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European Innovation Partnership (EIP) Wales

Improving horticultural yields with Molinia biochar and sheep manure/wool based soil amendments

Final Report

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Oliver Kynaston

Cronfa Amaethyddol Ewrop ar gyfer Datblygu Gwledig:
Ewrop yn Buddsoddi mewn Ardaloedd Gwledig
European Agricultural Fund for Rural Development:
Europe Investing in Rural Areas

Llywodraeth Cymru
Welsh Government

Executive Summary

Motivation

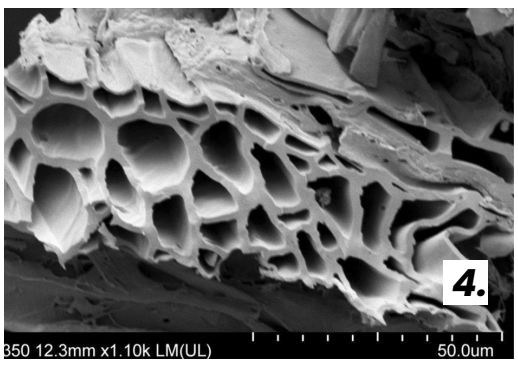
This project was initiated to understand whether biochar produced from an purple moor grass (molinia caerulea) and combined with compost derived from low-value sheep's wool and manure could be used to improve horticultural crop performance in Wales.

Biochar is a carbon-rich material produced by burning biomass in restricted oxygen environment, a process known as pyrolysis.

Tony Davies of Hefron Farm in central Wales has pioneered a technique of producing biochar from purple moor grass harvested from his upland sheep farm and has developed a range of products by combining it composted sheep wool and overwintered bedding.

The application of molina biochar within horticulture could provide a number of parallel benefits such as 1) sequestration of carbon over the long term, 2) a productive use for low-value wool and manured bedding, 3) improve horticultural crop yields in poor soil, and 4) control an invasive species common to the Welsh uplands.

This study investigates item 3) above, namely quantifying the performance of vegetable crops grown in soil amended with biochar and biochar compost mixtures.



1. *Purple moor grass (molinia caerulea) growing in the uplands.* ***2.*** *The 'Oxford Retort' used by Tony Davies to produce biochar for the trial.* ***3.*** *Application of biochar to the soil at William Robert's farm.* ***4.*** *Biochar structure revealed under and electron microscope indicating high surface area and water holding capacity.*

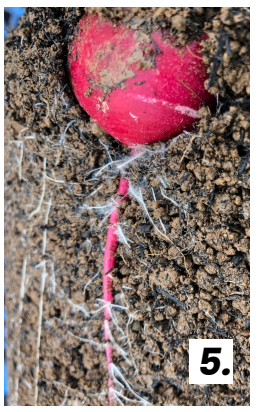
Trial Setup

The trial was conducted on four farm location over two growing seasons, beginning in March 2021 and concluding in July 2022. Details in the table below:

Farmer	Mike Warrick	William Roberts	Tony Davies	Charles Warner
Location	Llandrindod Wells	Ammanford	Rhayader	Cardigan
Farm description	Small scale vegetable production using organic principles.	Commercial no-dig vegetable production selling to local markets.	Upland Sheep farmer and small scale vegetable production.	Commercial herb and succulent grower selling to garden centers.
Experiments	Maize and Courgette grown in garden beds.	Cabbage grown in no-dig strip beds. Two years.	Radish grown in pots outside. Two years.	Basil grown in pots under cover.

Each farmer tested three applications and compared with a control: 1) Pure Biochar (biochar), 2) Biochar mixed with sheep's wool compost (biochar compost), 3) Sheep wool compost (compost).

Applications preparation, planting and data on crop performance (biomass yield, crop height and fruit production) was completed on site.



5. *Radish growing well in soil amended with pure biochar.* ***6.*** *Courgette seedling at M. Warrick's' farm.* ***7.*** *William Roberts watering in his cabbage seedlings.* ***8.*** *Basil crop harvested and measured after growing in pots by Charles Warner.*

Results and Discussion

During the two growing seasons 14 tests of crop performance were carried out on the four farms. The results varied significantly between sites and crop types ranging from a more than tripling of yields when biochar compost was added pot-grown radish, to a reduction of 50% in yield when sheep wool compost was replaced commercial compost in basil production.

