Integration of Regenerative Agriculture , Renewable Energy , Moisture and Carbon Drawdown; Preliminary Results; Confidential

Professor Stephen Joseph

Solar PV Farms Can be Carbon Negative

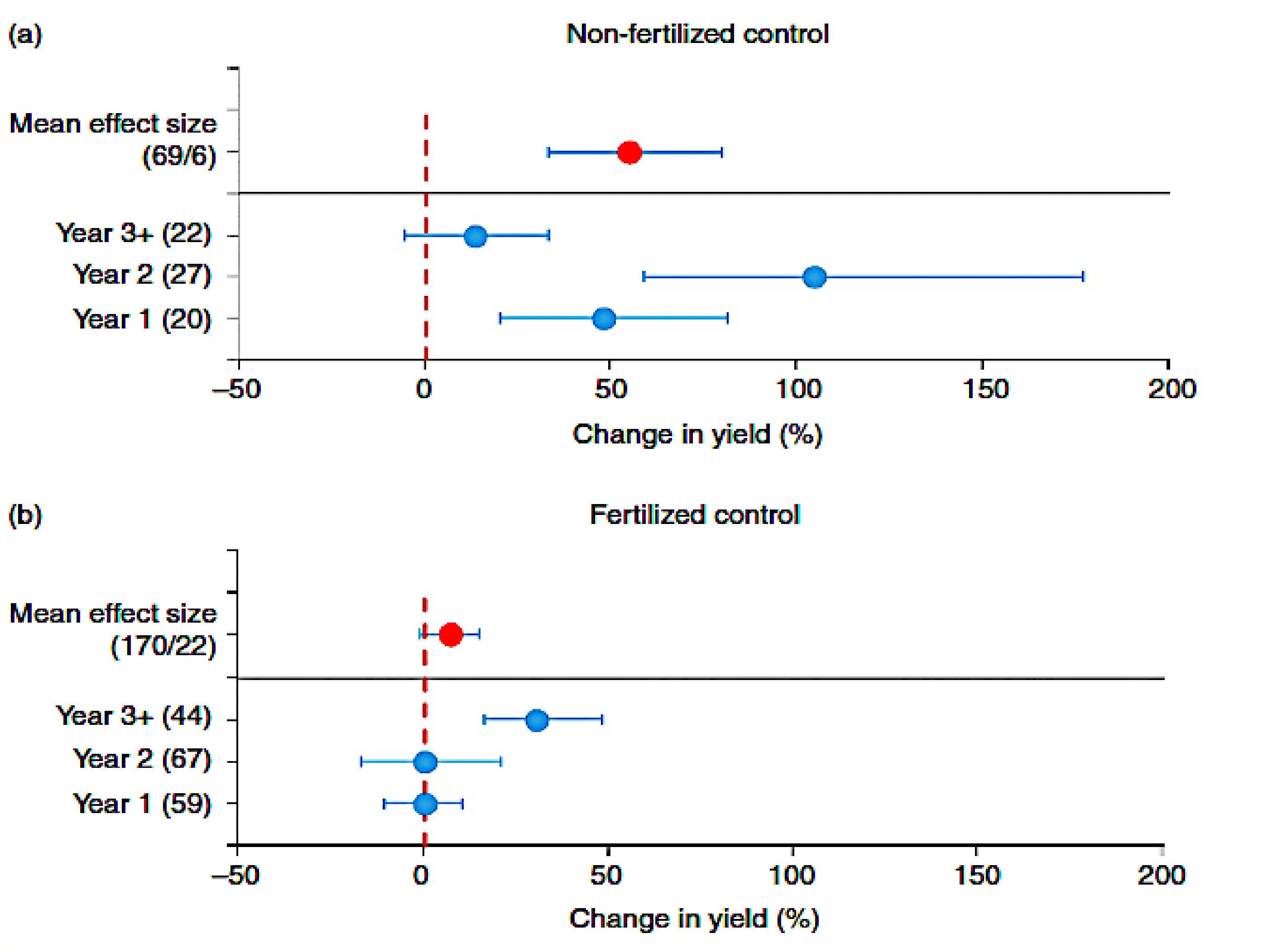
- On a life-cycle basis PV utility solar energy emits 48 grams of CO_2 equivalent per kWh of electricity produced.
- PV utility solar can displace productive agriculture and there is considerable opposition in rural areas in Australia
- However in certain climates up to 150,000 L of rainwater could be collected annually from a 105-kW facility, enough to provide irrigation of about 37.5 mm on 0.404 ha of land, that smaller animals could graze under the PVs without damaging to collectors, and shade tolerant forage crops, herbaceous plants and leaf vegetables (cabbage and lettuce) could grow.
- Feeding biochar to animals grazing in the PV farms and introducing dung beetles can build soil carbon

Solar PV Farms Can be Carbon Negative

- Biochar and electricity can be produced on or near the PV farm using available biomass residues and invasive species.
- Biochar can be utilised to produce silicon for solar cell manufacture
- Addition of biochar in solar PV farms could increase soil carbon and nutrient availability, crop/pasture productivity
- This strategy could result in PV farms becoming carbon negative and giving a greater return to the farmer the environment and the operators of the farm

The Results of Meta-Analysis

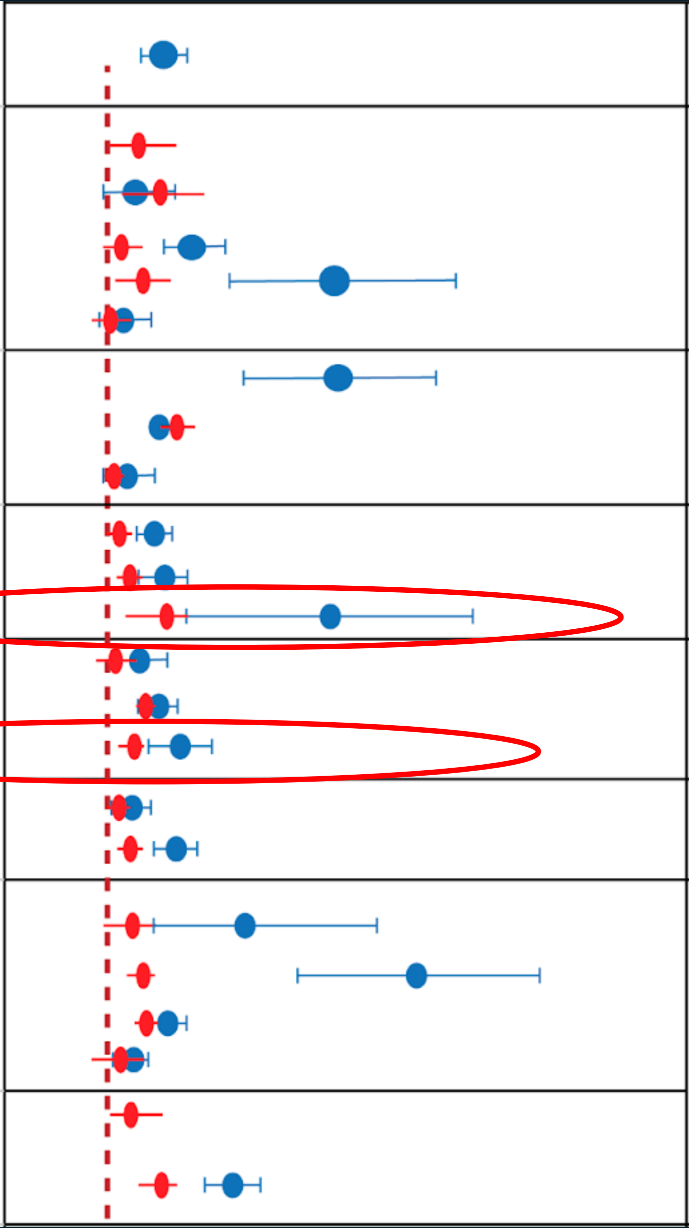
For applications rates of over 2 tonne/ha



Ye et al. Biochar effects on crop yields with and without fertilizer: A meta-analysis of field studies using separate controls Soil Use Manage. 2020;36:2–18.

