47] there have not been large scale trials carried out in Australia or New Zealand that the authors have found.

7) **Funding is required for large scale demonstration projects where biochar is a component of a larger effort to utilise a waste resource (e.g. wood residues from forestry clean commercial and industrial timber) to reduce nutrient runoff and increase soil health. The projects need to be well-resourced so that they do not require any significant input from farmers over and above their normal day to day activities.**

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Appendix 1: Biochar Survey

AUSTRALIA NEW ZEALAND
BIOCHAR INITIATIVE Inc. ANZBI

The Australian and New Zealand Biochar Initiative Inc. (ANZBI) is a collaborative group of growers, scientists, engineers and other stakeholders interested in advancing the understanding and application of viable Biochar systems both small scale and large scale.

ANZBI is seeking your assistance to better understand commercial users' experiences with Biochar and/or Wood Vinegar. Our objective is to gather data on the benefits of biochar and/or wood vinegar in different commercial applications (farming, horticulture, environmental management etc).

ANZBI will collate the data into a 2019 report. Contributors will receive a copy. The question we wish to address in the 2019 report is:

What are the benefits of biochar and/or wood vinegar that users have observed in application?

We realise a generic questionnaire such as this may not always capture all relevant information. Additional fields have been provided to upload documents and make additional comments
If you would like someone from ANZBI to call you and discuss your experiences with biochar or wood vinegar please email us (publicofficer@anzbi.org)

Personal information:

1. Your name	
2. Phone / mobile	
3. Email	
4. Address	
5. Website	

6. Do you wish for your name to be kept confidential in the final report?	

Please address the following:

7. What is your business	

8. What do you grow / produce that makes use of biochar / wood vinegar?	

9. How frequently have you used biochar / wood vinegar? *Please mark with an 'X'.*

	Biochar	Wood Vinegar
Once		
Once a year		
Once a month		
More frequently than monthly		

10. What was the biochar / wood vinegar made from? *Please mark with an 'X'.*

	Biochar	Wood Vinegar
Wood		
Straw		
Poultry manure		
Poultry bedding		
Green waste		
Paper waste		
Bagasse		
Other (please describe)		

11. Where was the biochar/wood vinegar produced?	
12. What was the cost of the biochar/wood vinegar? If you produced the material yourself, what do you estimate as the cost of production? (eg. $1000/tonne)	
13. What was the volume of biochar/wood vinegar that you acquired?	
14. How far did you need to transport the product between the biochar/wood vinegar supplier and the point of use? Please denote units (e.g. miles / kms)	

15. What is your purpose in using biochar / wood vinegar in your business? *Please mark with an 'X'.*

Animal feed (biochar)	
Soil carbon / GHG emissions abatement	
Horticultural growing medium	
Soil rehabilitation	
Soil drought tolerance	

Reduce synthetic chemicals	
Crop yield effect	
Crop health/quality	
Reduce soil greenhouse gas emissions	
Water decontamination / filtration	
Fuel	
Construction products	
Other (please describe)	

16. **Do you have a chemical analysis for the biochar? If you are willing, could you share a copy of the analysis?** (This is a major help in understanding which biochars cause different responses.)	
17. **Please describe your biochar/wood vinegar application rate, what 'dose' did you use?** (e.g. XX tonnes per ha or YY% in feed mixture)	
18. **How often did you apply biochar / wood vinegar?**	
19. **How did you apply the biochar / wood vinegar ?** (e.g. mixed in thoroughly, banded application, foliar spray?)	
20. **What is the best form of biochar for your use? E.g. moist powder, dry powder, prill/pellet, other**	
21. **Did your use of fertilisers or composts change with biochar application?** (e.g. N Fertiliser rate was rescued by 25%)	
22. **Did you modify the biochar with nutrients or micro-organisms prior to application? If so, how?**	
23. **Other comments about your 'recipe'**	

BENEFITS / COSTS OF BIOCHAR USE

Please describe

24. What benefits did you observe from using biochar and/or wood vinegar? (e.g. Crop yield improvement, water use efficiency, nutrient use efficiency).	

25. Were there any costs incurred or problems that you observed through using biochar and /or wood vinegar?	
26. What data have you collected to measure the benefits and/or costs of application? (e.g seasonal crop yield/quality or animal weight gain)	
27. Have you measured benefits (or costs) over multiple seasons? Would you be prepared to attach a copy of these measurements?	
28. What other observations have you made about the benefits or costs associated with your use of biochar / wood vinegar?	
29. What cost savings are involved when you use biochar / wood vinegar? (e.g. reduced fertiliser requirement).	
30. What additional costs are involved when you use biochar/wood vinegar? (E.g. dust suppression)	
31. Do you intend to continue using biochar/wood vinegar in your business?	
32. Are there other learnings from your use of biochar / wood vinegar that you are willing to share?	
33. Do you have suggestions for other surveys or research for the ANZBI to facilitate?	

Appendix 2: Saline Soil Remediation

Table 1. Composition of amendments for each treatment. The last 4 rows in the table provide details of the thickness of each layer. The permeable biomass well (PBW) treatments consisted of materials and amendments including biochar (from Simcoa Pty Ltd, WA – Appendix 3.3 Table 2) & aged wheat straw.

Treatment 1	Treatment 2	Treatment 3	Treatment 4	Treatment 5	Treatment 6
6 kg straw per layer, per 10 m making a total of 12kg mulched straw 6 kg (Simcoa Fines) Biochar per layer, per 10 m making a total of 12 kg of biochar fines Lactic Acid Bacteria @ (wheat/milk based) 100 ml of serum added to 10 L of rainwater per m of length per layer = Total for 2 layers in total 20 L rainwater per m with 200 ml LAB serum Wood Vinegar @ 30 ml per 10 L of rainwater per m EM-1 @ 30 ml per 10 L rainwater per m Molasses water @ 500g per 10 L rainwater per m Worm Juice @ 300 ml per 10 L rainwater per m Fermented Urine @ 30 ml per 10 L rainwater per m	6 kg straw per layer, per 10 m making a total of 12kg mulched straw 6 kg (Simcoa Fines) Biochar per layer, per 10 m making a total of 12 kg of biochar fines 10 L per m of rainwater	6 kg straw per layer, per 10 m making a total of 12kg mulched straw 6 kg (Simcoa Fines) Biochar per layer, per 10 m making a total of 12 kg of biochar fines Lactic Acid Bacteria @ (wheat/milk based) 100 ml of serum added to 10 L of rainwater per m of length per layer = Total for 2 layers in total 20 L rainwater per m with 200 ml LAB serum Wood Vinegar @ 30 ml per 10 L of rainwater per m Molasses water @ 500 g per 10 L of rainwater per m	6 kg straw per layer, per 10 m making a total of 12kg mulched straw 6 kg (Simcoa Fines) Biochar per layer, per 10 m making a total of 12 kg of biochar fines Lactic Acid Bacteria @ (wheat/milk based) 100 ml of serum added to 10 L of rainwater per m of length per layer = Total for 2 layers in total 20 L rainwater per m with 200 ml LAB serum Worm Juice @ 300 ml per 10 L of rainwater per m Molasses water @ 500g per 10 L of rainwater per m	6 kg straw per layer, per 10 m making a total of 12kg mulched straw 6 kg (Simcoa Fines) Biochar per layer, per 10 m making a total of 12 kg of biochar fines Lactic Acid Bacteria @ (wheat/milk based) 100 ml of serum added to 10 L of rainwater per m of length per layer = Total for 2 layers in total 20 L rainwater per m with 200 ml LAB serum Fermented Urine @ 30 ml per 10 L of rainwater per m Molasses water @ 500 g per 10 Litres of rainwater per m EM-1 @3 0ml per 10 L of rainwater per m	Untreated soil
150 mm top soil cover	150 mm top soil cover	150 mm top soil cover	150mm top soil cover	150 mm top soil cover	150 mm top soil cover
100 mm of biochar	100 mm of biochar	100 mm of biochar	100 mm of biochar	100 mm of biochar	Trenched and backfilled
200 mm of wheat straw	200 mm of wheat straw	200 mm of wheat straw	200 mm of wheat straw	200 mm of wheat straw	Trenched and backfilled
100 mm of biochar	100 mm of biochar	100 mm of biochar	100 mm of biochar	100 mm of biochar	Trenched and backfilled
200 mm of wheat straw	200 mm of wheat straw	200 mm of wheat straw	200 mm of wheat straw	200 mm of wheat straw	Trenched and backfilled

Table 2. Basic soil properties before setting up the permeable biomass wall (PBW) treatments

Treatment	pH in H_2O	pH in $CaCl_2$	EC (mS/cm)	C %	N %	C/N ratio	Ca mg/kg	Fe mg/kg	K mg/kg	Mg mg/kg	Mn mg/kg	Na mg/kg	P mg/kg	S mg/kg
Treatment 1	6.1	5.7	9.2	1.4	0.1	15.7	799.6	36.3	237.4	124.4	9.7	73.9	10.6	11.5
Treatment 2	5.9	5.6	7.2	1.6	0.1	14.4	755.6	40.8	265.4	121.1	12.5	50.7	13.9	11.5
Treatment 3	5.8	5.4	8.1	1.6	0.1	15.0	779.4	42.7	183.7	130.1	11.1	71.8	14.5	12.0
Treatment 4	6.1	5.4	4.5	1.4	0.1	16.0	829.8	38.2	162.9	132.5	11.8	57.1	7.8	10.7
Treatment 5	6.0	5.5	5.9	1.3	0.1	14.9	844.4	40.2	198.4	130.0	10.8	49.6	12.3	10.5
Treatment 6	5.9	5.4	4.2	1.3	0.1	16.3	731.9	35.9	135.7	128.1	10.0	46.8	9.5	10.3

Table 3. Soil properties one year after setting up the permeable biomass wall (PBW) treatments

Treatment	pH in H_2O	pH in $CaCl_2$	EC (µS/cm)	C %	N %	C/N ratio	Ca mg/kg	Fe mg/kg	K mg/kg	Mg mg/kg	Mn mg/kg	Na mg/kg	P mg/kg	S mg/kg
Treatment 1	6.1	5.5	73.4	1.9	0.16	11.9	761	18.2	175.8	263.3	4.9	63.0	3.0	12.5
Treatment 2	5.8	5.3	42.8	1.8	0.15	12.0	649	15.8	117.9	245.7	3.3	60.5	1.8	12.1
Treatment 3	6.1	5.1	46.2	1.9	0.17	11.2	903	18.7	171.7	226.4	5.6	49.7	3.1	12.3
Treatment 4	6.5	5.5	52.0	1.7	0.14	12.1	960	18.8	177.6	244.6	4.9	58.9	3.2	9.3
Treatment 5	6.7	5.2	29.6	1.5	0.12	12.5	1048	23.2	130.7	201.6	8.0	62.2	4.4	3.2
Treatment 6	5.4	5.0	39.2	1.2	0.09	13.3	895	27.7	141.0	197.7	7.9	56.4	6.3	8.0

Table 4. Effect of permeable biomass wall (consisting of amendments such as biochar (from Simcoa Pty Ltd, WA) and aged wheat straw (donated for the experiment by Balco Ltd, Brookton WA) on soil microbial biomass C, N and P.