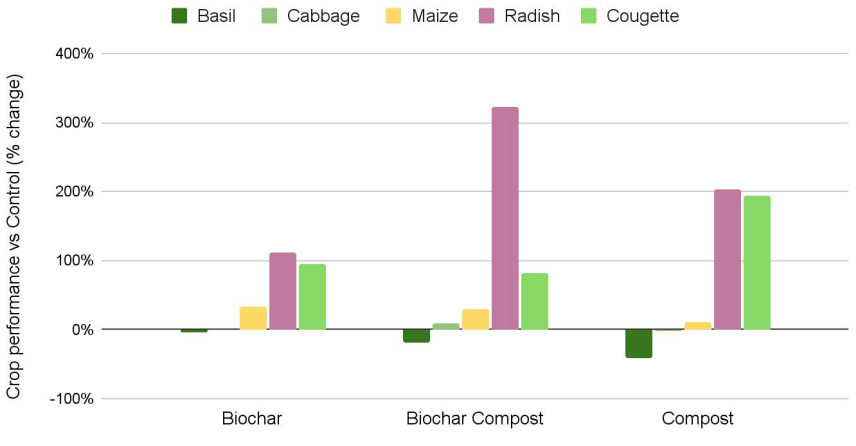
Data analysis suggested that there was a generally low statistical significance to the results, particularly with crops grown in beds outside, where variations in soil type, weather and pests impacted results.

Aggregation of crop performance - including of total biomass, crop biomass and crop size compared to the control - for each trial provide the following results:

- **Biochar** application at 10t/ha resulted in a **8.2% increase.**
- **Biochar Compost** applied at 30t/ha resulted in a **14.8% increase.**
- **Compost** applied at 30t/ha resulted in **7% decrease.**

Biochar application demonstrated the greatest benefit to crops planted in the lowest quality soil (pot grown radish in upland soil) and had the least beneficial effect when replacing commercial compost in pot grown basil.

Aggregated horticultural crop performance for 14 field and pot trials conducted at 4 farms in 2021 and 2022.



Molinia biochar mixed with compost showed improvements to yields in two thirds of trials.

Further research is recommended exploring the potential of combining biochar with high nutrient waste such as poultry and dairy manure.

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Trial 1 - Cabbage (Yr 1 & 2)

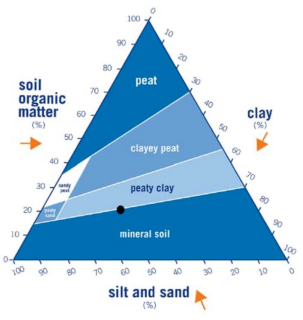
Setup

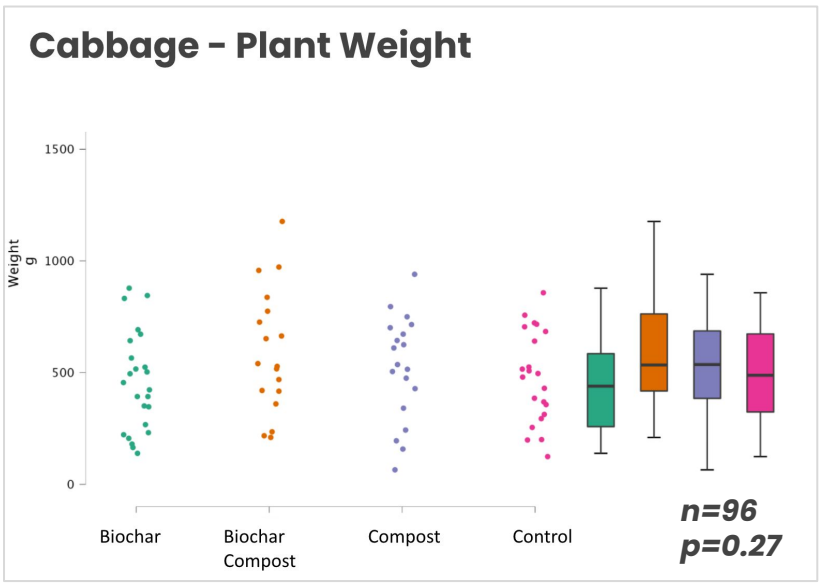
Commercial vegetable grower William Roberts farms on a 2 acre plot in the hills above Ammanford. He practices no-dig and applies municipal and homemade compost to his 22m strip beds.