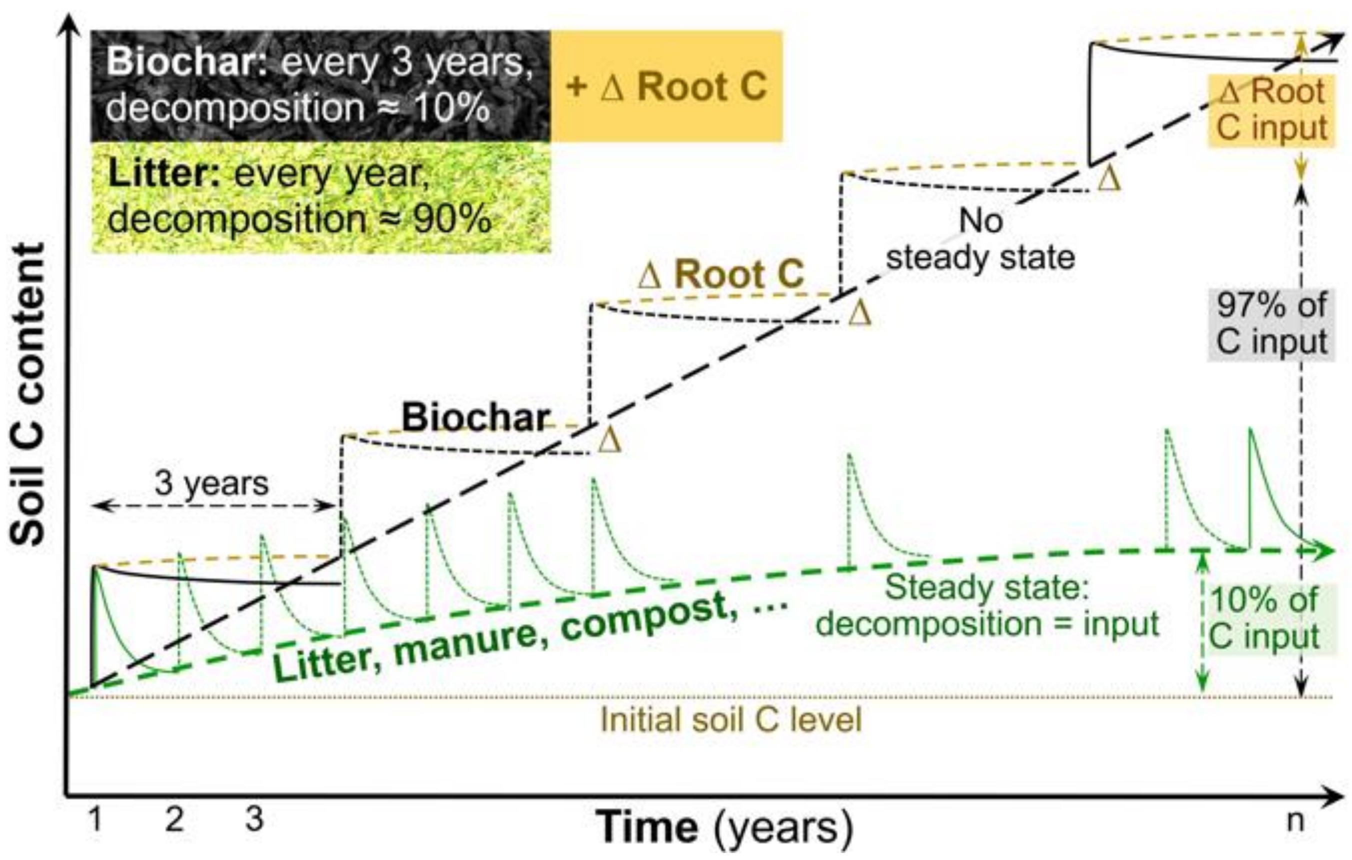
The Results of Meta-Analysis

Mean Effect size		BC increased yield 10%/29% relative to fertilised/unfertilised controls
Crops	Mixed vegetatbles Rapeseed/sunflower Wheat/Barely/Oat Maize Rice	Across all crops, maize gave the greastest yield increase relative to non-fertilised controls.
Feedstock	Cereal residue Ligneous material Papermill/ animal waste	Cereal grain residues (grass/straws, which have high nutrient content) gave greatest yield relative to unfertilised controls
HHT (°C)	550-700 400 - 550 <400	BC produced at low temperature (<400°C) were the most effective in increasing yield
BC rate (t/ha)	10-20 5-10 <5	BC produced greatest yield benefits at 5-10t/ha relative to fertilised controls, and <5t/ha relative to unfertilised controls
OC (g/kg)	>20 <20	BC has most impact for soils with low SOC
N Rates	>200 100 - 200 <100 0	BC worked much better when combined with inorganic fertilisers. It can complex with inorganic fertilisers. It can complex with the fertiliser providing a slow release function. Similar benefits occurred for BC combined with organic amendment. N rates should be adjusted to the soils and plant.
Treatments	BC + IF BC	



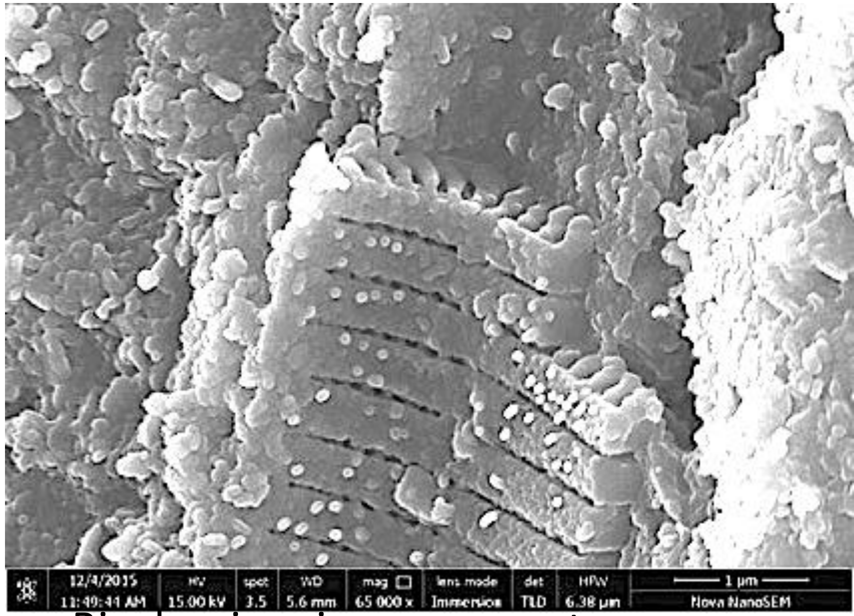
Ye et al. Biochar effects on crop yields with and without fertilizer: A meta-analysis of field studies using separate controls Soil Use Manage. 2020;36:2–18.

Model and Cost for Building Soil Carbon based on Weng et al (2017). Root exudates are adsorbed in biochar pores and then stabilised with mineral matter. Biochar fractures and is stabilized in microaggregates



Joseph et al. (2021) How biochar works, and when it doesn't: A review of mechanisms controlling soil and plant responses to biochar https://onlinelibrary.wiley.com/doi/pdf/10.1111/gcbb.12885

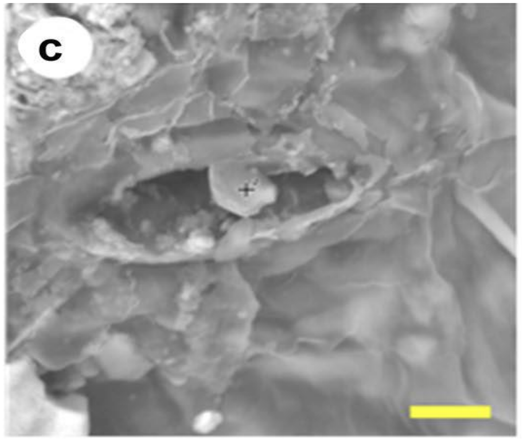
At $US 500/tonne BC incorporated into the ground to sequester approximately 15.2 t/stable C from the BC and building 11.06 SOC over 10 years approximately the cost is approximately $280US/tonne C

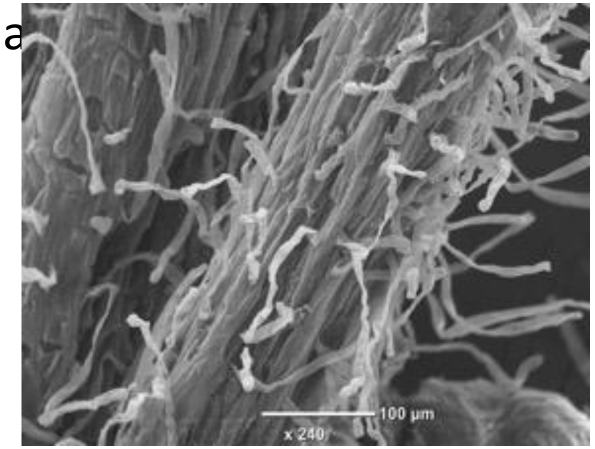


Biochar in micro- aggregate

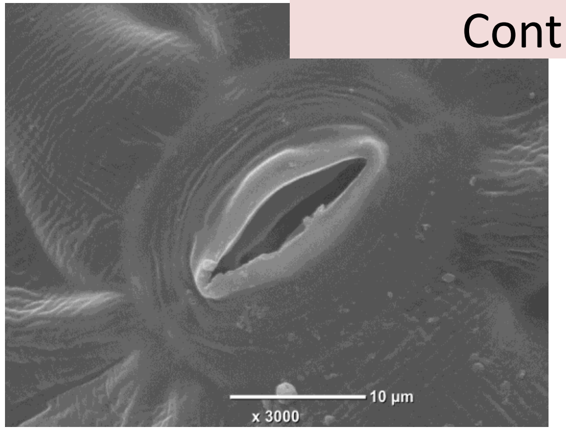
10kg/ha of biochar liquid applied as a foliar spray enhance lettuce growth by up to 80% and increase carotenoids and anthocyanins strengthening plant defence and increase root fungal growth.