Parameters measured (mg/kg)	Treatment 1	Treatment 2	Treatment 3	Treatment 4	Treatment 5	Control
Microbial biomass carbon (C)	255±9	236±7	223±6	213±4	201±4	154±6
Microbial biomass nitrogen (N)	22±3	18±3	16±2	16±5	14±3	11±7
Microbial biomass phosphorus (P)	15±3	12±1	10±2	9±2	8±1	6±2

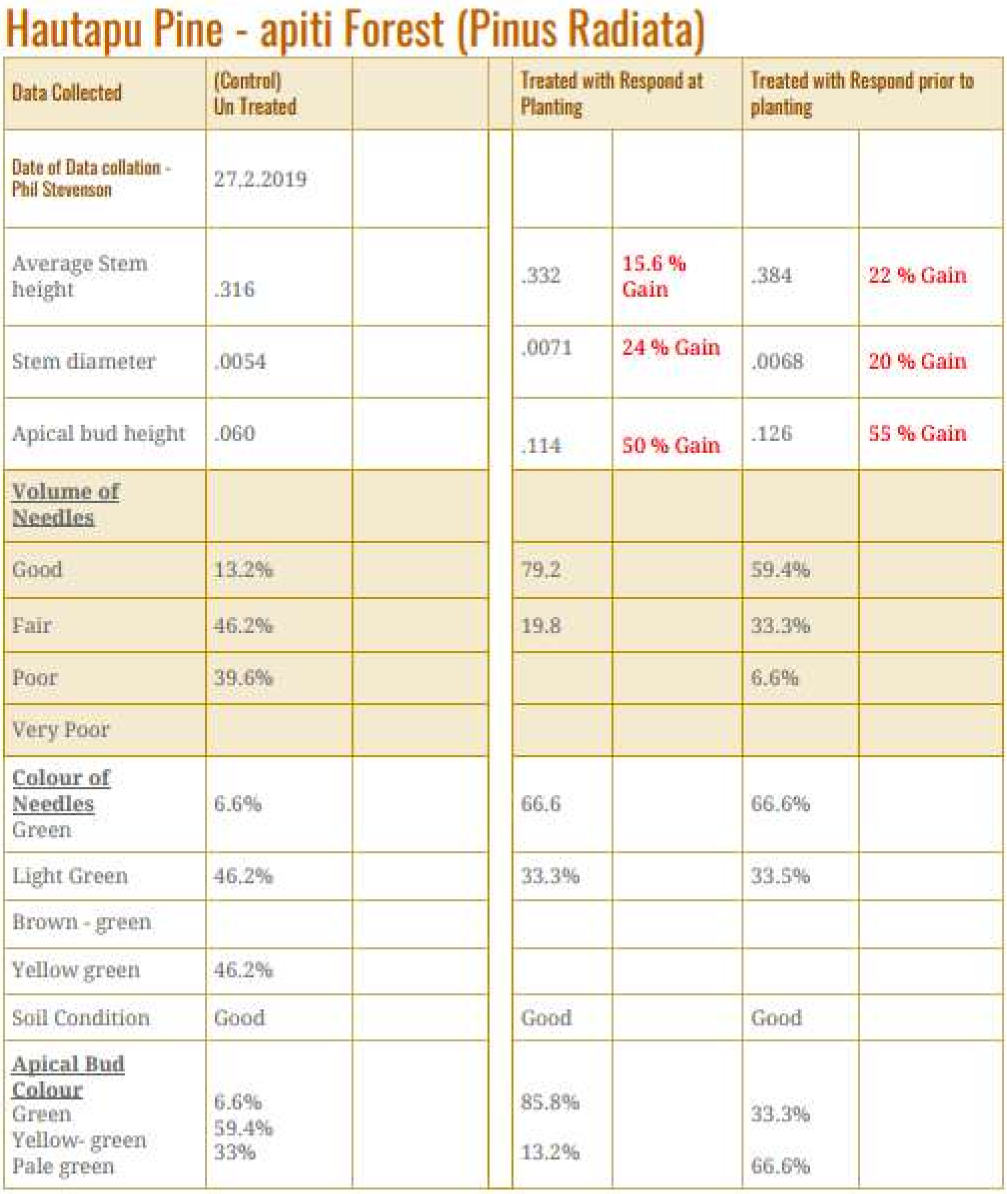
Appendix 3: Biochar testing and field trial results

Appendix 3.1: Biochar chemical analysis: Renewable Carbon Resources Australia (RCRA)

Reference	Units	PQL	WN160874	WN160874	WN160874
Client ID			Siepen 1	Siepen 2	Siepen 3
Lab No			1	2	3
Electrical Conductivity	dS/m	0.001	0.4	0.39	0.38
pH ($CaCl_2$)	pH units	0.04	7.3	7.4	7.4
Acid Neutralising Capacity	% $CaCO_3$ Equivalent	0.5	7.8	7.4	6.6
Formic Acid Soluble P **	mg/kg	3	12	13	14
Water Soluble Phosphorus**	mg/kg	3	<3	<3	<3
Bray Phosphorus	mg/kg	0.06	0.2	0.13	0.11
Total Organic Carbon	%	0.20	73	73	71
Total Carbon	%	0.20	76	75	74
Total Nitrogen	%	0.02	0.39	0.38	0.38
KCl Extractable Ammonium-N	mg/kg	0.3	0.86	0.7	0.69
KCl Extractable Nitrate-N	mg/kg	0.2	<0.2	<0.2	<0.2
<u>Exchangeable Cations</u>					
Aluminium	cmol(+)/kg	0.1	<0.1	<0.1	<0.1
Calcium	cmol(+)/kg	0.03	11	11	9.8
Potassium	cmol(+)/kg	0.01	0.48	0.5	0.58
Magnesium	cmol(+)/kg	0.007	0.53	0.53	0.52
Sodium	cmol(+)/kg	0.03	0.069	0.074	0.083
CEC (effective)	cmol(+)/kg	0.20	12	12	11
Calcium/ Magnesium			21	21	19
Aluminium Saturation	% of ECEC		N/A	N/A	N/A
Exchangeable Calcium	% of ECEC		91	91	89
Exchangeable Potassium	% of ECEC		3.9	4.2	5.3
Exchangeable Magnesium	% of ECEC		4.4	4.4	4.7
Exchangeable Sodium	% of ECEC		0.57	0.61	0.76
<u>ICP Elements</u>					
Aluminium	%	0.0005	0.037	0.046	0.059
Arsenic	mg/kg	5	<5	<5	<5
Boron	mg/kg	4	<4	<4	<4
Calcium	%	0.0010	3.5	3.5	3.5
Cadmium	mg/kg	0.3	<0.3	<0.3	<0.3
Cobalt	mg/kg	0.4	<0.4	<0.4	<0.4
Chromium	mg/kg	0.2	2.3	2.6	2.5
Copper	mg/kg	0.2	0.97	0.94	1
Iron	%	0.0010	0.053	0.063	0.075
Potassium	%	0.0004	1.5	1.5	1.5
Magnesium	%	0.0010	0.051	0.051	0.05
Manganese	mg/kg	0.1	12	23	21
Molybdenum	mg/kg	1.0	<1.0	<1.0	<1.0
Sodium	%	0.0005	0.0046	0.0053	0.0051
Nickel	mg/kg	0.7	<0.7	<0.7	0.77
Phosphorus	%	0.0010	0.003	0.0028	0.0029
Lead	mg/kg	2	<2	<2	<2
Sulfur	%	0.0006	0.0097	0.0095	0.0099
Selenium	mg/kg	4	<4	<4	<4
Zinc	mg/kg	0.8	4.1	5.5	4.8

Appendix 3.2: Dugald Hamilton

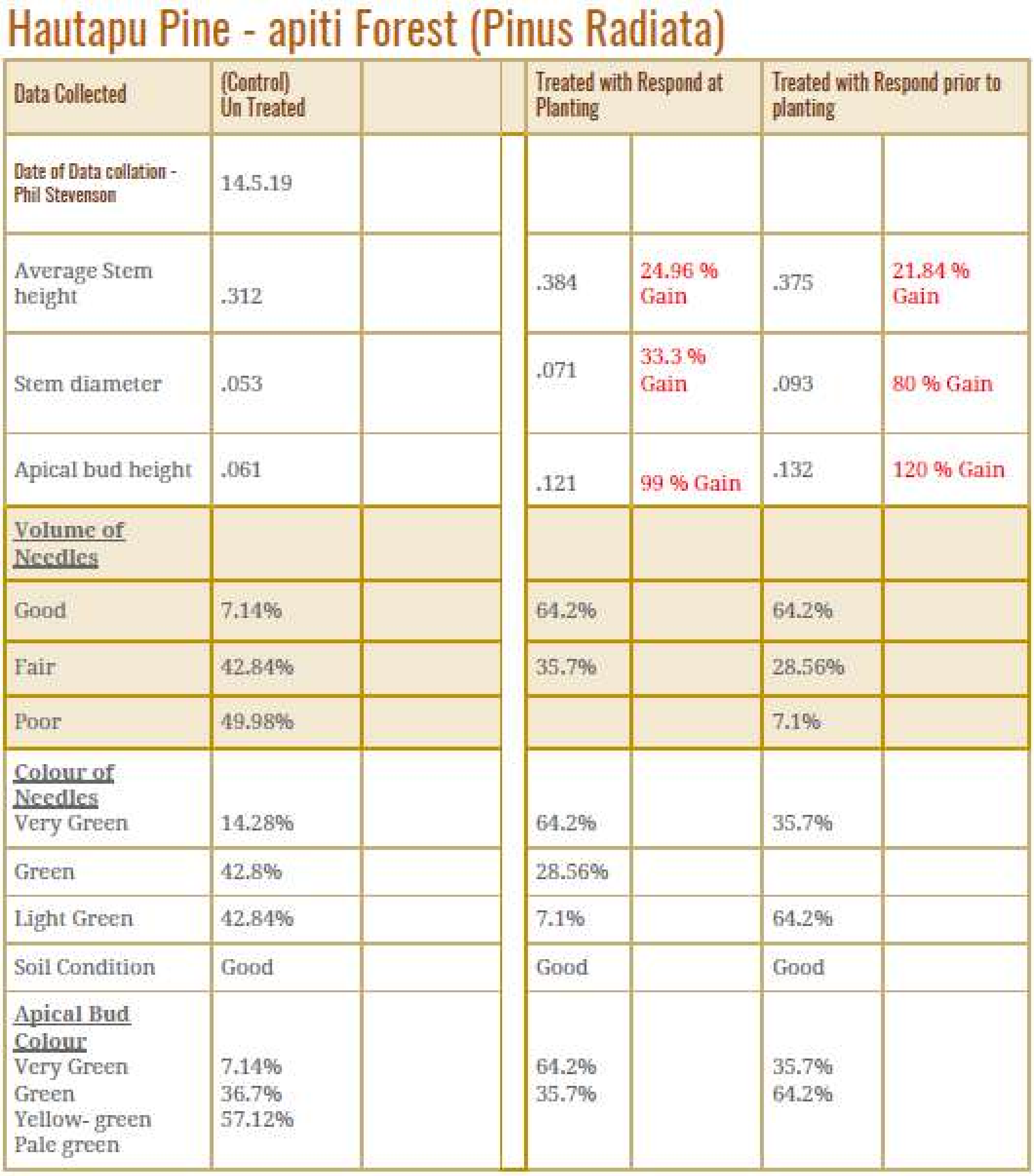
Table 1: Measurements on 27th of February, 2019



Hautapu Pine - apiti Forest (Pinus Radiata)