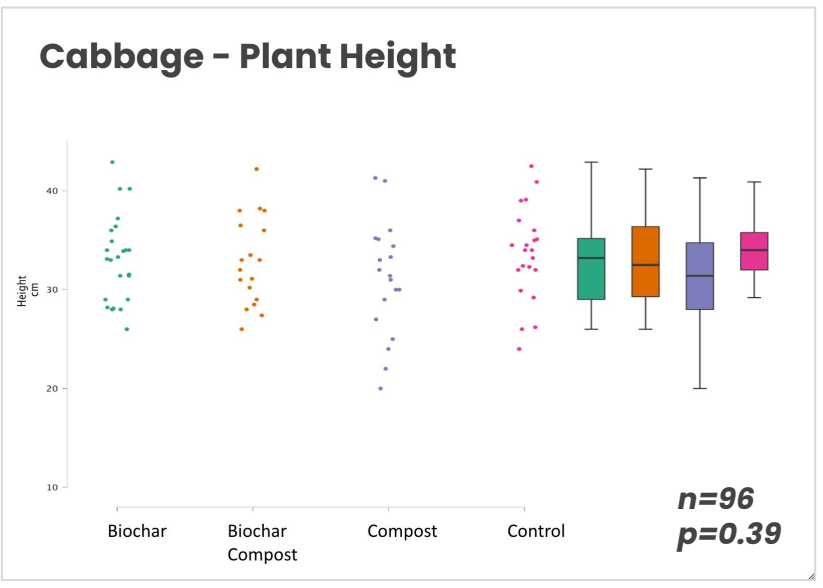
	Year 1	Year 2
Grower	William Roberts	
Location	Ammanford, Carmarthenshire	
System	Commercial organic market garden. Trial bed 22m x 1.4m. Seedling planted at 45cm spacing in two rows.	
Crop / Variety	Spring Cabbage, Anatalope F1	
Sowing date	5/03/2021	15/03/2022
Planting out date	12/04/2021	24/04/2022
Harvest date	25/06/2021	3/06/2022
Preparations	Biochar - 15t/ha - 253g per plant Biochar Compost - 30t/ha - 501g per plant Compost - 30t/ha - 501g per plant	
Replications	3	
Plants per preparation	24	
Total number of plants	96	

1. *Application of biochar at 15t/ha.* ***2.*** *Cultivating preparations down to 15 cm with hand cultivator* ***3.*** *Planting out of 4x seedlings into each of the 12 plots.*
4. *Harvest of cabbages 112 days after sowing*

Results Yr1







Soil was sampled with an auger to 20cm depth over the entire length of the growing bed used in the trial. Soil texture analysis showed peaty clay loam with good structure. Very high organic matter content of 20.8%. Very high N values of 22,000 kgN/ha and pH of 6.2. Measurements performed by NRM, fertiliser manager suite.