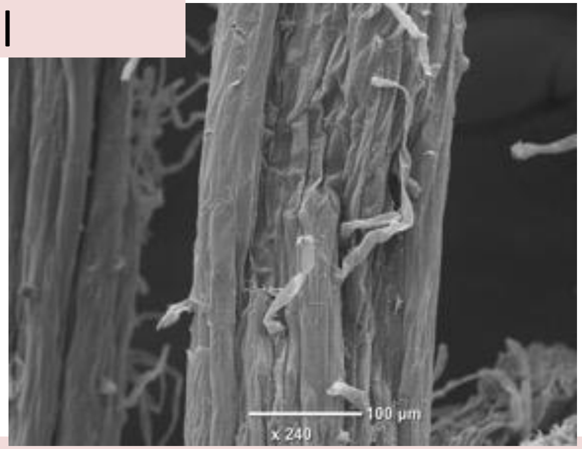
Mixed feedstock

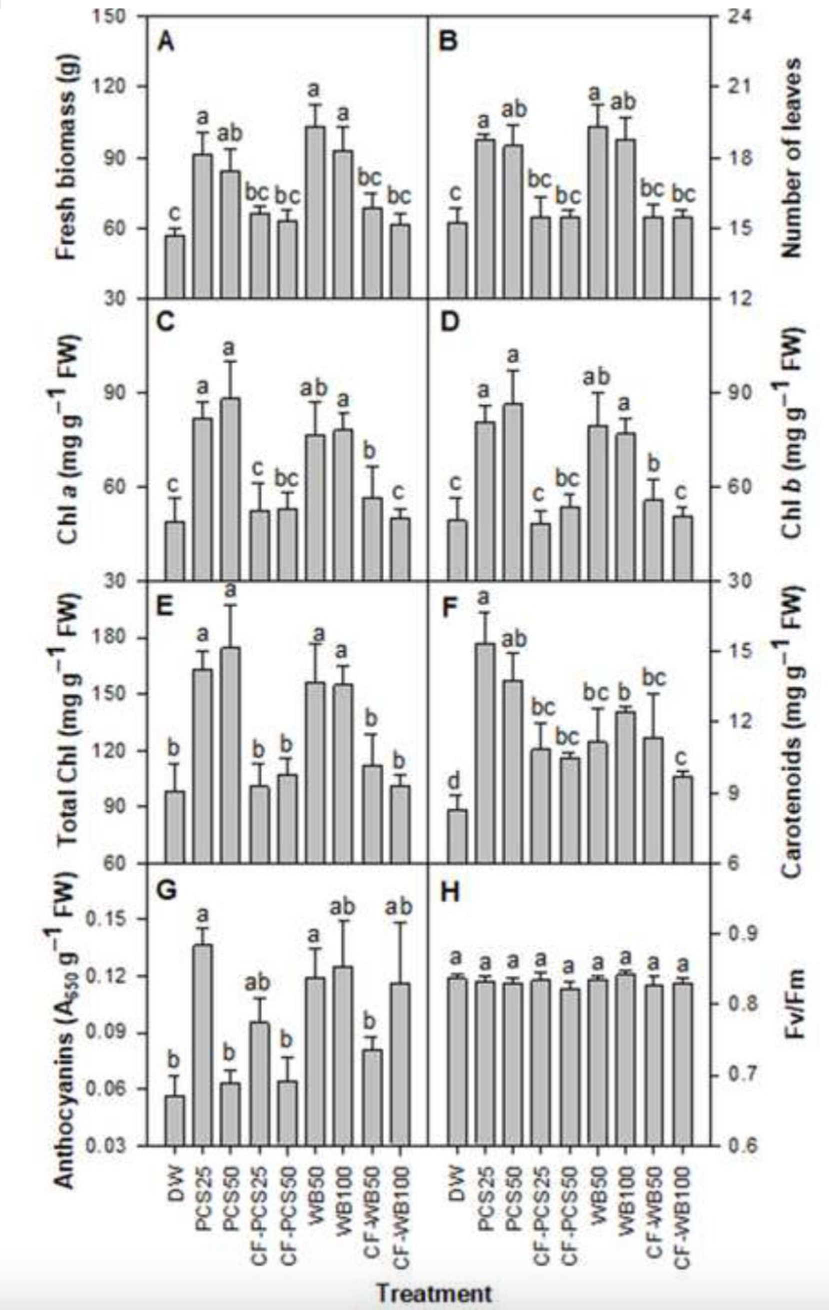




Control







Kumar, A., Joseph, S., Graber, E.R. *et al.* Fertilizing behavior of extract of organomineral-activated biochar: low-dose foliar application for promoting lettuce growth. *Chem. Biol. Technol. Agric.* **8**, 21 (2021)

Feasibility of producing Biochar and Biochar mineral complex (BMC) solid formulations that build soil C. Yield and cost

From the work we have done in Australia indicates

1. Feed wood/clay biochar to animals and then collect the dung and either subsoil apply, spread on the ground and then incorporate into the top soil. Wood/clay biochar has a yield of approximately 35-40% and cost approximately $US300/tonne to produce in Australia in a 1 tonne/hr output plant.
2. Add dung/biochar to the soil surface with added dung beetles which do the incorporation for you. Results from a trial indicates that the increase of soil carbon in the top 10cm is 8% per year, e.g. If soil C is 2.0% then after one year soil carbon could increase to 2.16%
3. Feed biochar to the cows on the soil where you want to build soil and apply dung beetles. Field tria indicates that you can build up of soil carbon of approximately 1.5% over 3 years up to 800mm in a Ferrosol

Depth	Soil Properties No BC	Soil Properties With BC
0-5cm	C= 5.7 N=.48 pH= 5.4	C= 6.0 N=.47 pH= 6.2
25cm	C= 2.1 N=.13 pH= 5.0	C= 3.6 N=.24 pH= 6.1
40cm	C= .67 N=.03 pH= 5.3	C= 2.0 N=.11 pH= 5.8

Dung Beetle mix biochar with soil and bury it

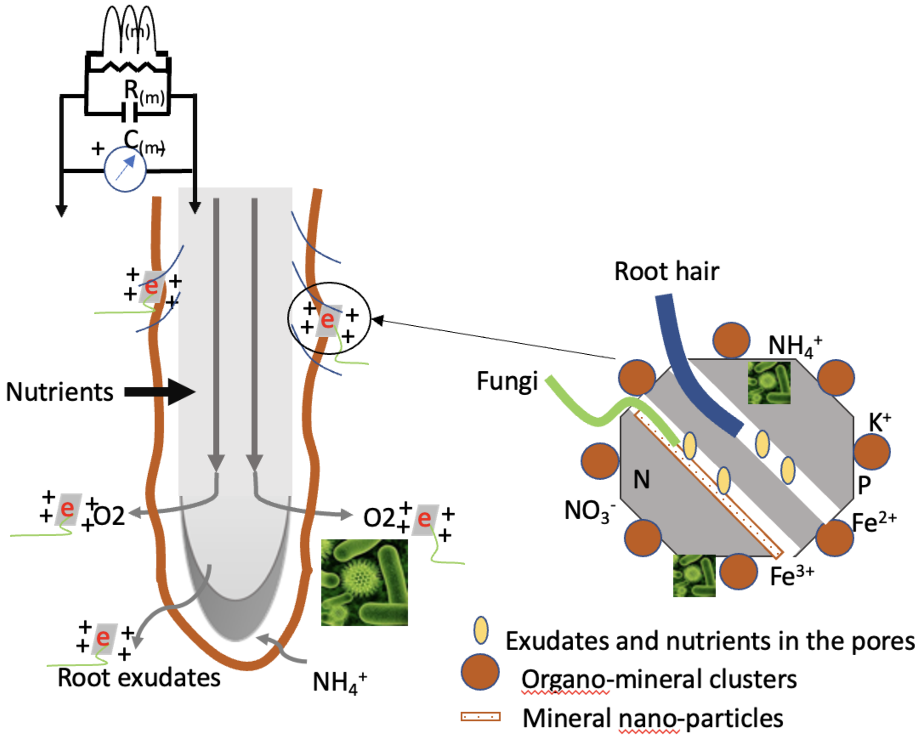
	User net benefit (NPV)	User net benefit (NPV) per tonne of biochar
Beef biochar - Doug Pow 60 cows, 0.3kg biochar per day, 1 year	$12,000 (per 60 cows)	$1,700 Payback 1 year

The Science; Small is Best

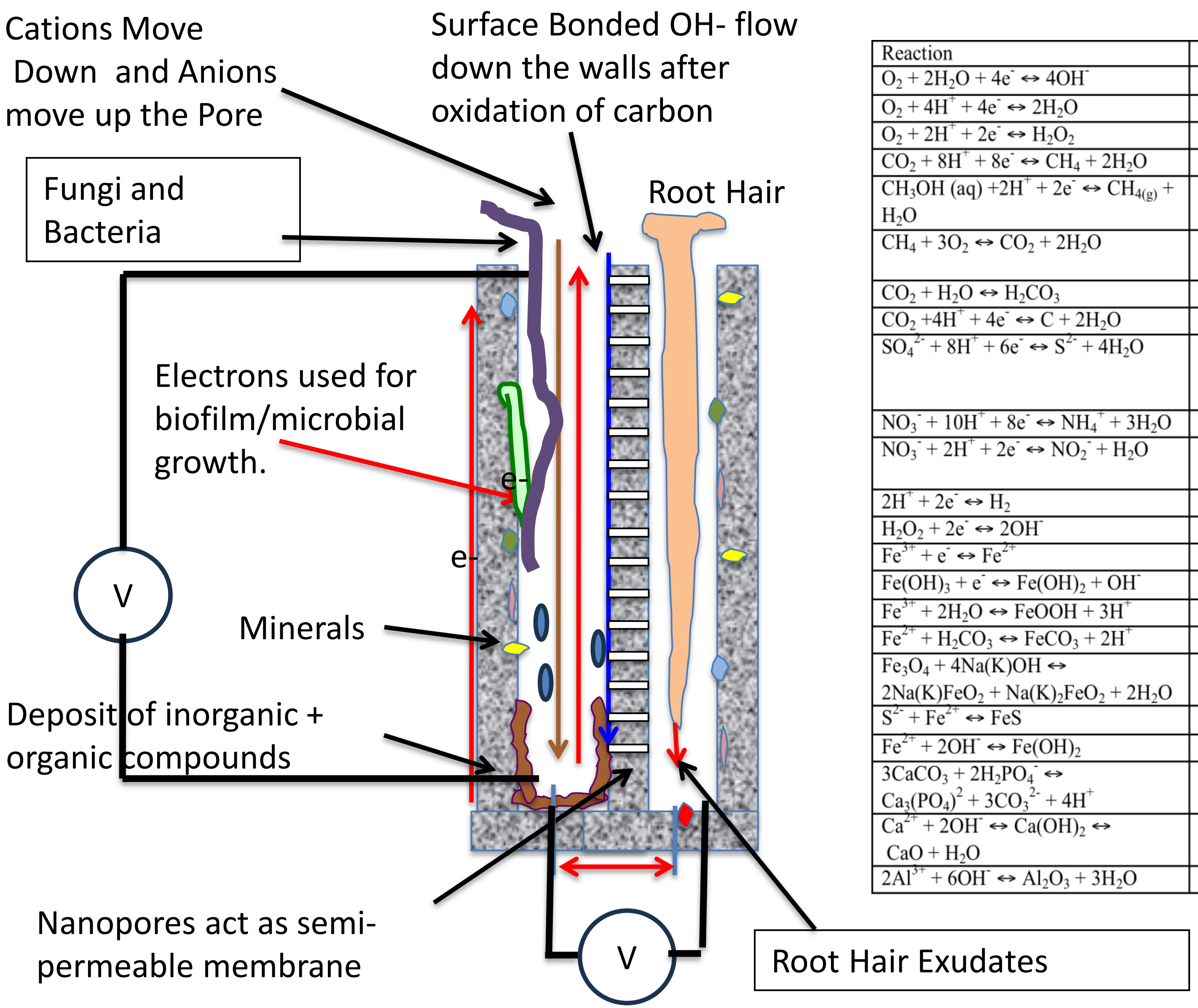
Engineered micron sized biochars particles can act as a microbial fuel cell that can