Data Collected	(Control) Un Treated		Treated with Respond at Planting		Treated with Respond prior to planting	
Date of Data collation - Phil Stevenson	27.2.2019					
Average Stem height	.316		.332	15.6 % Gain	.384	22 % Gain
Stem diameter	.0054		.0071	24 % Gain	.0068	20 % Gain
Apical bud height	.060		.114	50 % Gain	.126	55 % Gain
Volume of Needles						
Good	13.2%		79.2		59.4%	
Fair	46.2%		19.8		33.3%	
Poor	39.6%				6.6%	
Very Poor						
Colour of Needles Green	6.6%		66.6		66.6%	
Light Green	46.2%		33.3%		33.5%	
Brown - green						
Yellow green	46.2%					
Soil Condition	Good		Good		Good	
Apical Bud Colour Green Yellow- green Pale green	6.6% 59.4% 33%		85.8% 13.2%		33.3% 66.6%	

Table 2: Measurements on 14th of May, 2019



Hautapu Pine - apiti Forest (Pinus Radiata)

Data Collected	(Control) Un Treated			Treated with Respond at Planting		Treated with Respond prior to planting	
Date of Data collation - Phil Stevenson	14.5.19						
Average Stem height	.312			.384	24.96 % Gain	.375	21.84 % Gain
Stem diameter	.053			.071	33.3 % Gain	.093	80 % Gain
Apical bud height	.061			.121	99 % Gain	.132	120 % Gain
Volume of Needles							
Good	7.14%			64.2%		64.2%	
Fair	42.84%			35.7%		28.56%	
Poor	49.98%					7.1%	
Colour of Needles							
Very Green	14.28%			64.2%		35.7%	
Green	42.8%			28.56%			
Light Green	42.84%			7.1%		64.2%	
Soil Condition	Good			Good		Good	
Apical Bud Colour							
Very Green	7.14%			64.2%		35.7%	
Green	36.7%			35.7%		64.2%	
Yellow- green	57.12%						
Pale green							

Appendix 3.3: Doug Pow[14]

Table 1: Some basic properties of soil in the study field in 2011 (before the introduction of biochar) and 2015 (biochar addition *via* animal feed application over a 3-year period)

Property	2011	2015
Electrical conductivity (dSm-1)	0.063	0.124
pH (H2O)	5.9	5.9
pH (CaCl2)	4.9	5.2
Total N (gkg-1) NMa)		4.7
Total C (gkg-1) NM		58.1
Total P (mgkg-1) NM		938
Colwell P (mgkg-1)	49	102
Colwell K (mgkg-1)	55	205
KCl-extractable NH+	21	10
KCl-extractable NO	15	33
Total organic C(g kg-1)	41.7	46.7
Al (cmol(+) kg-1)<	0.069	0.168
Ca (cmol(+) kg-1)	5.1	6.78
K (cmol(+) kg-1)	0.17	0.5
Mg (cmol(+) kg^{-1})	0.63	0.76
Na (cmol(+) kg^{-1})	0.1	0.18

Table 2: Proximate and ultimate analyses of the fresh biochar

Proximate analysis	
Moisture	1%
Ash	7.8%
Volatile matter	16.2%
Fixed C	75%
Ultimate analysis	
Total C	82%
H	2%
N	0.4%
Total S	0.03%
O	15.57%

Appendix 3.4: Ian Stanley – biochar field trial data

Project Rainbow Bee Eater

Biochar field trials
Summary of 2008 season

Ian Stanley (left) and Peter Burgess (right) at the trial site in Kalannie, 2008.

Report prepared by

Stephen Davies – Western Australian Department of Agriculture and Food
Peter Burgess – Project Rainbow Bee Eater
Ian Stanley – Project Rainbow Bee Eater & Kalannie wheat farmer
Syd Shea – Project Rainbow Bee Eater

Sponsored by Alumina Ltd

Supported by WA Department of Agriculture and Food

Introduction

Project 'Rainbow Bee Eater' was initiated by Peter Burgess, Syd Shea and Ian Stanley in 2007 to investigate the feasibility of manufacturing and utilising biochar in a number of Australia's wheat production areas, using local crop and plantation waste from existing cleared farmland as feedstock.

A prefeasibility study was undertaken to study:

- i) logistics of biomass collection and biochar delivery based on regional biochar 'nodes'
- ii) technologies capable of converting crop and plantation waste to biochar and electricity for sale to the local grid
- iii) multi year impacts to a wheat farm of closed loop biomass collection & biochar return
- iv) project economics and risks
- v) indirect impacts on the regions involved

Interest in biochar is increasing. Larger scale, practical demonstration and research have been limited by non-availability of affordable, large tonnage quantities of biochar of known quality and origins. The Rainbow Bee Eater team believed that larger scale, multi year field trials on a dryland farm with larger quantities of biochar of known quality and origins would contribute to the overall knowledge base.

Subsequently two biochar experiments were established at Kalannie in 2008 to investigate the effect of biochar application on growth of dryland (rainfed) wheat. The experiments were implemented and managed by the Western Australian Department of Agriculture and Food with assistance from Ian, Clint and Travis Stanley.

The aims of these experiments were to assess:

1. the value of biochar as a soil amendment;
2. the impact of biochar on the yield and quality of rainfed wheat.

Soil description and 2008 climate

There was good rainfall at the Kalannie site for 2008 with a little over 100mm of rain falling in July (Figure 1). Growing season (April-October) rainfall was 263 mm. This meant that despite the late sowing of the experiments grain yields obtained were reasonable.

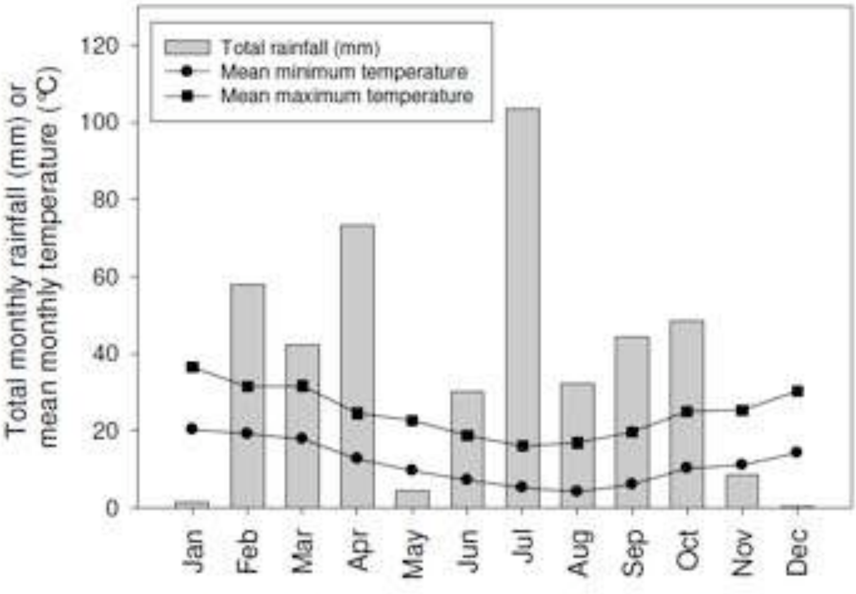


Figure 1. Monthly total rainfall (mm) and mean monthly minimum and maximum temperatures at the Kalannie biochar site for 2008.

The soil at the site as a yellow sandy earth with 30% or more ironstone gravel commencing at between 20-40 cm across the site.

Soil samples were collected during the season in September (after biochar application) from selected treatments of both experiments. Samples were analysed in an accredited laboratory for pH, exchangeable aluminium, nitrate, ammonia, phosphorous, sulphur, organic carbon and total carbon.

Biochar source

The experiments used two types of biochar produced for Project Rainbow Bee Eater by Alterna Energy Pty Ltd, Johannesburg from South African wheat straw and by Ansac Pty Ltd, Bunbury, from Western Australian oil mallee residues. Approximately twenty five tonnes of biochar was manufactured. The wheat straw biochar was finely crushed and had a large dust component while the oil mallee biochar was coarser and had less dust (Figure 2).

Figure 2. Images showing mallee (left) and wheat (right) biochar

Table 1. Carbon, nitrogen and sulphur content and C:N for wheat straw and oil mallee biochars used in the experiments at Kalannie, 2008. Values are means of three replicate samples ± standard error of the mean.

Biochar type	N %	C %	S %	C/N
Wheat straw	0.88 ±0.05	78.1 ±2.8	0.15 ±0.03	89 ±8
Oil mallee residues	1.29 ±0.02	66.5 ±1.0	0.29 ±0.06	52 ±1

Mallee biochar has higher N and S content compared with the wheat straw biochar but lower C content (Table 1). XRF elemental analysis of the biochar ash residue (the ash remaining after C, N, S and water have been removed) indicates that the mallee biochar contains considerably more Ca and Mg but the wheat straw biochar is higher in Si, K, P and Cu (Table 2).

Table 2. XRF elemental analysis of the wheat straw and oil mallee biochar ash. Values are means of three replicate samples ± standard error of the mean.

Biochar Ash Type	Al %	Si %	Fe %	Mn %	Ca %	K %	Mg %	Na %	P %	Cu Mg/kg	Zn mg/kg
Wheat straw	3.1 ±0.2	66 ±0.4	1.7 ±0.3	0.1 ±0.01	4.2 ±0.5	10.9 ±1.5	2.5 ±0.3	2.3 ±0.3	4.0 ±0.4	328 ±12	280 ±51
Oil Mallee Residues	4.0 ±0.3	46 ±1.4	4.3 ±0.8	0.5 ±0.03	24.7 ±1.3	3.6 ±0.2	4.8 ±0.3	2.4 ±0.1	1.8 ±0.1	242 ±18	349 ±59

Experiment 1 - Banded biochar

Methods

This experiment is a double-banked randomized complete block design with 4 replicates comprising 80 plots. Each plot is 20m long and 1.8 m wide. Biochar was banded into the soil prior to sowing at rates of 0, 6.5, 13 and 26 t/ha to a depth of 12 cm using a cone-seeder with narrow knife-point tynes (Figure 3). Multiple passes of the cone-seeder were required to achieve the higher biochar rates as a maximum of 6.5 t biochar/ha could be applied in a single pass and nil biochar controls with and without additional coneseeder passes were also included. Biochar bands were spaced 22 cm apart, the same as the crop rows, and an attempt was made to sow the crop rows directly on top of the banded biochar (Figure 4).

Figure 3. Banding of biochar using a coneseeder at Kalannie on 18th June 2008.

Plots were seeded with Wyalkatchem wheat at a rate of 80 kg/ha using a coneseeder on 19th June 2008. Fertiliser ('Agstar': 14.1% N; 14.1% P; 9.2% S; 0.1% Cu; 0.2% Zn) was applied at either standard rate of 100 kg/ha or a half rate of 50 kg/ha.

Figure 4. Mallee (left image) and wheat (right image) biochar banded in the soil at Kalannie, showing depth of placement and position of crop rows.

Plant establishment counts were conducted 32-33 days after sowing on 22 July 2008 at Kalannie. Harvest index cuts were taken from every plot at Kalannie on the 25th November. From the large banded biochar plots 4x2 m crop row was harvested. Harvest index cuts were assessed for total weight, head number, head weight, grain yield and 1000 grain weight. Plots were machine harvested using a plot harvester on 26th November 2008. Grain samples from the machine harvest were analysed for grain protein, screenings (weight of unmillable material including small grains and contaminants that pass through a screen with 12.7mm x 2mm slots) and hectolitre (test) weight.

Results

There was no measurable effect of either banded biochar, fertiliser rate or soil disturbance on crop establishment (data not shown) with an average plant density of 122 plants/m^2.

There was no effect of cultivation, biochar or fertiliser rate on grain yield. Grain yields for the experimental site ranged from 1.8-2.3 t/ha (Table 3).

Table 3. Grain yield, grain protein, screenings and hectolitre weight of Wyalkatchem wheat in response to cultivation, biochar and fertiliser rate at Kalannie in 2008.