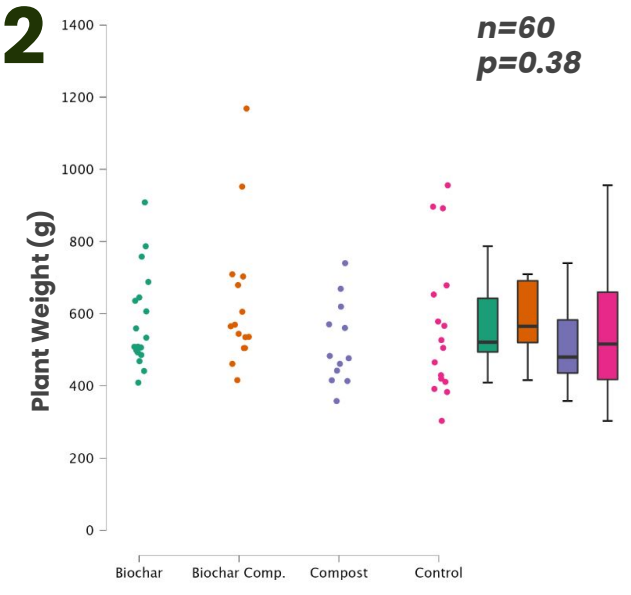
Preparation	Number of mature plants	Average Weight (g)	Average Height (cm)	Weight vs Control	Height vs Control
Biochar	24	455.8	33.1	-5%	-2%
Biochar Compost	18	593.1	32.9	24%	-2%
Compost	19	521.8	31.1	9%	-7%
Control	22	478.9	33.6	0%	0%

Results Yr 2

During the second year no additional applications were added to the soil. Visual inspection revealed obvious residues of biochar present.

Mole damage resulted in 36 plants not reaching maturity.

Biochar application had a slight increase in yield and biochar Compost had a moderate increase vs the control whereas Compost showed no improvement.

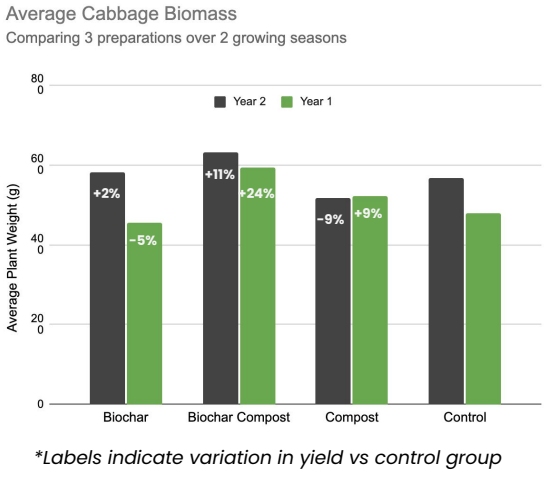


Statistical significance was low

Preparation	N of mature plants	Average Weight (g)	Average Height (cm)	Weight vs Control	Height vs Control
Biochar	18	580.0	42.7	2%	1%
Biochar Compost	15	630.3	43.1	11%	2%
Compost	12	517.4	42.7	-9%	1%
Control	26	566.0	42.2	0%	0%

Analysis

- Overall yields were better in second year..
- Biochar application went from having slight negative impact to slight positive impact on yield in second year.
- Biochar Compost had a moderate positive impact in both years.
- Yield improvement for compost in Yr1 was reversed in Yr2
- Both sets of results had low statistical significance, whereby the variation *within* preparations was almost as great as the variation *between* preparations.



**Labels indicate variation in yield vs control group*

Existing high levels of organic matter in the soil, together with generally high nutrient availability and a relatively neutral pH may explain the reduced relative impact of the applications on crop yield. Studies suggest that biochar application has the highest impact when added to degraded or low-organic matter soils.

Trial 2 – Basil

Setup

Commercial succulent and herb grower Charles Warner tested the applications as both a growing medium and soil amendment with more than 500 basil plants grown in 32 pots under cover.

Grower	Charles Warner	
Location	Cilgerran, Ceredigion	
System	2L square pots in commercial polytunnel. Plugs of approx 16 plants transplanted after 3 weeks	
Crop / Variety	Basil, Greek	
Sowing date	05/05/2021	
Harvest date	21/06/2021	
Preparations	Biochar_low - 15t/ha - 26g per pot BiocharCompost_low - 30t/ha - 52g/pot Compost_low - 30t/ha - 52g per pot	Biochar_high - 30t/ha - 52g/pot BiocharCompost_high - 240g/pot Compost_high - 250g/pot
Replications	4	4
Plants per preparation	65	65
Number of plants	234	287

1. Plugs after transplant into 2L pots. 2. Average of 16 plants per pot before harvest. 3. Harvesting basil to and weighing above and belowground biomass

Results

The trial was designed to test both soil amendment (Low Application) and growing medium properties (High Application) of the preparations against the existing commercial compost (Sylvamix Peat Free Potting Mix manufactured by Melcourt).