1. That increases the abundance of microbes that fix carbon and increase nutrient availability,
2. Store and release nutrient rich water
3. Accept and donate electrons;
4. Create or destroy reactive oxygen species;
5. Reduce emissions of N2O, respiratory CO2 and in some instances CH4;
6. Reduce the energy required for plants to take up nutrients
7. Reduce disease severity

Micron sized biochar particles loaded with nanoparticulate minerals that are redox active usually give the greatest soil/plant benefits when on or next to roots (Rhizosphere)



The Complex Chemistry Inside Pore



Reaction	E° (V vs SHE) / Notes
$O_2 + 2H_2O + 4e^- \leftrightarrow 4OH^-$	0.40
$O_2 + 4H^+ + 4e^- \leftrightarrow 2H_2O$	1.23
$O_2 + 2H^+ + 2e^- \leftrightarrow H_2O_2$	0.70
$CO_2 + 8H^+ + 8e^- \leftrightarrow CH_4 + 2H_2O$	0.168
CH_3OH (aq) $+2H^+ + 2e^- \leftrightarrow CH_{4(g)} + H_2O$	+0.50
$CH_4 + 3O_2 \leftrightarrow CO_2 + 2H_2O$	Chemical reaction; gas phase possibly; catalyzed on the biochar surface
$CO_2 + H_2O \leftrightarrow H_2CO_3$	Chemical reaction
$CO_2 + 4H^+ + 4e^- \leftrightarrow C + 2H_2O$	0.207
$SO_4^{2-} + 8H^+ + 6e^- \leftrightarrow S^{2-} + 4H_2O$	0.204; Big change in oxidation state! There are many sulfur oxidation states in between that may occur.
$NO_3^- + 10H^+ + 8e^- \leftrightarrow NH_4^+ + 3H_2O$	0.88
$NO_3^- + 2H^+ + 2e^- \leftrightarrow NO_2^- + H_2O$	0.94; There are a lot of different nitrogen oxidation states
$2H^+ + 2e^- \leftrightarrow H_2$	0.00
$H_2O_2 + 2e^- \leftrightarrow 2OH^-$	0.933
$Fe^{3+} + e^- \leftrightarrow Fe^{2+}$	0.77
$Fe(OH)_3 + e^- \leftrightarrow Fe(OH)_2 + OH^-$	-0.549
$Fe^{3+} + 2H_2O \leftrightarrow FeOOH + 3H^+$	Hydrolysis reaction
$Fe^{2+} + H_2CO_3 \leftrightarrow FeCO_3 + 2H^+$	Carbonation reaction
$Fe_3O_4 + 4Na(K)OH \leftrightarrow 2Na(K)FeO_2 + Na(K)_2FeO_2 + 2H_2O$	Dissolution-re-precipitation reaction
$S^{2-} + Fe^{2+} \leftrightarrow FeS$	Sulfide precipitation reaction
$Fe^{2+} + 2OH^- \leftrightarrow Fe(OH)_2$	Hydrolysis reaction; pH dependent
$3CaCO_3 + 2H_2PO_4^- \leftrightarrow Ca_3(PO_4)^2 + 3CO_3^{2-} + 4H^+$	pH dependent reaction in terms of phosphate speciation
$Ca^{2+} + 2OH^- \leftrightarrow Ca(OH)_2 \leftrightarrow CaO + H_2O$	Precipitation and hydrolysis
$2Al^{3+} + 6OH^- \leftrightarrow Al_2O_3 + 3H_2O$	Hydrolysis and precipitation