No.	Fertiliser Rate	Biochar Rate	Biochar Type	Cultivation (coneseeder passes)	Grain Yield (t/ha)	Protein (%)	Screenings (%)	Hectolitre Weight (kg/hL)
1	Standard	0	Nil	0	2.0	13.3	2.8	73.7
2	Standard	0	Nil	1	2.1	12.8	2.3	75.7
3	Standard	0	Nil	2	1.8	12.9	2.3	74.1
4	Standard	0	Nil	4	2.0	13.2	2.2	75.1
5	Standard	6.5	Wheat	1	2.0	13.0	2.3	75.0
6	Standard	13	Wheat	2	2.0	13.1	2.5	74.1
7	Standard	26	Wheat	4	2.1	12.9	2.2	74.5
8	Standard	6.5	Mallee	1	2.3	12.3	2.3	72.2
9	Standard	13	Mallee	2	2.0	12.9	2.2	73.6
10	Standard	26	Mallee	4	1.9	12.9	2.3	74.6
11	Half	0	Nil	0	2.2	12.6	2.4	76.4
12	Half	0	Nil	1	2.0	12.2	2.5	75.2
13	Half	0	Nil	2	2.1	12.5	2.2	74.6
14	Half	0	Nil	4	2.1	12.4	3.1	74.7
15	Half	6.5	Wheat	1	1.9	12.8	2.6	75.7
16	Half	13	Wheat	2	2.0	12.9	2.3	75.6
17	Half	26	Wheat	4	1.8	12.4	2.6	75.6
18	Half	6.5	Mallee	1	2.0	12.5	2.7	74.1
19	Half	13	Mallee	2	1.9	12.4	2.5	74.9
20	Half	26	Mallee	4	1.9	12.7	2.8	76.6

There was no significant impact of banded biochar on total shoot biomass but there was a trend towards lower shoot biomass with increasing number of coneseeder passes.

Table 4. Total shoot dry weight (t/ha) determined from harvest index cuts

Cultivation (Biochar rate, t/ha)	Nil Biochar		Wheat biochar		Mallee biochar	
	Standard fertiliser	Half fertiliser	Standard fertiliser	Half fertiliser	Standard fertiliser	Half fertiliser
0 (0)	3.9	3.7				
1 (6.5)	3.9	3.7	3.6	3.6	3.8	3.8
2 (13.0)	3.6	3.8	3.8	3.9	3.7	3.8
4 (26.0)	3.5	3.9	3.5	3.4	3.5	3.5

Similarly there was no significant impact of banded biochar on head (ear) number but there was a trend towards lower head numbers with increasing number of coneseeder passes. Note that this did not result in a decline in machine harvest yields.

Table 5. Number of heads (ears) per m^2 determined from harvest index cuts

Cultivation (Biochar rate, t/ha)	Nil Biochar		Wheat biochar		Mallee biochar	
	Standard fertiliser	Half fertiliser	Standard fertiliser	Half fertiliser	Standard fertiliser	Half fertiliser
0 (0)	186	178				
1 (6.5)	198	190	184	178	198	191
2 (13.0)	195	192	186	201	188	187
4 (26.0)	179	152	181	169	182	175

Experiment 2 - Incorporated biochar

Methods

This experiment is a randomised complete block design with 4 replicates in 4 banks comprising 80 plots. Biochar was spread by hand at rates of 0, 20, 60 and 100 t/ha over a 4 x 1.8 m area and fully incorporated throughout the topsoil to a depth of 12 cm using a rotary hoe (Figures 5 and 6). Nil biochar controls with and without rotary hoe cultivation were also included. Plots were seeded with Wyalkatchem wheat at a rate of 80 kg/ha using a coneseeder on 19th June 2008. Fertiliser ('Agstar': 14.1% N; 14.1% P; 9.2% S; 0.1% Cu; 0.2% Zn) was applied at either standard rate of 100 kg/ha or a half rate of 50 kg/ha. Seeding depth was adjusted when sowing the cultivated plots to ensure good establishment.

Figure 5. Rotary hoe incorporation of surface spread biochar into the soil at Kalannie.

Plant establishment counts were conducted 32-33 days after sowing on 22 July 2008 at Kalannie. Harvest index cuts were taken from every plot at Kalannie on the 26th November, 2x2 m row samples were harvested. Harvest samples were assessed for total shoot dry weight, head number, grain yield and grain quality parameters including average kernel weight (thousand grain weight), screenings and grain protein.

Results

Crop establishment was decreased from an average 70 plants/m^2 to 40 plants/m^2 in treatments where wheat biochar was incorporated at 100 t/ha (data not presented). There are a number of possible explanations for this decline in plant numbers. It was observed that wheat seeds were sown deeper on these treatments despite adjusting the seeding depth for the cultivated plots. It was also observed that the finely crushed wheat biochar at these very high rates caused clumping in the soil surface potentially causing a physical barrier to emergence. It is also possible that there were toxic or inhibitory compounds in the biochar which at high rates affected germination and seedling growth. There was no decrease in crop establishment for the oil mallee biochar.

Figure 6. Rotary hoe incorporated wheat (left image) and mallee (left image) biochar at rates of 60 t/ha in the soil at Kalannie, showing depth of placement and degree of incorporation.

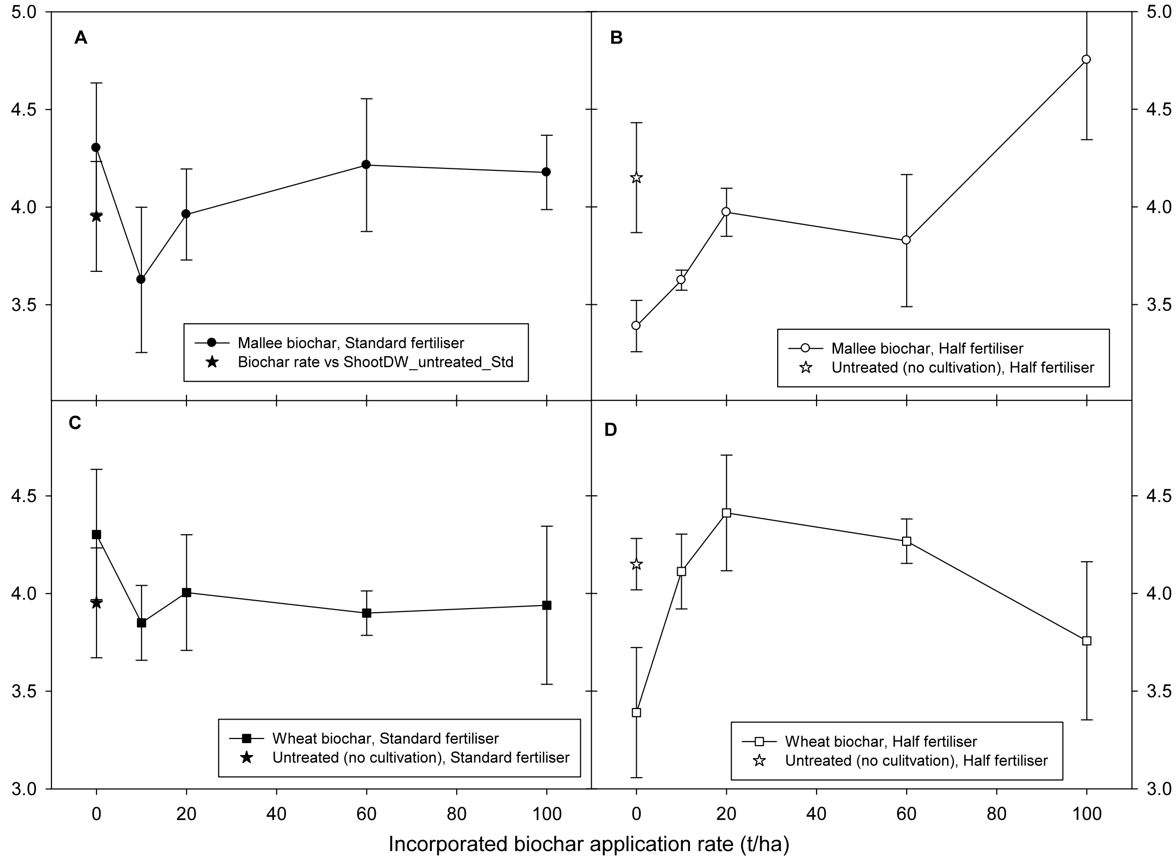


Figure 7. Impact of increasing rates of incorporated mallee (A,B) and wheat (C,D) biochar on total shoot dry weight (t/ha) of Wyalkatchem wheat grown with standard (A,C) or half-standard (B,D) fertiliser rates at Kalannie, 2008.

At the standard fertiliser rate neither cultivation nor addition of biochar had an impact on shoot dry weight (Figure 7A&C). At the half-fertiliser rate cultivation decreased shoot dry weight and addition of both wheat and mallee biochar increased shoot dry weight (Figure 7B&D).

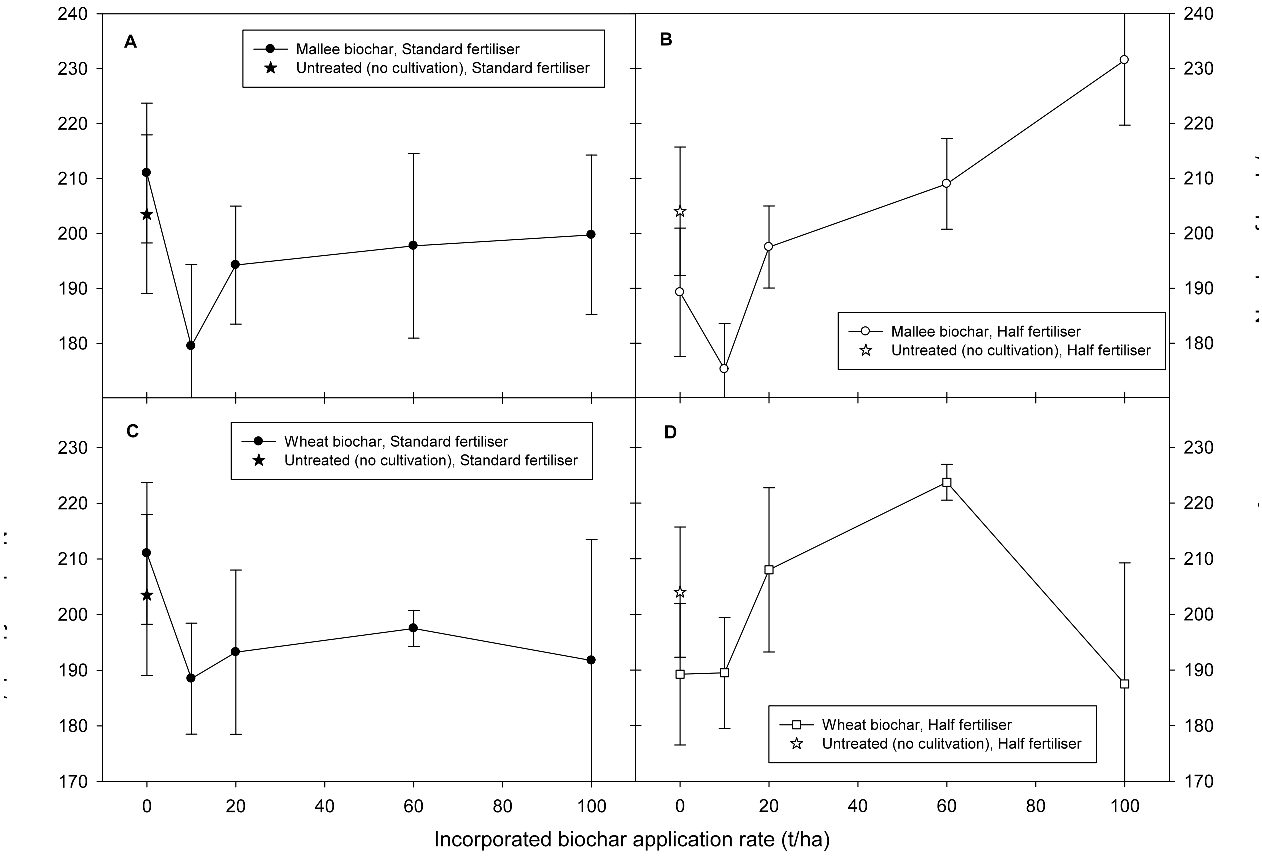


Figure 8. Impact of increasing rates of incorporated mallee (A,B) and wheat (C,D) biochar on number of heads/ears (heads/m^2) of Wyalkatchem wheat grown with standard (A,C) or half-standard (B,D) fertiliser rates at Kalannie, 2008.