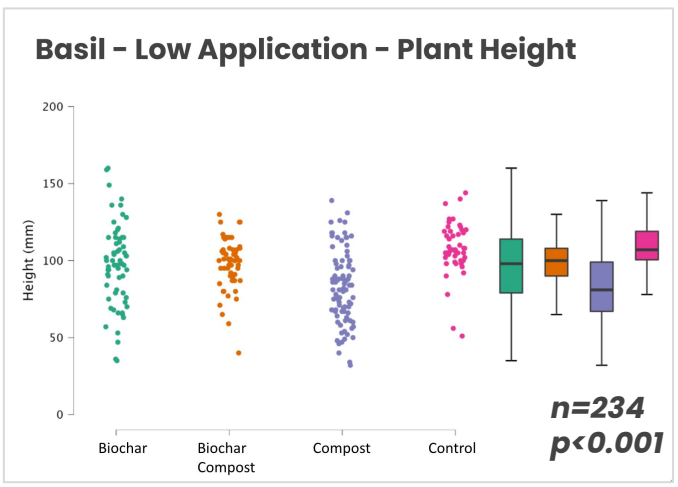
All plants grew well except for High Application Compost and Biochar Compost which failed to develop roots outside of their transplanted plug and displayed visibly yellowing leaves.

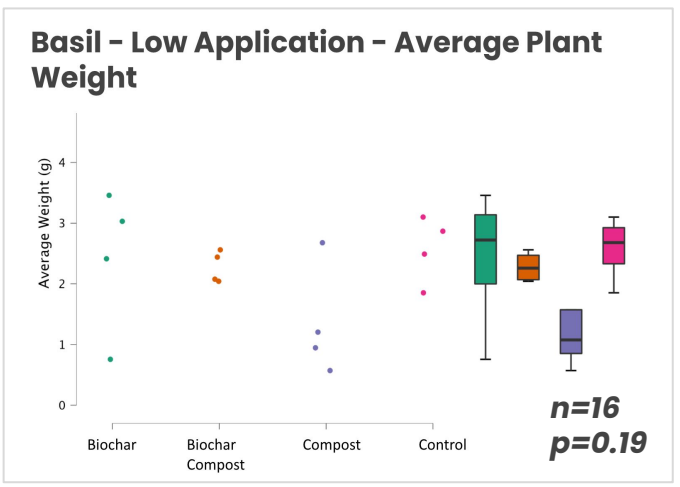
Two variables were measured for each preparation after harvest:

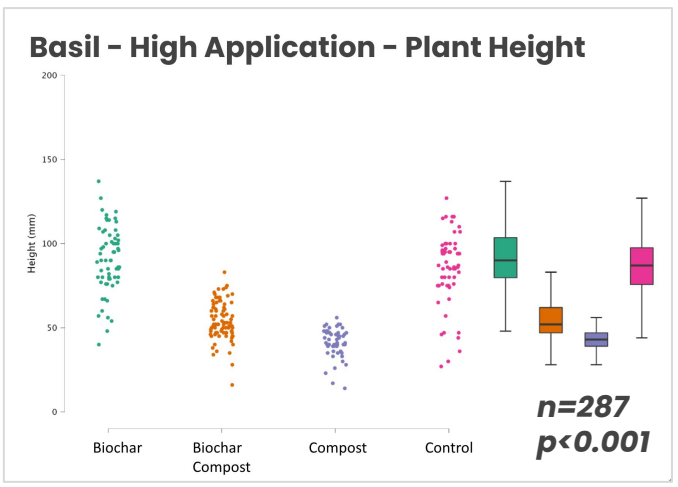
1) Total above ground biomass (Plant Weight) calculated on a per pot basis rather than individual plants to avoid potential compound measurement error of weighing very small plants.
2) Length of plant excluding roots (Plant Height), measured on an individual plant basis to nearest mm.