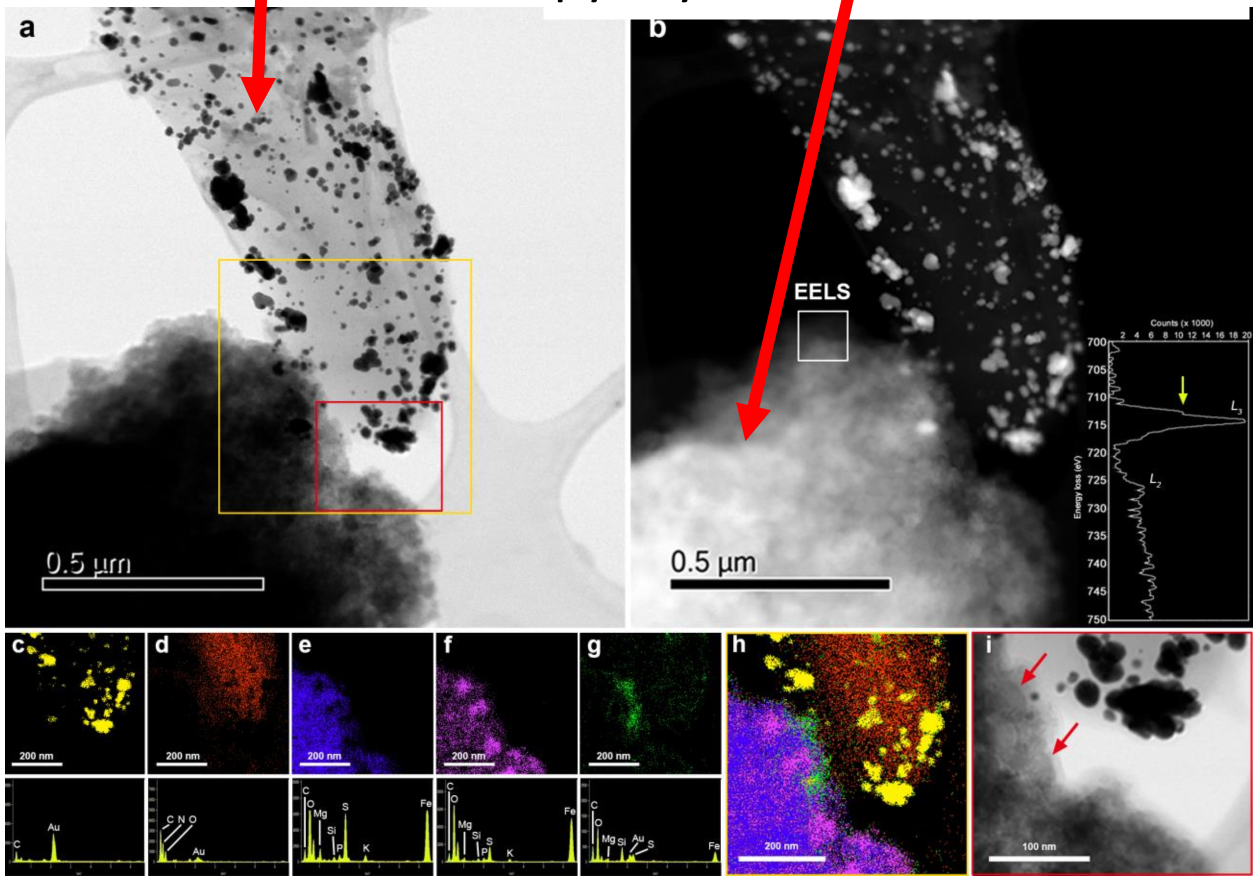
ΔG1, ΔV1, ΣCi, pH 1

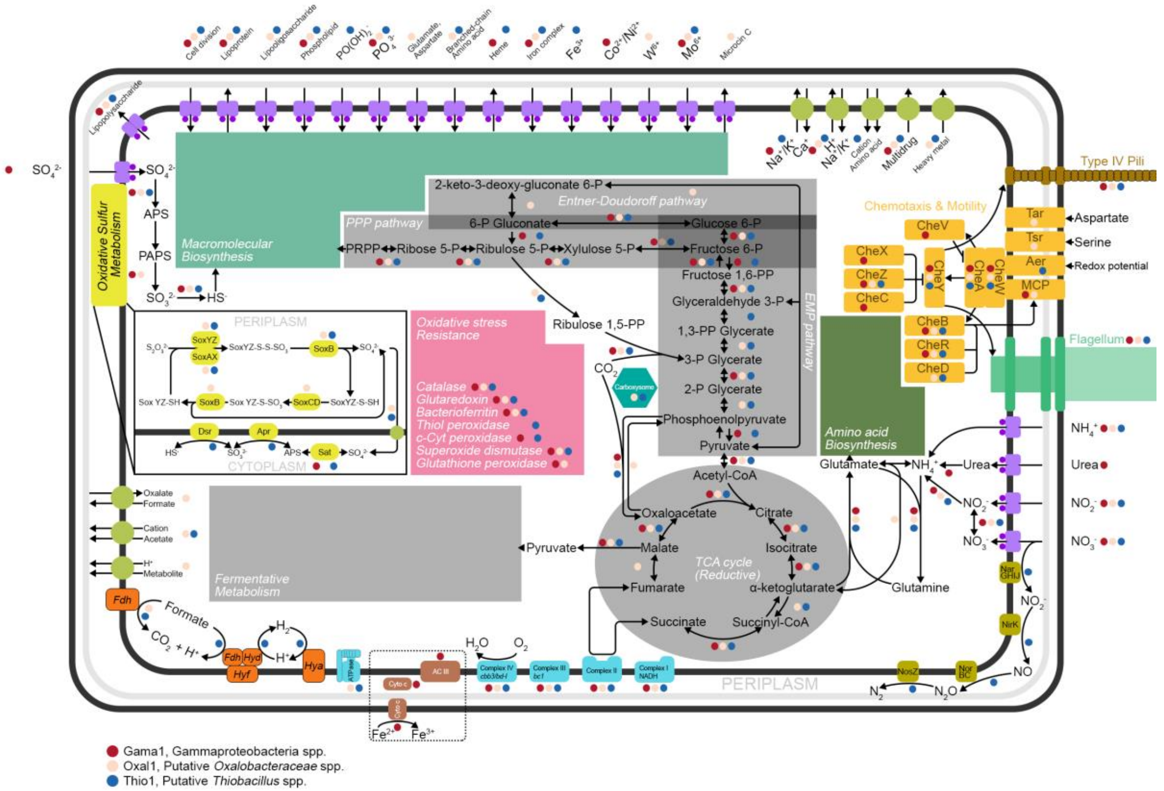
ΔG2, ΔV2 ,ΣCi, pH 2

Surface Nanoparticles can Promote Beneficial Microbes that can fix CO2, N2 and Enhance Plant Available Iron and Sulphur

Plant Growth Promoting Bacterial

Nanoparticles of magnetite FeSO4, SiO2 and Bentonite applied to bamboo before pyrolysis

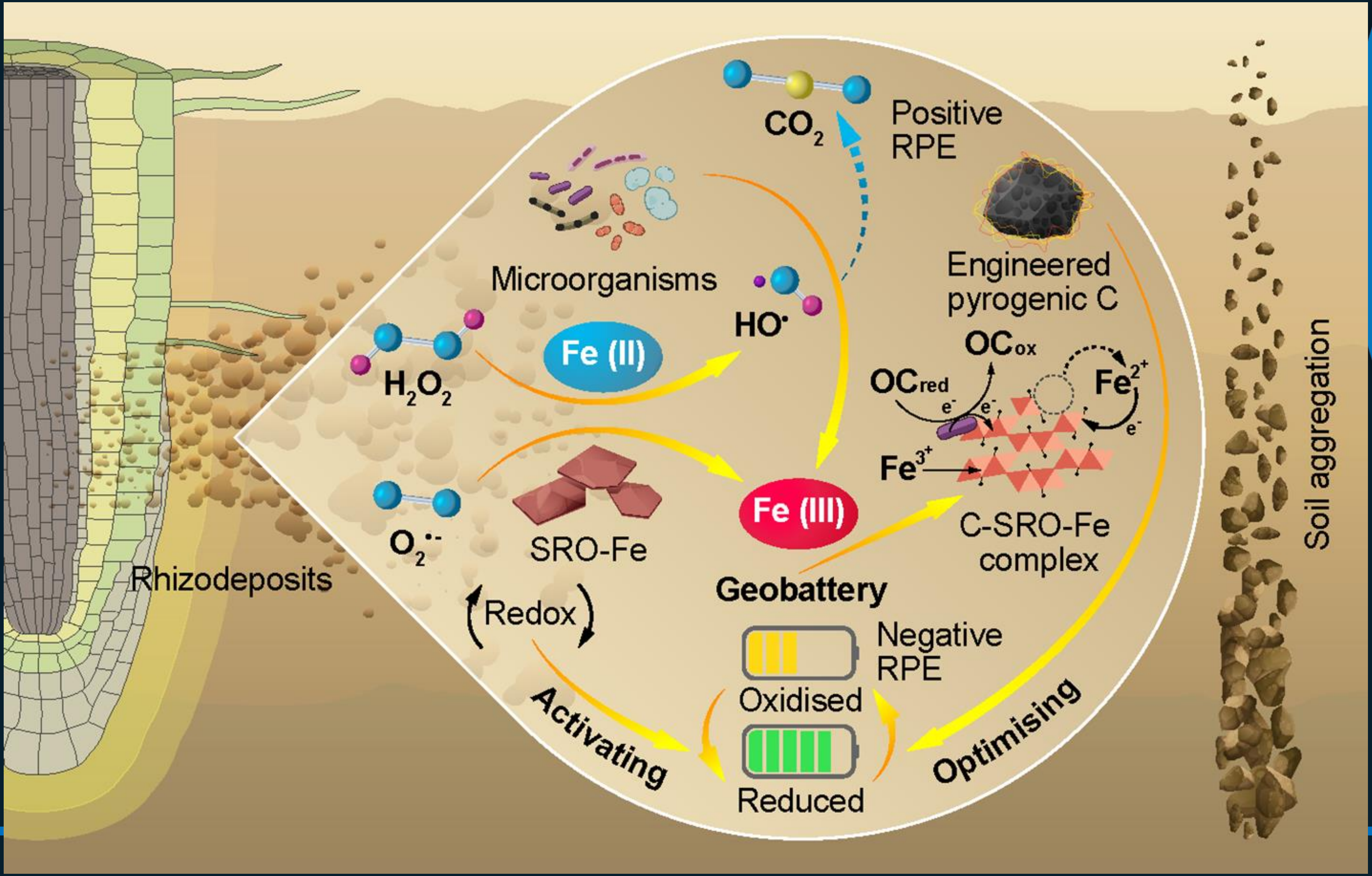




Metabolic reconstructions of the three dominant bacteria that Fix C, make S and Fe more available

Jun Ye et al. 2017 ISME

The Science; Electro Active Rhizosphere

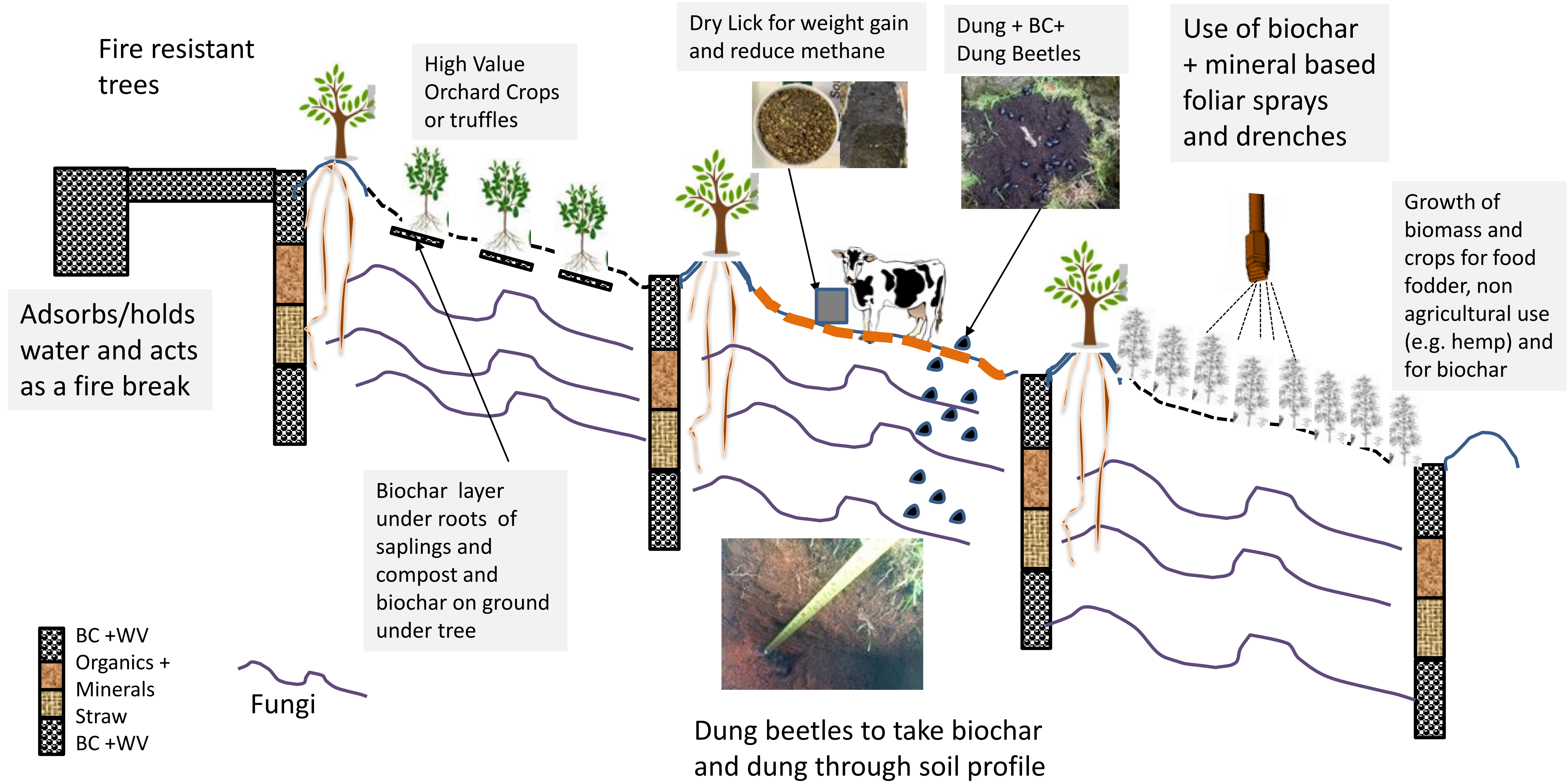


Hypotheses related to Carbon and Water Drawdown

The following hypotheses have been developed from limited field trials and from the experience of farmers