Head numbers showed similar trends to total shoot biomass with both biochars at the half-fertiliser rate increasing head number (Figure 8B&D). The decline in head number for 100t/ha of wheat biochar is consistent with a decrease in the plant population (Figure 8D). There was no significant impact of the biochar on head number at the standard fertiliser rate.

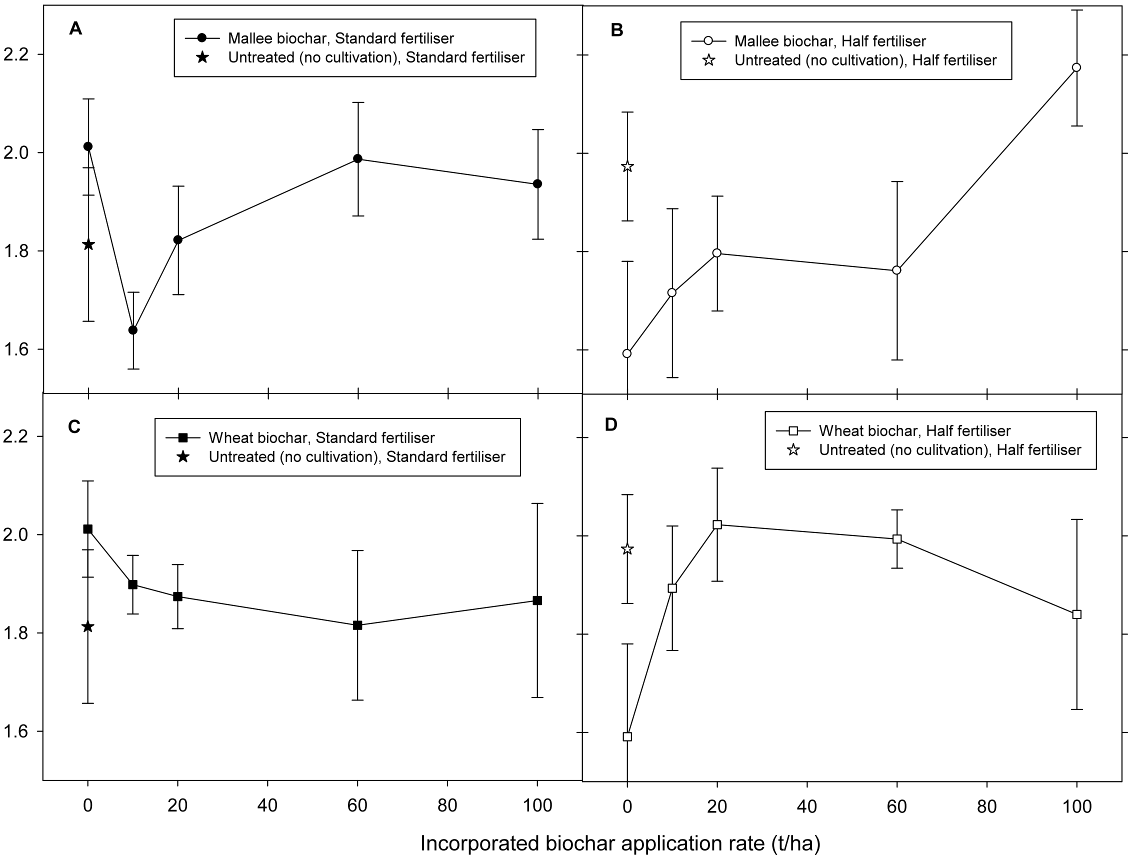


Figure 9. Impact of increasing rates of incorporated mallee (A,B) and wheat (C,D) biochar on grain yield (t/ha) of Wyalkatchem wheat grown with standard (A,C) or half-standard (B,D) fertiliser rates at Kalannie, 2008.

Cultivation at the half-standard fertiliser rate reduced grain yields by 0.4 t/ha from 2.0 t/ha to 1.6 t/ha (Figure 9B&D). Addition of both biochars helped grain yields recover to yields similar to the uncultivated control. Halving the fertiliser rate did not significantly reduce grain yield in the absence of cultivation (Figure 9) implying that the site is reasonably fertile. Grain yields were very similar to those obtained in the neighboring banded biochar experiment which was machine harvested.

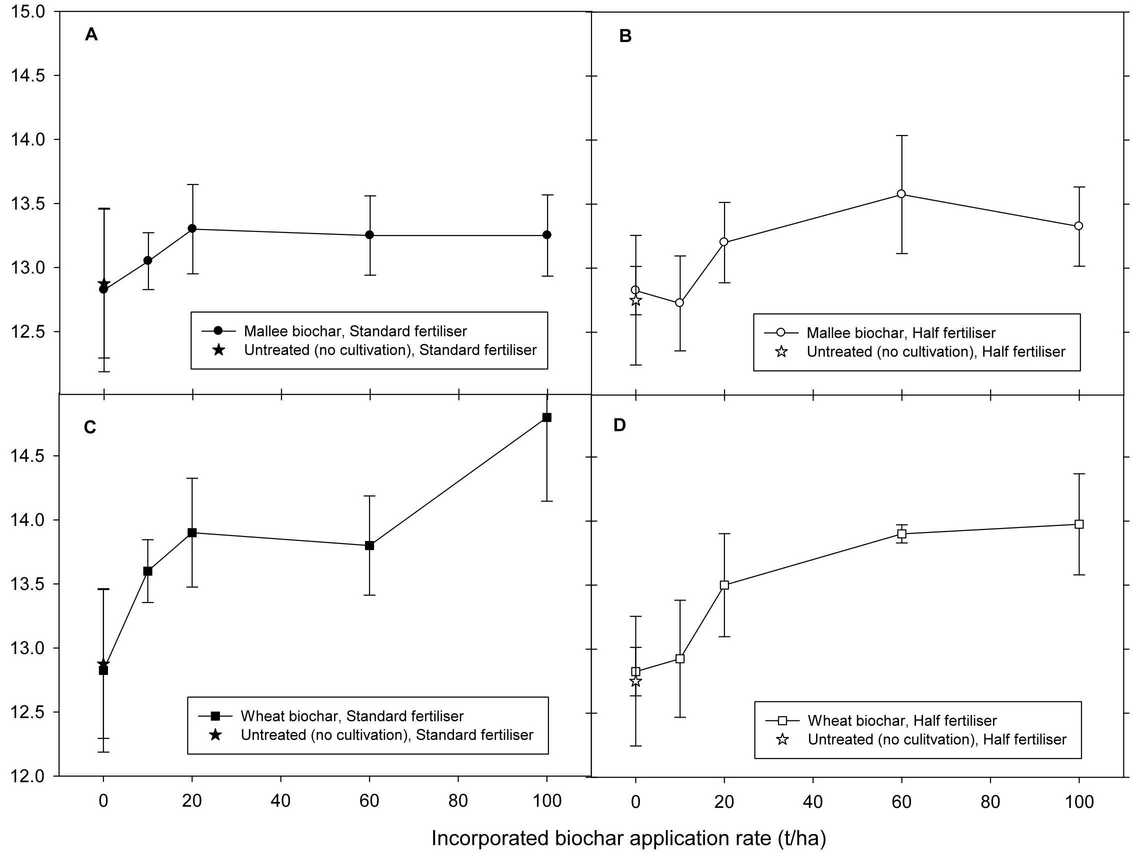


Figure 10. Impact of increasing rates of incorporated mallee (A,B) and wheat (C,D) biochar on grain protein concentration (%) of Wyalkatchem wheat grown with standard (A,C) or half-standard (B,D) fertiliser rates at Kalannie, 2008.

Cultivation had no effect on grain protein (Figure 10). Wheat biochar at both standard and half-fertiliser rates significantly increased grain protein at the higher application rates (Figure 10C&D) Mallee biochar at the half-fertiliser rate showed a trend of increasing grain protein concentration (Figure 10B).

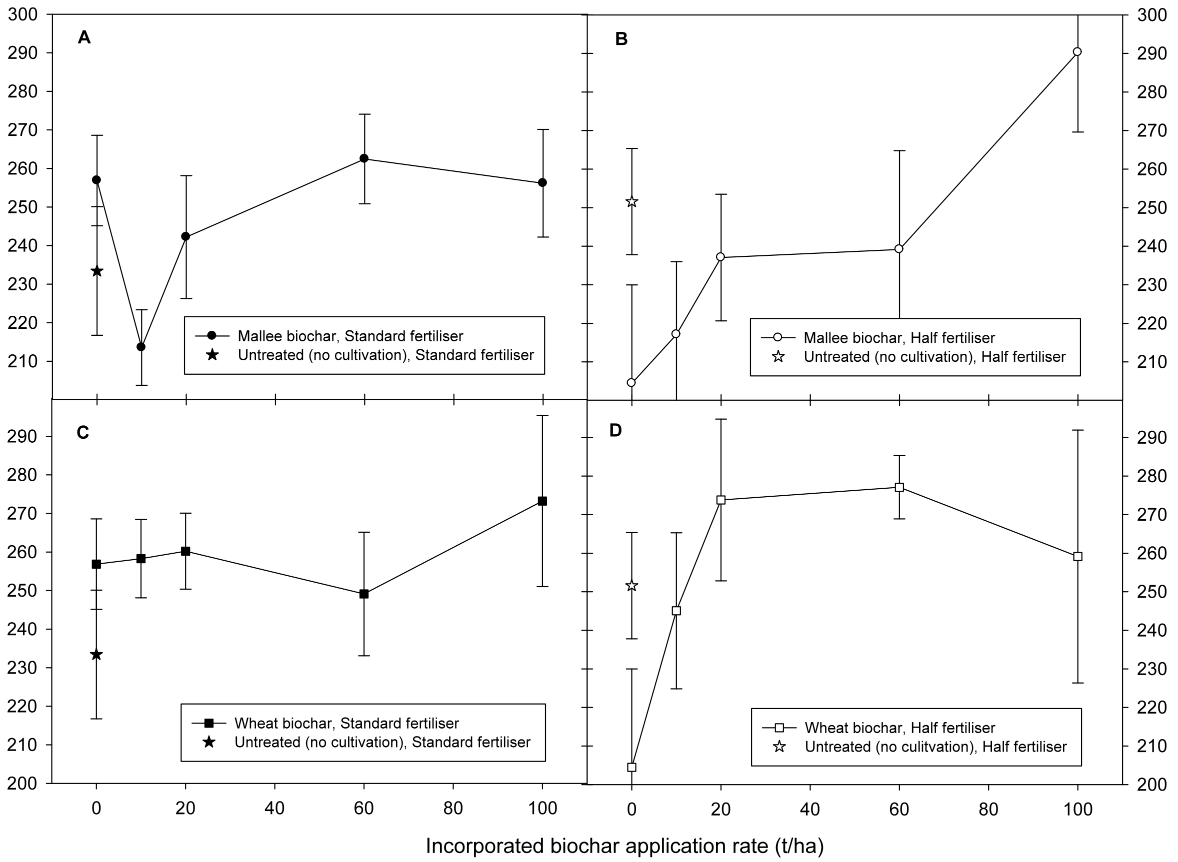


Figure 11. Impact of increasing rates of incorporated mallee (A,B) and wheat (C,D) biochar on grain protein yield (kg grain protein/ha) of Wyalkatchem wheat grown with standard (A,C) or half-standard (B,D) fertiliser rates at Kalannie, 2008.