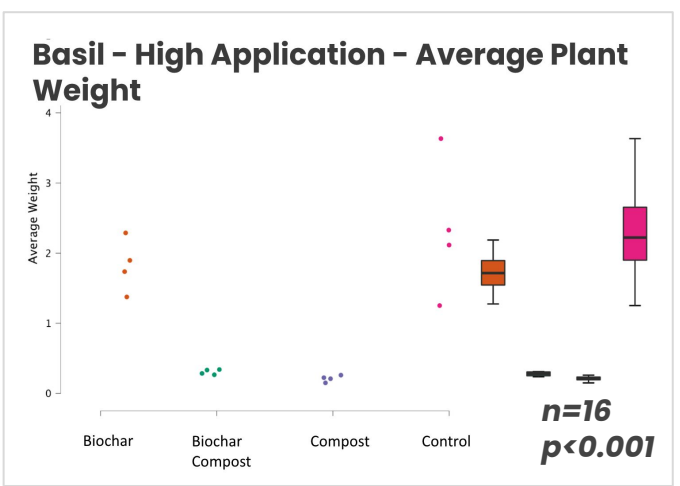
All tests except for Plant Weight with Low Application showed highly statistical significant results.

There is strong correlation between Plant Weight and Plant Height









Preparation	Plant Weight (g)	Plant Weight vs Control	Plant Height (mm)	Plant Height vs Control	Number of Plants
Biochar_low	2.41	-6%	97.3	-10.04%	65
BiocharCompot_low	2.28	-12%	98.6	-8.80%	59
Compost_low	1.35	-48%	82.7	-23.49%	87
Control_low	2.58	0%	108.1	0.00%	46
Biochar_high	1.75	-25%	90.5	6.10%	64
BiocharCompost_high	0.30	-87%	54.0	-36.72%	87
Compost_high	0.21	-91%	41.2	-51.65%	53
Control_high	2.33	0%	85.3	0.00%	60

Analysis

This trial produced perhaps the clearest result of the 5 crop trials completed during this stage of the project. The Biochar Compost and Compost are not appropriate substrates to be used as a 100% growing medium for small plants ($p<0.001$). Both Plant Height and Plant Weight we significantly lower than the control for these preparations and the plants were visibly nutrient deficient.

The control group performed best in all but the Plant Height Biochar_high preparation indicating that the Sylvamix commercial compost was better suited than the substrates under investigation in most cases.

Further investigation should be directed towards understanding the optimal concentration of biochar with the high biochar concentration performing better than the low.

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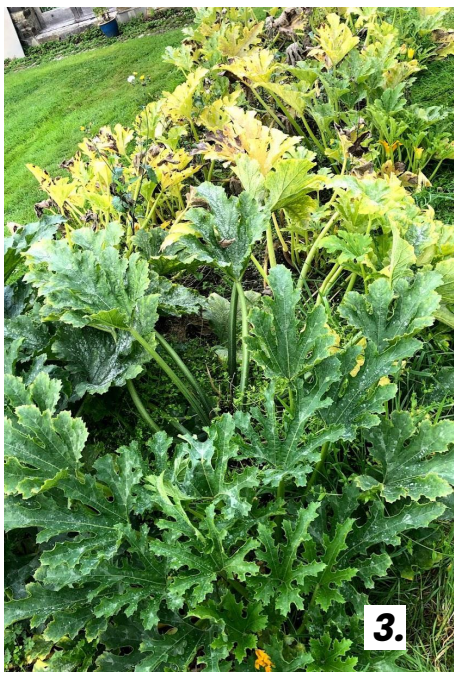
Trial 3a - Courgette

Setup

Organic grower Mike Warrick conducted a trial of courgette plants in 3x2m vegetable beds. 4 applications of were trialled with 2 replications of 2 plants each. Soil was clay loam with high SOM values and regular application of home made compost.