1. Liquid organomineral biochar fertilizer applied at application rates of less than 500kg/ha can increase pasture and crop yield , soil moisture and soil carbon.
2. Trenches and wells that are loaded with biochar, organic and mineral matter can act as a focus for building soil organic carbon and abundance of growth promoting
3. The trenches can act as barriers to prevent influx of salt and other toxic substances and to reduce leaching from fields

A Model System to Build Soil Carbon Produce Fuel Feed Fodder and Non Agricultural Biomass



Large Scale Trial In WA to Integrate Biochar Wells and Reactive Barriers for the production of Fruit Bearing in Western Australia

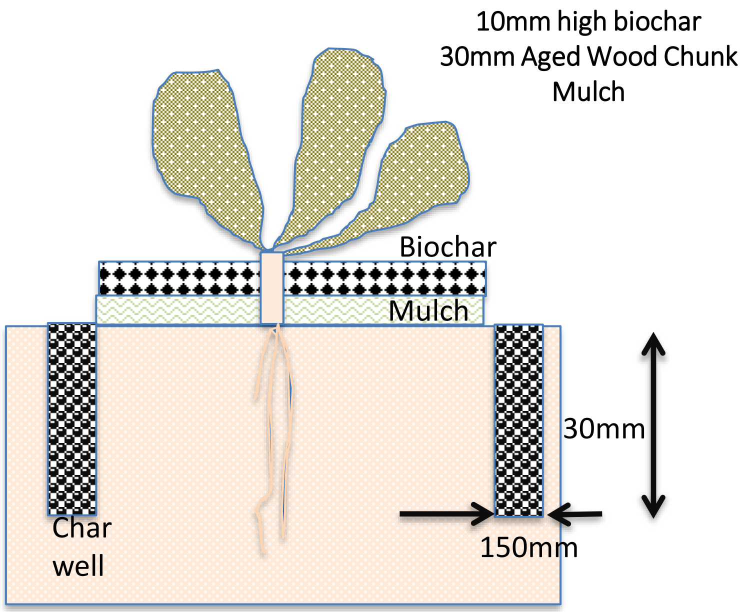
Saline; Low OC and Compacted

2014

After Biochar based Reactive Barriers and Char Well

2018

- Charwells 30cm deep diameter of 15cm.
- The charwells were filled with biochar, lucerne fines, and a range of organic amendments
- They are place around trees that are mulched
- These wells promoted new growth, enable the ponded water to access the soil profile and drainage of the area occurred more quickly, usually within 4 hours



2 years on

Integrating Biochar Into Regenerative Agriculture Practices Using Biochar Present Trials at Mara Seeds/S.O.F.T Agriculture Farm at Mallanganee NSW 2021-2022

Stephen Joseph, Shane MacIntosh, Stuart Larsson, Lukas van Zwieten, Graham Lancaster, Annette Cowie, Alicia Hidden, Don Coyne, Yang Wang,

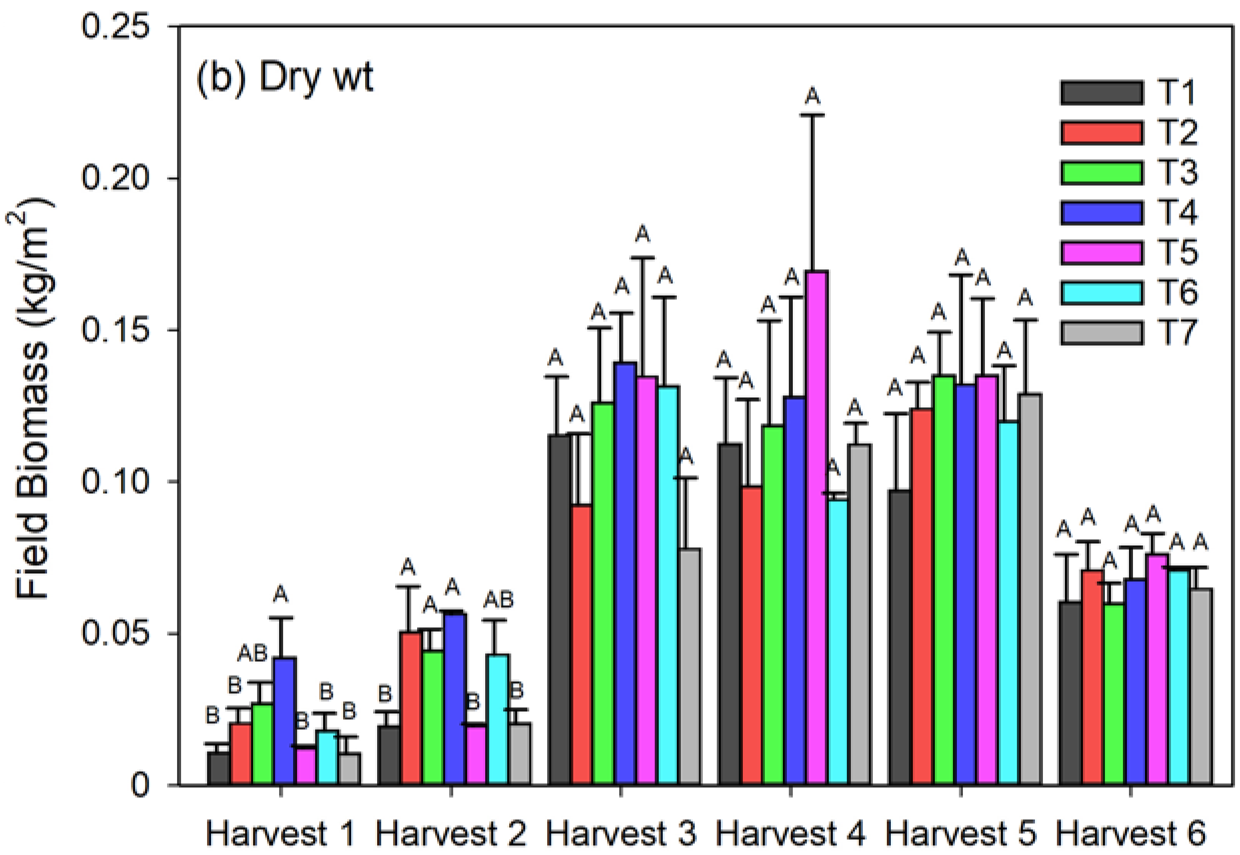
Applying Biochar

Initial Germination

2nd Harvest

4th Harvest

Yields Over 6 Harvests



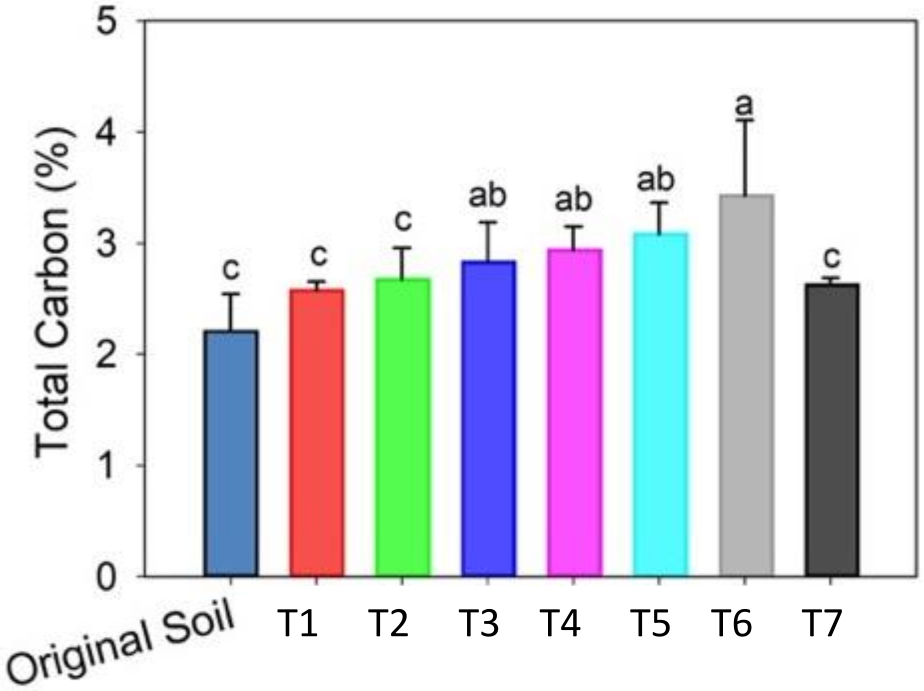
1. Unamended Control
2. Fertilised Control: NPK (matching Treatment 5)
3. Liquid biochar +Charlie carp 200kg/ ha
4. Liquid biochar at 200kg /ha + NPK
5. Manure from cattle fed biochar, 10t DM/ha
6. Biochar + NPK (@7.24T/ha), same total C as Treatment 5
7. Liquid biochar (without Charlie Carp) 200kg/ ha

Start 26.8.21
Harvest 1 28.10.21
Harvest 21.11.21 Little rain
Harvest 3 3.12
Harvest 4 13.1.2022 High rain
Harvest 5 10.2.22
Harvest 6 17.3.22

1. Application of liquid biochar with NPK resulted in the highest biomass yield in the first 2 months.
2. In the third harvest highest yield y was in the treatment liquid biochar +NPK, manure with biochar and 7.24t/ha of biochar and NPK.
3. Highest overall yields in harvest 4 when heavy rains started (especially in manure/biochar treatment) but no significant difference between treatment
4. No significant difference in yield the next 2 harvests

Biochar Amendments with Nutrients Increased Total Soil Carbon and Estimated Organic Matter after 6 months