This showed that application of wheat or mallee biochar at the standard fertiliser rate had little impact on total protein yield per ha (Figure 11A&C). Application of both biochars at the half-standard fertiliser rate did increase total protein yield.

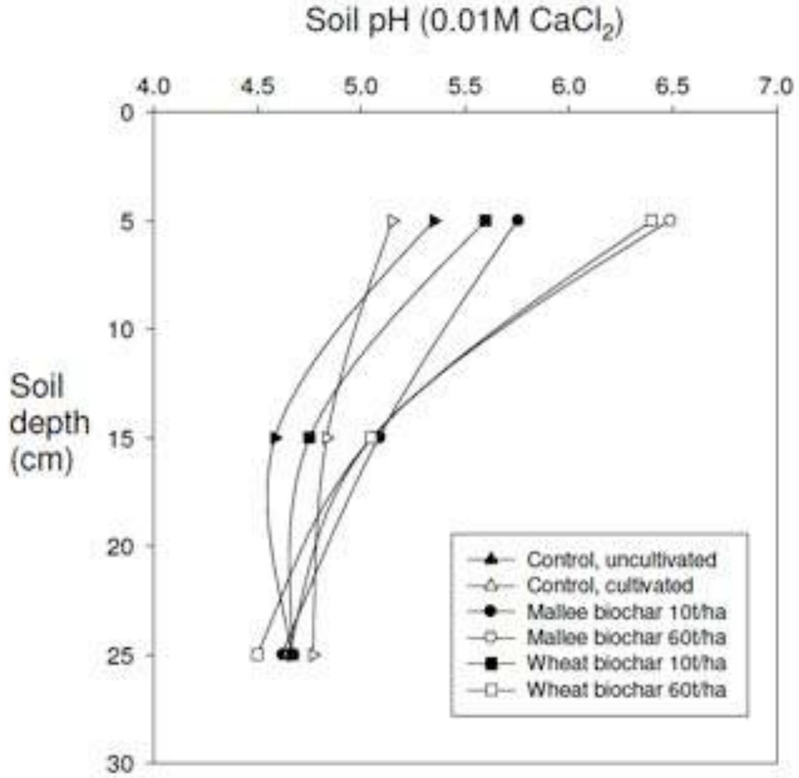


Figure 12. Impact of rotary hoe incorporated mallee and wheat biochar applied at rates of 10 and 60 t/ha on soil pH compared with untreated controls with and without cultivation at Kalannie, 2008.

Soil pH at the site without cultivation or biochar addition were slightly acid in the topsoil with a pH of 5.4 and moderately acid in the subsoil with a pH of 4.6-4.7 (Figure 12). Cultivation marginally decreased the topsoil pH and increased the pH of the 10-20 cm layer due to mixing of the topsoil. Addition of biochar increased the topsoil pH and at the higher rates of 60 t/ha increased the subsoil pH a 10-20 cm above 5.0. Neither cultivation nor biochar substantially altered the pH at 20-30cm as this was below the incorporation depth of the rotary hoe.

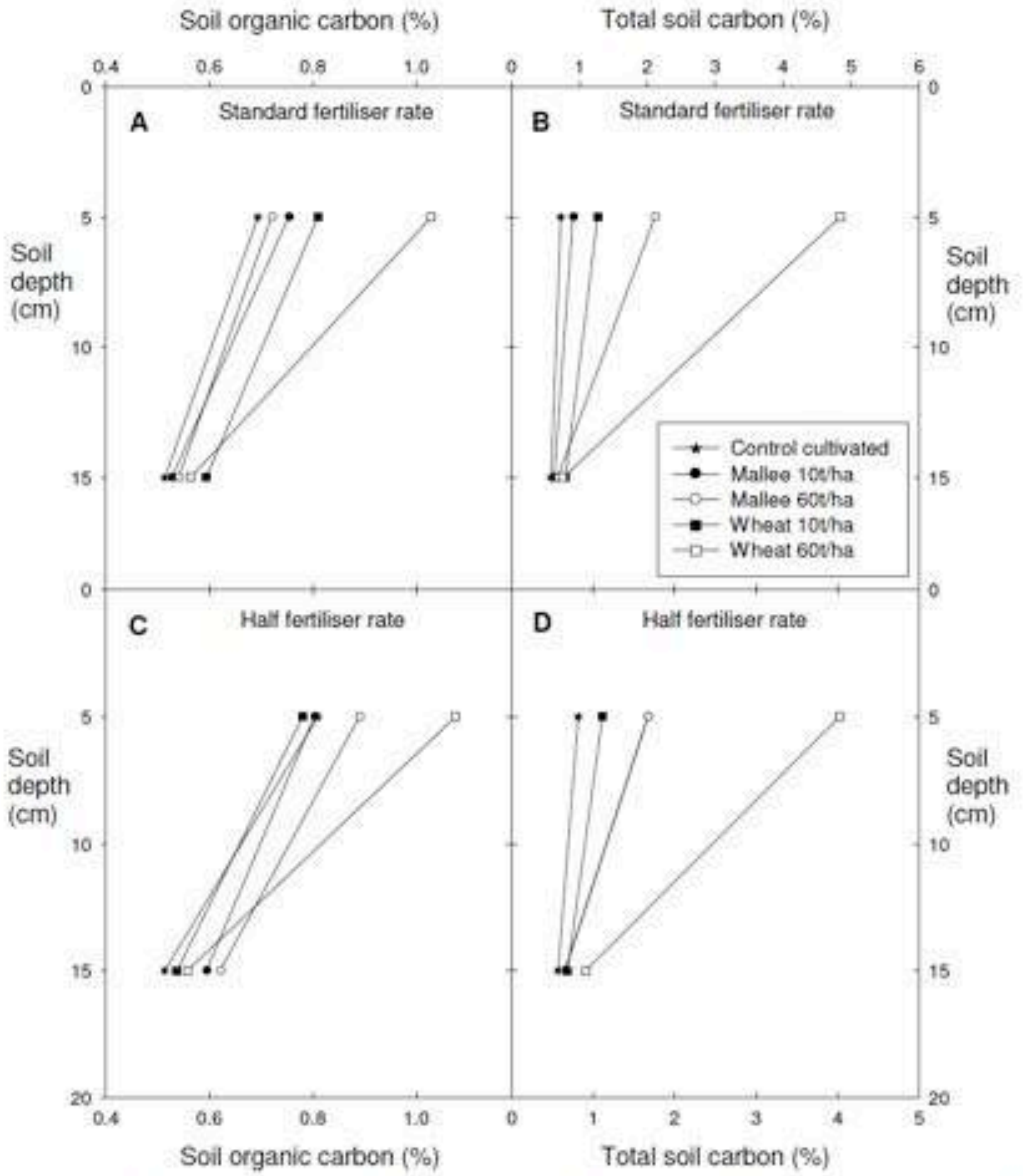


Figure 13. Impact of mallee and wheat straw biochar on soil organic carbon (A,C) and total soil carbon (B,D) at either standard (A,B) or half (C,D) fertiliser rates, at Kalannie, 2008.

Addition of biochar particularly at the higher rate of 60 t/ha increased the initial soil organic and total carbon content in the top 10 cm (Figure 13). The wheat straw biochar increased soil carbon content in the topsoil more than the mallee biochar.

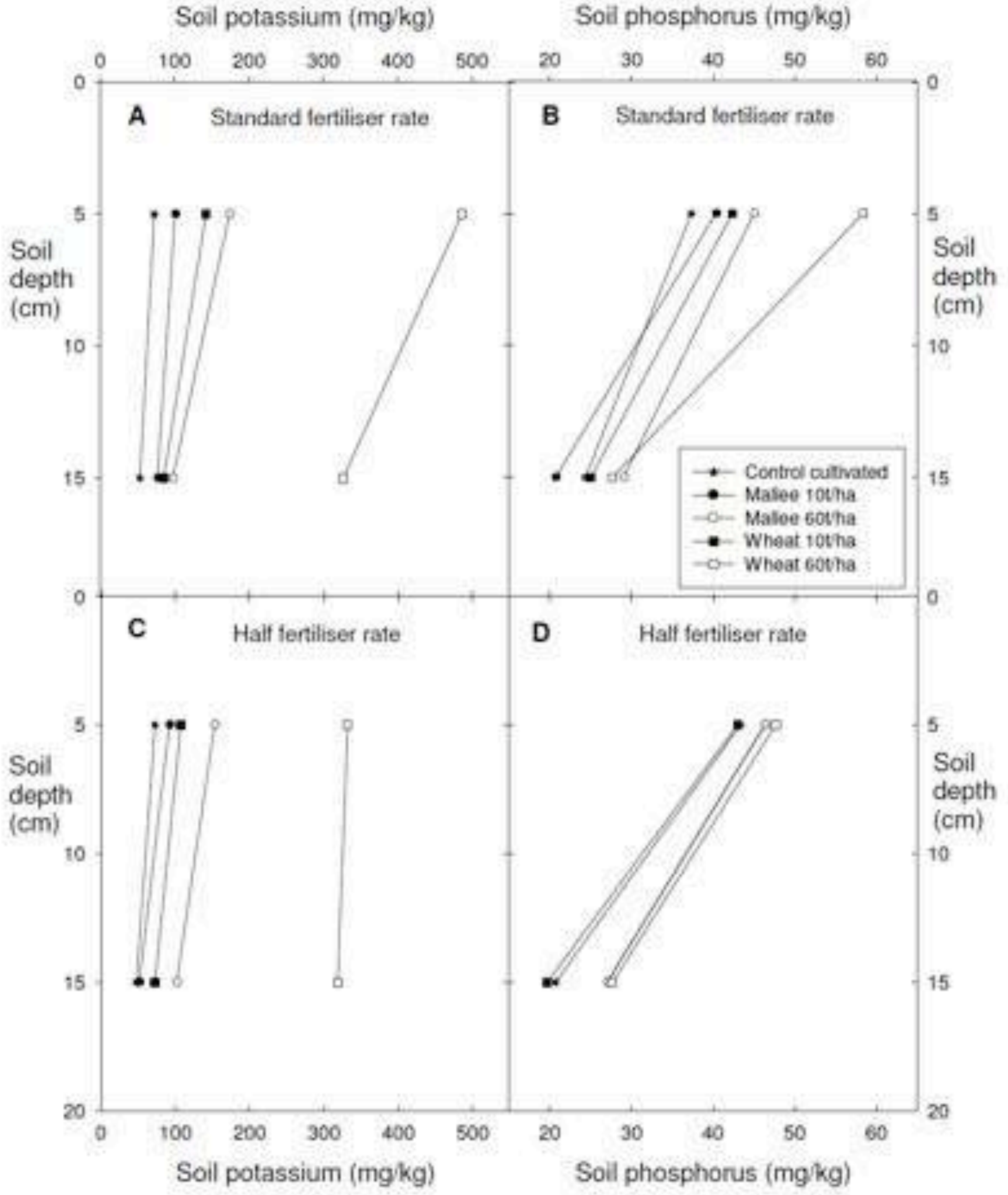


Figure 14. Impact of mallee shoot residues and wheat straw biochar on soil potassium (A,C) and phosphorus (B,D) concentrations at either standard (A,B) or half (C,D) fertiliser rates, at Kalannie, 2008.