- The largest increase in soil carbon and estimated soil organic matter (figure in brackets) in the top 10cm of soil was measured in the treatment where a large amount of biochar was added (P6) and this was significantly greater than control and treatments T1, 2,and 7 but not with treatment T3,T4 and T5.
- There was a significant increase in total carbon for the liquid biochar/nutrient samples compared to control and the NPK and liquid biochar without added nutrients
- However the increase in total C was not as great as the added biochar in treatment 5 and 6 indicating either movement down the soil profile or out of the trial site either through run off or mineralisation



treatment	increase % Total C and (OM) compared with control at 6 months	increase %C and (OM) compared with soil at commencement	Increase in kg/ha of C and (OM) in top 10cm of soil in 6 months
T2	0.1 (.18)	0.47 (.81)	568(970)
T3	0.25 (.44)	0.63(1.08)	752(1292)
T4	0.36 (.64)	0.74(1.27	884(1523)
T5	0.51(.89)	0.88(1.52)	1056(1824)
T6	0.85 (1.49)	1.23(2.13	1472(2552)
T7	0.05(.729	0.42(.72)	508(865)

T1. Unamended Control

T2. Fertilised Control: NPK (matching Treatment 5)

T3. Liquid biochar 200kg + Charlie Carp/ ha

T4. Liquid biochar at 200kg /ha + NPK

T5. Manure from cattle fed biochar, 10t DM/ha

T6. Biochar + NPK (@7.24T/ha), same total C as Treatment 5

T7. Liquid biochar (without charlie carp) 200kg/ ha

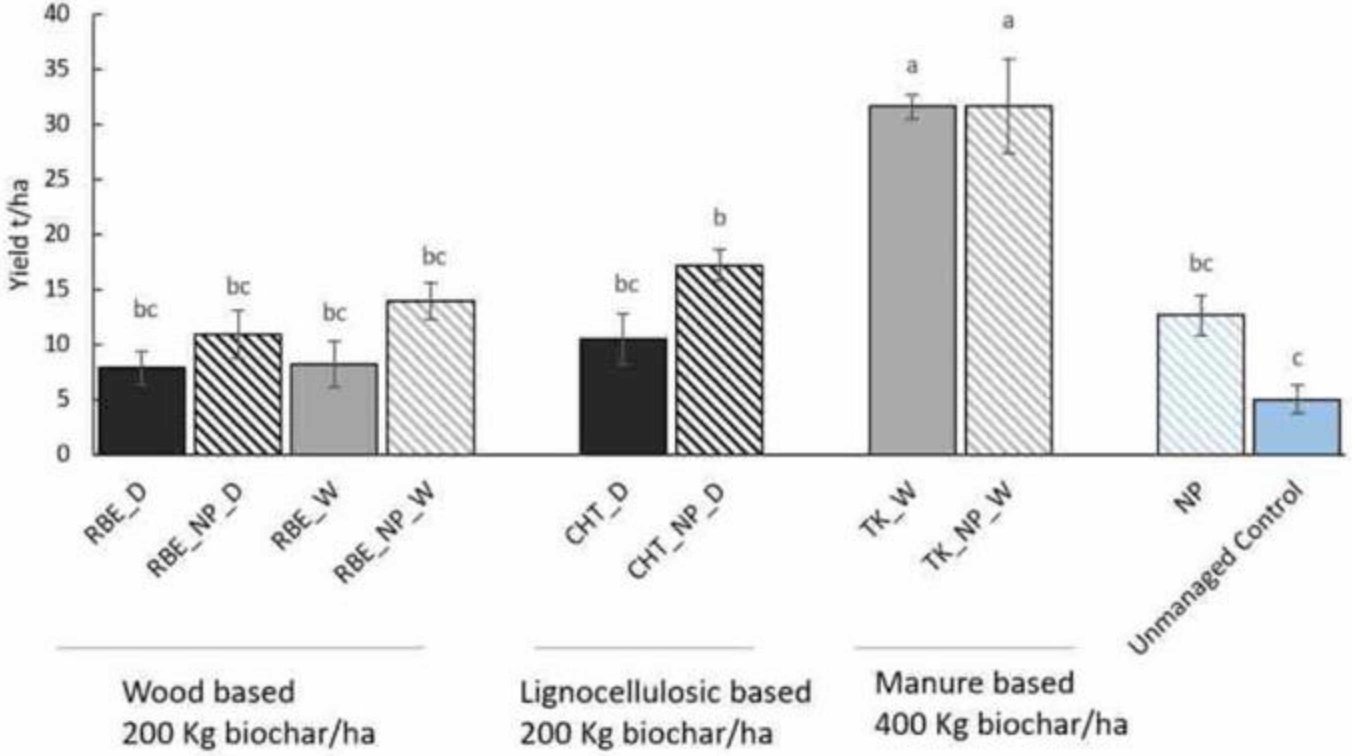
Pasture Trial:

Rainbow Bee Eater (RBE)-Berrigan NSW

This study will examine a range of liquid organic biochar-based fertilisers in a pasture rotation system and specifically aims to:

- Investigate what formula of liquid biochar fertiliser will increase biomass yield and quality,
- Explore the potential for soil nutrient retention and,
- Assess changes in microbial/fungal ratio plant root/soil colonisation.
- Explore the potential for soil labile and stable C to improve
- Undertake a cost benefit analysis
- One biochar from RBE and one biochar mineral complex from Carbon Powered Minerals (T and K)

Pasture yield



LEGEND

RBE: Wood-based biochar
TK: Manure-based biochar provided by CPMTP
CHT: Lignocellulosic based provided by CHT
D: Dispersant provided by CHT added to biochar
NP: DAP and Urea top dressed at 100 kg/ha

Reactive barriers – Progress photos; Liquid biochar from hard wood gasifier 600C was sprayed on one half of the barrier