Soil Potassium and Phosphorus levels before biochar addition are adequate for crop needs. Application of biochar resulted in an increase in soil potassium concentration (Figure 14 A,C) with a larger increase for wheat biochar compared with biochar made from mallee residues. Biochar applied at 60t/ha also increased soil phosphorus concentration with this increase being greatest in the topsoil for wheat at the standard fertiliser rate (Figure 14B,D).

SUMMARY

The 2008 biochar experimental trials were conducted as part of the Project Rainbow Bee Eater prefeasibility study and provided valuable learning.

The banded biochar experiment best represents the application method that farmers are likely to use. While there was no response to banded biochar in the first year of application the experiment will continue in 2009 and beyond to assess what benefits if any occur in later years. The site had good soil fertility for dryland wheat production and this may have limited any response to biochar as a nutrient source. There may be value in applying biochar in less fertile situations as some research is suggesting biochar can provide bigger benefits in these circumstances.

The incorporated biochar trial in which higher biochar rates were applied showed promising results. Cultivation tended to have a negative effect on crop growth at the half fertiliser rate and incorporation of biochar in the cultivated soil improved crop growth and increased both grain and protein yield.

Development of the pyrolysis and dust free biochar incorporation equipment is continuing as part of Project Rainbow Bee Eater. Both experiments will be sown to wheat again in 2009 as we further develop our understanding of the longer term impacts to a wheat farm of closed loop biomass collection & biochar return. Evolution of grain yield and protein, weed population, chemical and fertilizer consumption, soil conditions and carbon sequestration are all of interest in this multi year study.

Acknowledgements

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Appendix 3.5: Energy Farmers Australia Cucumber Trial

2017 Poultry Litter Biochar for Horticulture
1612-05-05

Energy Farmers Australia

NACC Managing Natural Resources

Australian Government | National Landcare Program

1.0 AIM

This project was to examine the effect of applying poultry litter biochar to soil in a horticultural system and its effect on nutrient availability, plant health and yield. The assumption is that by adding biochar to the soil it will assist in fertiliser efficiency by holding nutrients in the soil profile and improve soil and crop health.

2.0 BACKGROUND

This project was initiated by Energy Farmers Australia (EFA) in 2016 after discussions with the owner of a cucumber farm in Geraldton, Western Australia. Their interest was in reducing the amount of nutrients lost on their sandy soils, reducing input costs and improving yield in their main crop, cucumbers.

Energy Farmers had been working with the poultry industry, producing poultry litter biochar from poultry litter waste and thought that poultry litter biochar could be a good fit to alleviate the problems that the cucumber farmer were having with nutrient runoff as well as potentially supplying nutrition to the crop.

The basis of this assumption was through research EFA had conducted on biochar they had produced, which demonstrated that poultry litter biochar could supply, albeit low levels (compared to traditional fertilisers) N, P and K to the crop (see Appendix 1).

In addition to this, the increasing evidence around the world that biochar can provide many benefits when used in food production. Some of these benefits might include;

- Improved soil fertility and crop yields
- Increased fertilizer efficiency use
- Improved water retention, aeration and soil tilth
- Higher cation exchange capacity and less nutrient runoff
- Increasing soil pH
- Biomass energy production from crop residues and forest debris
- Net sequestration of carbon from the atmosphere to the soil thereby increasing soil organic carbon (SOC)
- Provide habitat for soil microbes and increase microbial activity

(Source: International Biochar Initiative)

Poultry litter biochar on top of the rows

Weight recording stations

3.0 DEMONSTRATION SITE/S DETAILS

The farm is located near Geraldton, Western Australia. The subsoil is dominated by sand to depths of at least 80cm, often highly leached with poor nutrient status and retention

4.0 METHOD

The trial was first established in 2016 with the poultry litter biochar being produced through Energy Farmers Australia pyrolysis kiln from poultry waste supplied by a poultry farmer in the Gingin Shire.

The trial aim was to try and use a high and low rate of biochar with a high and low rate of starter fertiliser. We also wanted to use a high and low rate of biochar on its own.

Each greenhouse block has 10 houses and each house has 5 rows where the cucumbers are planted. Each row rate was calculated by measuring the row length (50 meters) x the width (0.5m). therefore, every row was 0.0025 of a Ha.

The farmer applied his base fertilisers by hand and the biochar was applied shortly after with a small fertiliser spreader. Both fertiliser and biochar were then incorporated into the soil by a rotary hoe. To prevent edging effect, we spread the biochar only on the inside 3 rows of each house.

Cucumbers were planted by the farmer and managed as part of their normal farming operation. During the harvest period, cucumbers were picked and weights recorded for each treatment.

In the 2016 season the biochar was laid down on the 10th March with the cucumber seedlings planted on the 6th May

In the 2017 season no extra biochar was applied. However, the farmer did apply 5kg of CPM (starter fertiliser) across the whole farm as a base. In this season the cucumber seedlings were planted on the 28th April.

Recording sheets were installed at the end of each row and a set of scales supplied. Cucumber weights for each row were recorded during picking.

Table 1: 2016 Treatments and cost of treatments

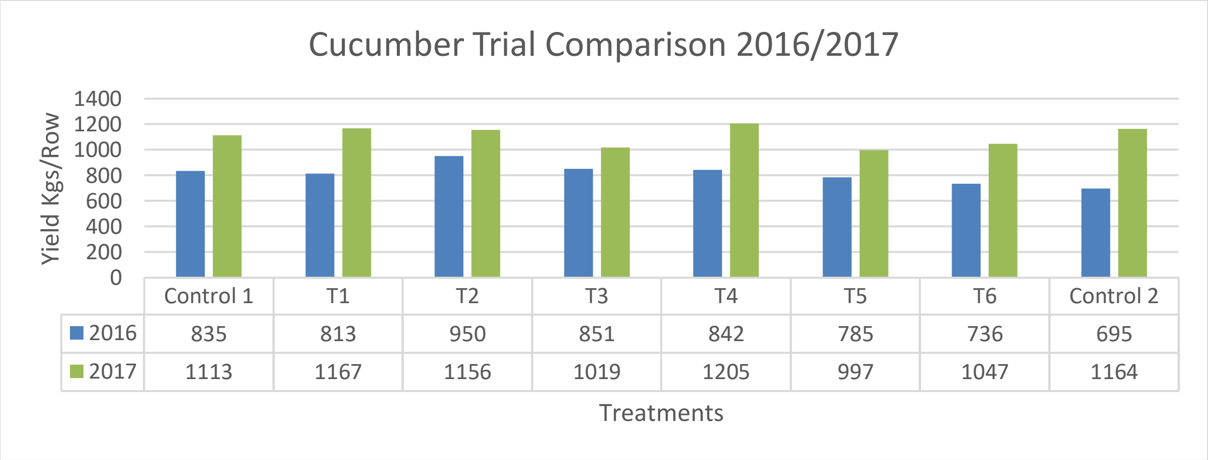
Treatment	**CPM**		**NP**		**PLB**		Total Cost
	kg/row	$/row	kg/row	$/row	kg/row	$/row	**$/row**
Control 1	9	7	5	7.8		0	**15**
T1	9	7	5	7.8	7	5	**20**
T2	9	7	5	7.8	13	10	**25**
T3					13	10	**10**
T4	1	1	2	3.12	7	5	**9**
T5	1	1	2	3.12	13	10	**14**
T6					33	25	**25**
Control 2	9	7	5	7.8		0	**15**

Key: CPM - Compound Poultry Manure, NP – Nitrophoska, PLB – Poultry Litter Biochar
Costs based on: $1000/t NP and $750/t for PLB & CPM

5.0 RESULTS

Trial 1 – Results

gure 1: Trial 1 yield for 2016 and 2017



	Control 1	T1	T2	T3	T4	T5	T6	Control 2
🟦 2016	835	813	950	851	842	785	736	695
🟩 2017	1113	1167	1156	1019	1205	997	1047	1164

6.0 CONCLUSION

Yields across the board were higher in 2017 as opposed to 2016 however, this cannot be attributed to the biochar effect only, as the controls were also higher.

Treatment 4 was the highest performer at 1205kg/row. This treatment is a low rate of biochar with low rate of fertiliser and our cheapest treatment. This is very encouraging as it supports other research that using biochar with fertilisers improves fertiliser efficiency (See Ref NSWDPI).

Control 2 was the second-best performer at 1164kg. This may have been due to this treatment being down the slope to all the other treatments and nutrients and moisture from the fertigation system moving through the soil profile. However, this is not conclusive.

Treatments 1 and 2 both performed well at 1167kg and 1156kg respectively. Both these treatments had a blend of biochar and fertiliser, again supporting the theory that using biochar with fertilisers improves the efficiency of fertilisers.

Both Treatments 3, (1019kg) and 6 (1047Kg) were among the lowest yielding treatments as was Treatment 5 being the lowest at 997kg. It is difficult to determine the exact reasons for this, but the common thread is that they all had high rates of biochar which could mean that there are some other factors playing a role such as the biochar taxing nutrients from the soil.

Economic Analysis

Table 2: Economic analysis of the treatments over two years

Treatment	Control 1	T1	T2	T3	T4	T5	T6	Control 2	Avg of Control
Total kg 2016	835	813	950	851	842	785	736	695	765
Total kg 2017	1113	1167	1156	1019	1205	997	1047	1164	1138
Total kg	**1948**	**1980**	**2106**	**1870**	**2047**	**1782**	**1783**	**1859**	**1903**
Cucumber Price									
2016 $2.5/kg	2087	2032	2375	2127	2105	1962	1840	1737	1912
2017 $2.5/kg	2782	2918	2890	2547	3012	2493	2618	2910	2846
2016 Cost	15	20	25	10	9	14	25	15	15
2017 Cost	0	0	0	0	0	0	0	0	0
Total Cost	**15**	**20**	**25**	**10**	**9**	**14**	**25**	**15**	**15**
Gross margin 2016	2072	2012	2350	2117	2096	1948	1815	1712	1897
Gross Margin 2017	2782	2918	2890	2547	3012	2493	2618	2910	2846
Total gross margin	**4855**	**4930**	**5240**	**4665**	**5108**	**4441**	**4430**	**4632**	**4742**
+/- control		188	498	-77	**366**	-301	-312		

*Note that total cost does not include the standard fertigation costs during the year applied to all treatments

The economic analysis points to Treatments 2 and 4 having a significant economic advantage over the normal practice over a two year period but in cases where biochar is used at high rates of biochar with minimal or no starter fertiliser, it can have a negative impact on financial returns.

This trial was very basic in nature and the results largely anecdotal, but it has confirmed that the implications of applications of biochar onto soil is not fully understood. However, there could be financial and environmental benefits from doing so and longer-term trials are needed to demonstrate this.

7.0 REFERENCES

DAFWA - https://www.agric.wa.gov.au/mycrop/mysoil-pale-deep-sands-mid-west
International Biochar Initiative
Lukas Van Zweiten - NSW Department of Primary Industries – Biochar

Poultry Litter Biochar for Horticulture was delivered by Energy Farmers Australia. It was supported by NACC through funding from the Australian Government's National Landcare Program.

8.0 Appendix

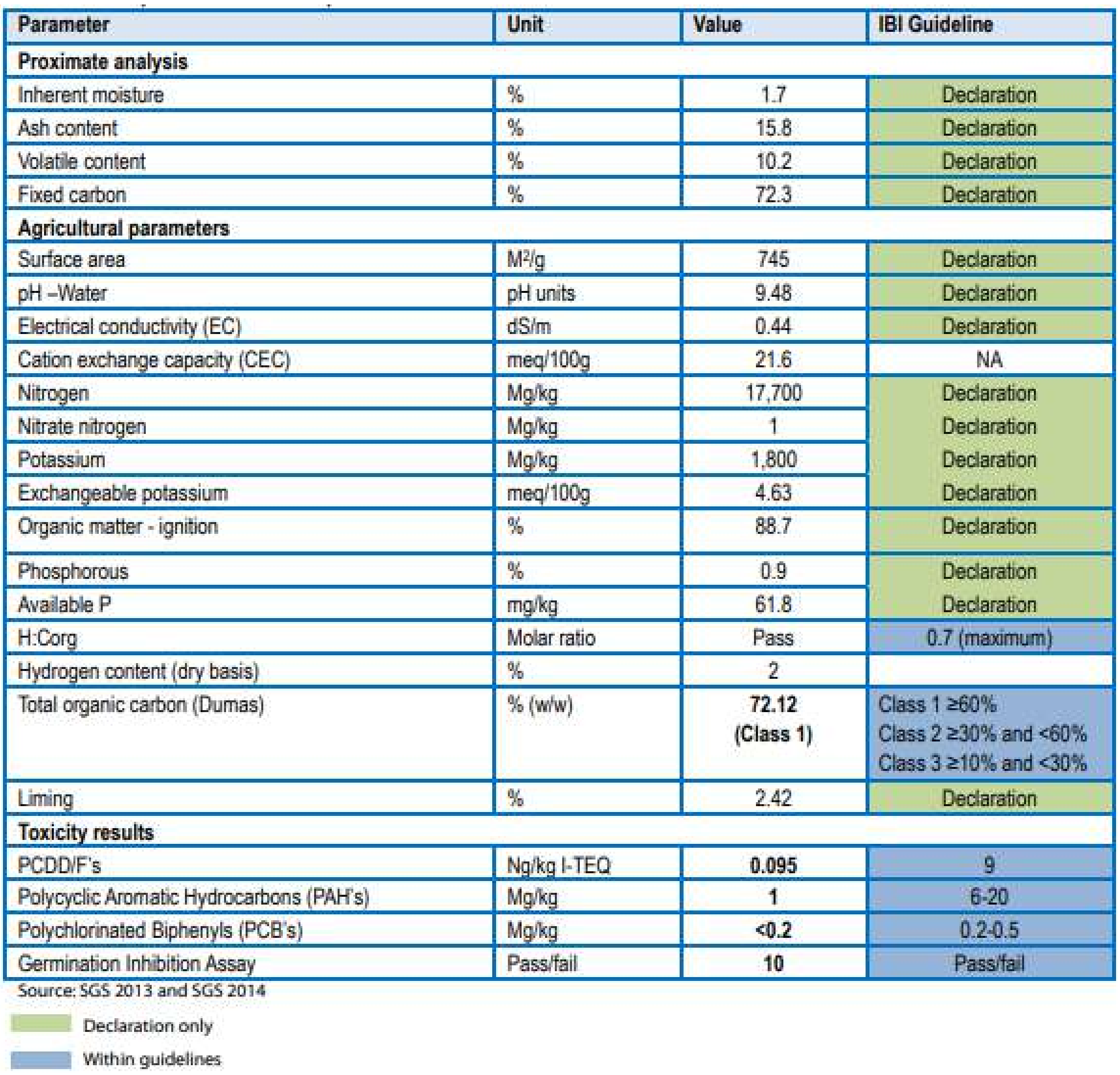
Appendix 1

Poultry Litter Analysis

	pH (H20)	PH (CaCl2)	EC (mS/cm)	Total C	CN Ratio	Total N	P %	K %
2016 Poultry Litter BC	9.0	8.5	7.7	38.8	10.6	3.7	2.53	2.80

Appendix 3.6: Green Man Char

Table 1: Key characteristics of pine biochar used in trials



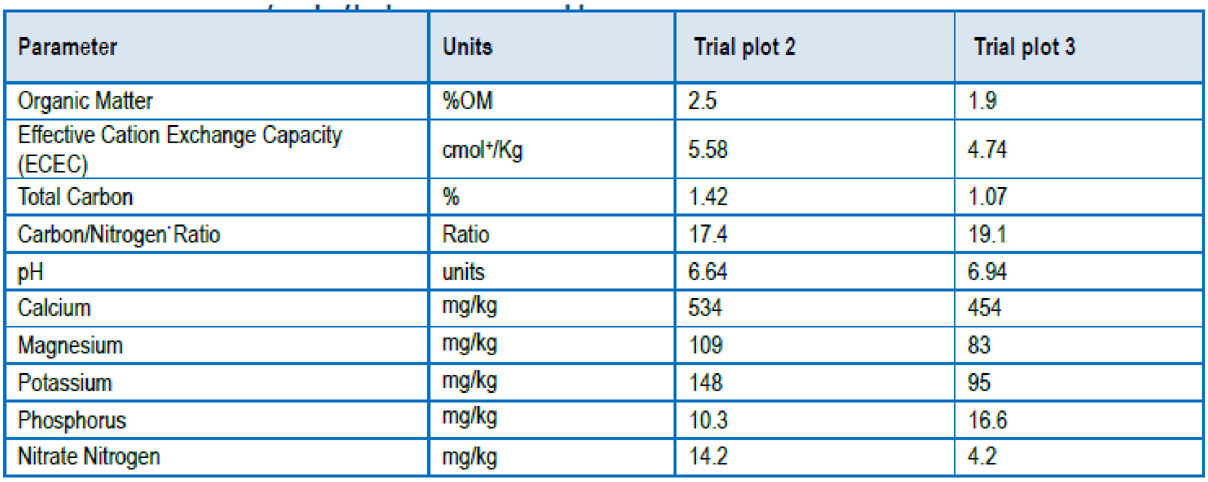
Parameter	Unit	Value	IBI Guideline
Proximate analysis			
Inherent moisture	%	1.7	Declaration
Ash content	%	15.8	Declaration
Volatile content	%	10.2	Declaration
Fixed carbon	%	72.3	Declaration
Agricultural parameters			
Surface area	M^2/g	745	Declaration
pH –Water	pH units	9.48	Declaration
Electrical conductivity (EC)	dS/m	0.44	Declaration
Cation exchange capacity (CEC)	meq/100g	21.6	NA
Nitrogen	Mg/kg	17,700	Declaration
Nitrate nitrogen	Mg/kg	1	Declaration
Potassium	Mg/kg	1,800	Declaration
Exchangeable potassium	meq/100g	4.63	Declaration
Organic matter - ignition	%	88.7	Declaration
Phosphorous	%	0.9	Declaration
Available P	mg/kg	61.8	Declaration
H:Corg	Molar ratio	Pass	0.7 (maximum)
Hydrogen content (dry basis)	%	2	
Total organic carbon (Dumas)	% (w/w)	**72.12 (Class 1)**	Class 1 ≥60% Class 2 ≥30% and <60% Class 3 ≥10% and <30%
Liming	%	2.42	Declaration
Toxicity results			
PCDD/F's	Ng/kg I-TEQ	**0.095**	9
Polycyclic Aromatic Hydrocarbons (PAH's)	Mg/kg	**1**	6-20
Polychlorinated Biphenyls (PCB's)	Mg/kg	**<0.2**	0.2-0.5
Germination Inhibition Assay	Pass/fail	**10**	Pass/fail

Source: SGS 2013 and SGS 2014

🟩 Declaration only

🟦 Within guidelines

Table 2: Soil baseline by crop type prior to biochar application



Parameter	Units	Trial plot 2	Trial plot 3
Organic Matter	%OM	2.5	1.9
Effective Cation Exchange Capacity (ECEC)	$cmol^+/Kg$	5.58	4.74
Total Carbon	%	1.42	1.07
Carbon/Nitrogen Ratio	Ratio	17.4	19.1
pH	units	6.64	6.94
Calcium	mg/kg	534	454
Magnesium	mg/kg	109	83
Potassium	mg/kg	148	95
Phosphorus	mg/kg	10.3	16.6
Nitrate Nitrogen	mg/kg	14.2	4.2

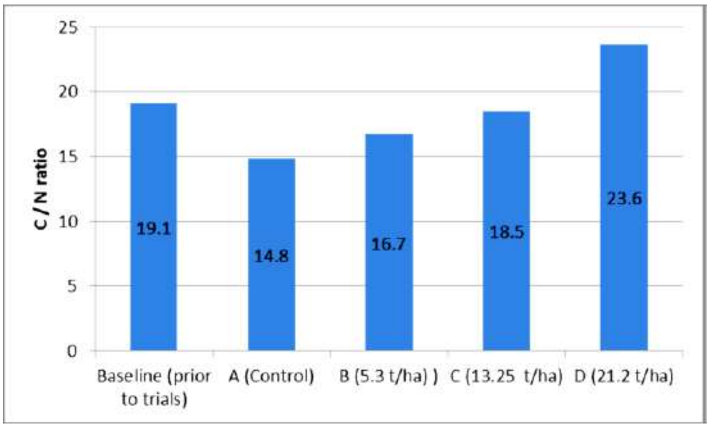


Figure 1. Carbon / nitrogen ratio across watermelon baseline, control and three biochar treatment plots.

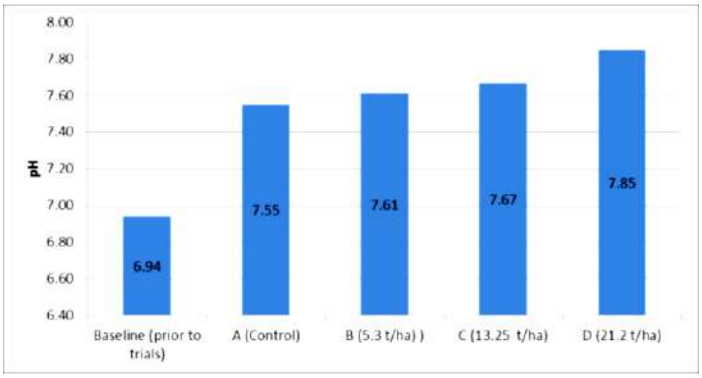


Figure 2. pH levels across watermelon baseline, control and three biochar treatment plots.

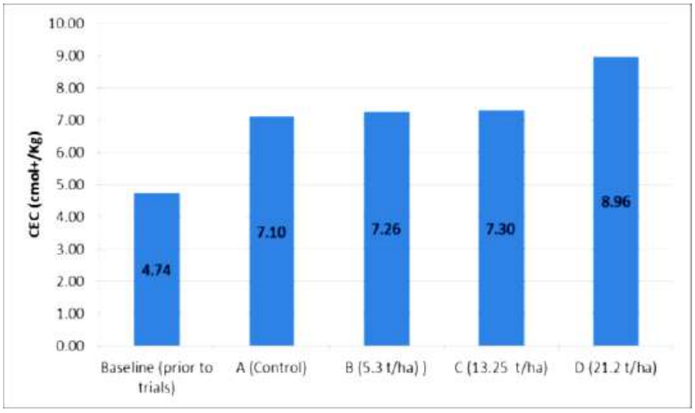


Figure 3. Cation exchange capacity across watermelon baseline, control and three biochar treatment plots