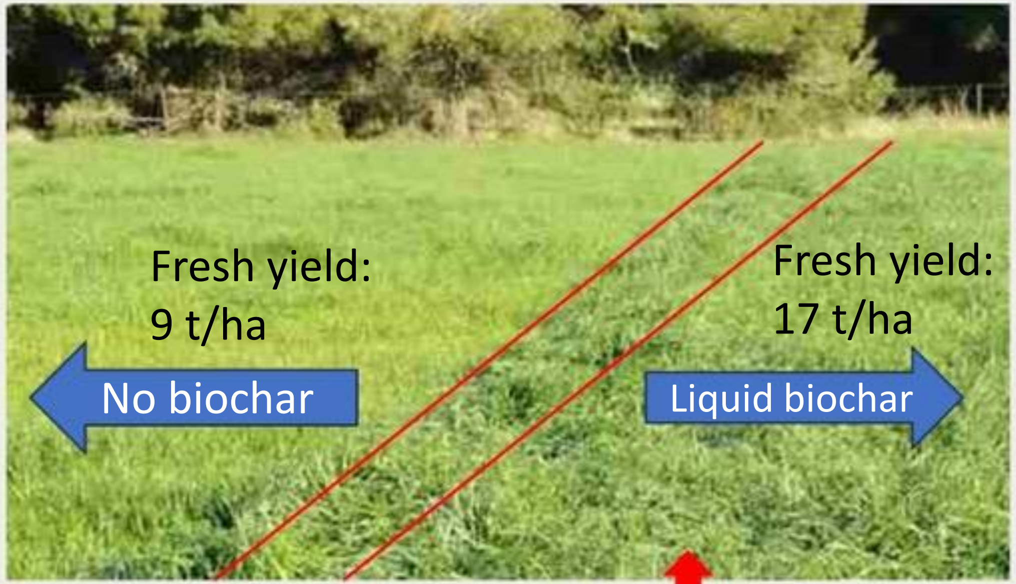
May 2023
Establishment

Week 3

Week 6

Week 10

August 2023
Week 16



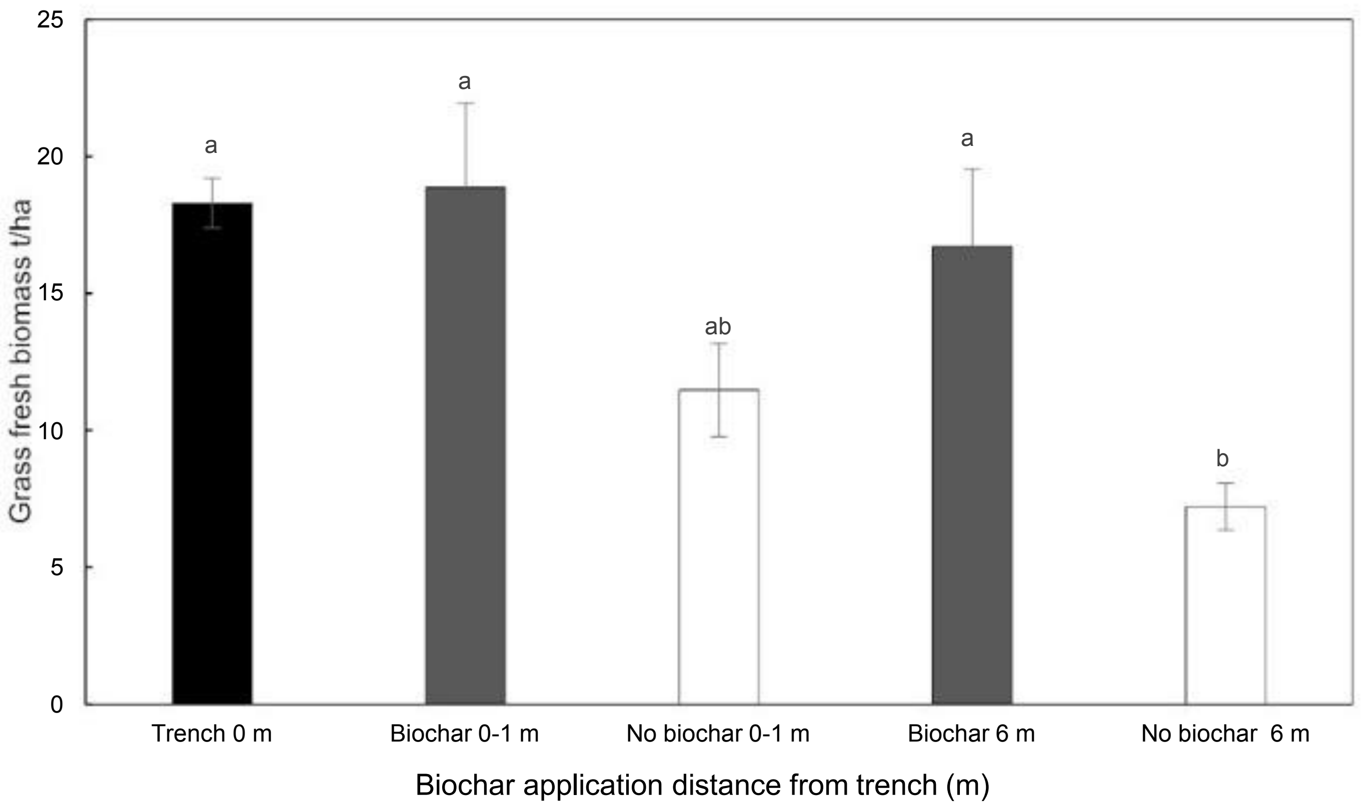
Reactive barrier

Biochar with dispersant provided by CHT

Interestingly
Yield (fresh weight): almost doubled when liquid biochar was spray onto the ground compared with no biochar

Grass yield from trench

400 kg/ha liquid biochar mineral complex (BMC), applied twice as 200 kg/ha BMC on two occasions, May and July 2023
Biochar with dispersant provided by CHT
Yield measured in 1 m^2 on trench and at 1 and 6 m from trench



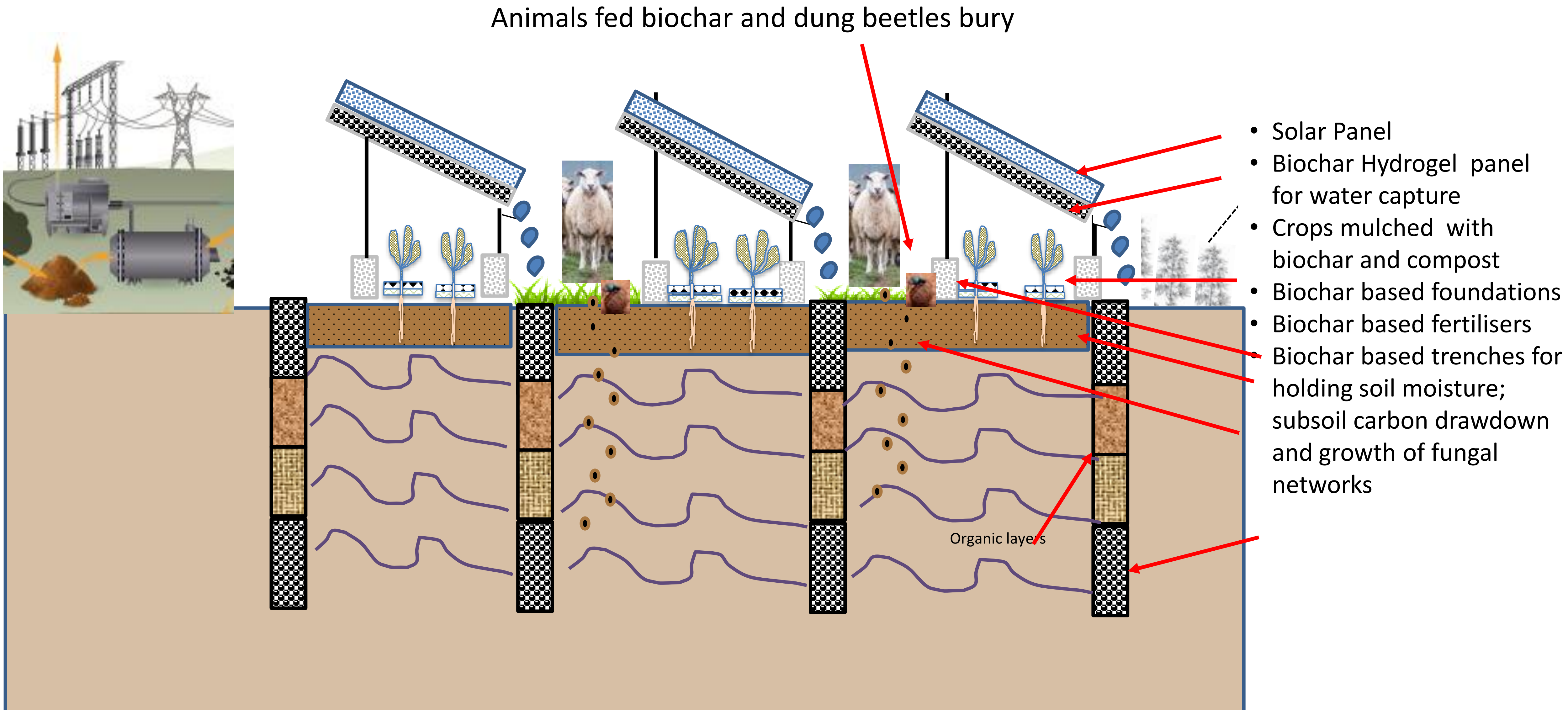
Fresh weight

- Grass yield was similar on top of trench compared with those 1 m and 6 m away from trench (black and grey columns)
- No biochar and biochar area 1 m away from trench had similar yield
- No biochar side of trench 1 m away had 11.4 t/ha whereas 6 m apart has 7.2 t/ha (white columns)

Dry weight

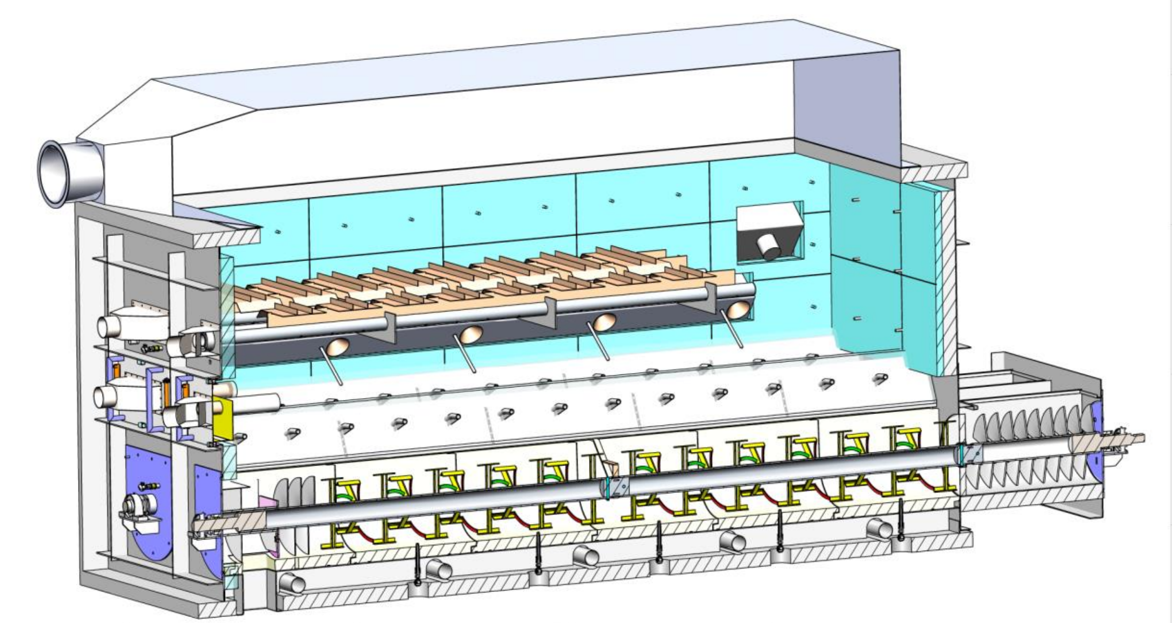
Biochar area: 2.8-3 t/ha
No biochar area: 1.5-2.4 t/ha

Integrating Regenerative Agriculture, Carbon and Water Drawdown with Solar Energy Production; A conceptual model



Components of an Integrated Large Scale Commercial Demonstration Project

1. Multi-hectare PV Farm with access for 3-5 years project
2. 1 tonne/hr containerised Pyrolysis System with ORC electricity generation using local biomass residues
3. Ability to isolate different areas of the farm to study response of different crops and grazing practices
4. Remote sensing equipment and water
5. Full time staff and budget for regular soil analysis



Possible Project Partners and Project Outline

1. Universities; UNSW (PV and Biomass); Deakin University Hydrology and PV; Griffith University and NSW DPI soil and agriculture; Others
2. PV company; ANZBIG Industry Partners and Extension; Solar PV Industries Group

Project Outline

Year 1; Finalise detailed trial design. Apply biochar and monitoring equipment to soil in PV farm purchased from ANZBIG members; Soil analysis and crop/pasture/animal measurements

Start building pyrolysis unit and getting EPA/Local/State Government approval for installing biochar/electricity generating plant for R and D

Year 2; Evaluate the results from agronomic trials year one and refine trials; Add more biochar where required; Soil analysis and crop/pasture/animal measurements

Install and commission biochar plant;

Year 3; Evaluate the results from agronomic trials from 2nd year and refine trials; Add more biochar where required; Soil analysis and crop/pasture/animal measurements Evaluate performance of biochar plant and modify to increase efficiency

Year 4; Carry out CBA and LCA