Grower	Mike Warner
Location	Llandrindod Wells, Powys
System	Outside, strip beds, non-commercial, organic. Bed size
Crop / Variety	Courgette, Zucchini F1
Sowing date	10/04/2021
Planting out date	11/05/2021
Harvest date	15/09/2021
Preparations	Biochar - 15t/ha - 3.3kg Biochar Compost - 30t/ha Compost - 30t/ha
Replications	2
Plants per preparation	4
Total number of plants	16



__1.__ Seedling planted out after long germination over cold spring. __2.__ 4x plants for each application. No replications due to lack of space.
__3.__ Harvest X days after planting out. Total of 357 courgette crops harvested

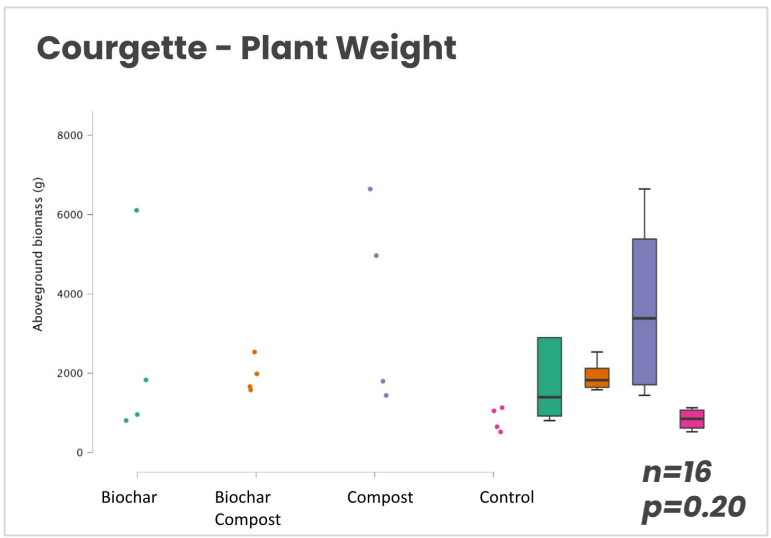
Results

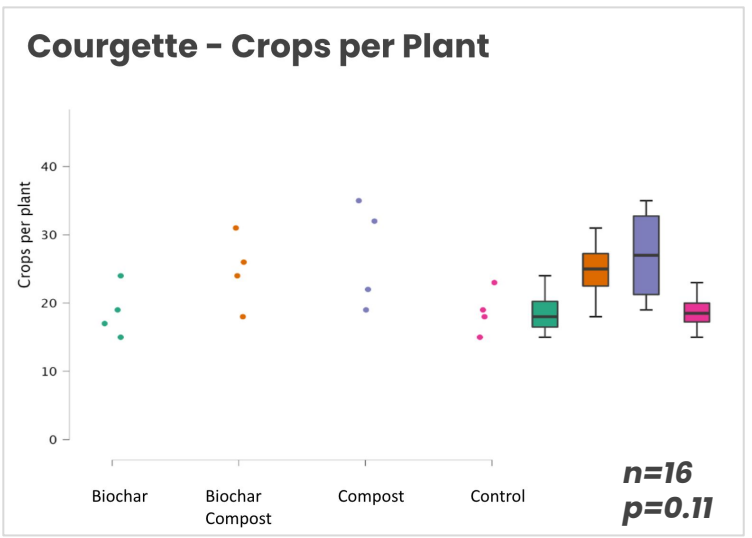
Two variables were measured during the trial - total above ground biomass of the courgette plant (Plant Weight) and the number of courgette fruit harvested per plant (Crops per Plant).

Crops per Plant was recorded during the trial by the grower who picked fruit once it had reached ~10cm in length and recorded the weight (average 102g per fruit, standard deviation 51g)

Plant Weight was measured by cutting plants at ground level and weighing on a calibrated mass balance accurate to 0.1g

Soil analysis indicated high soil organic matter (10.3%), high nitrogen stock (9,200 kgN / ha), neutral (pH 6.5) and silt loam texture.





Preparation Group	Preparation	Number of mature plants	Average Plant Weight (g)	Crops per Plant	Plant Weight vs Control	Crops per Plant vs Control
B	Biochar	4	2,425	75	190%	0%
BC	Biochar Compost	4	1,940	99	132%	32%
C	Compost	4	3,712	108	344%	44%
Cn	Control	4	837	75	0%	0%

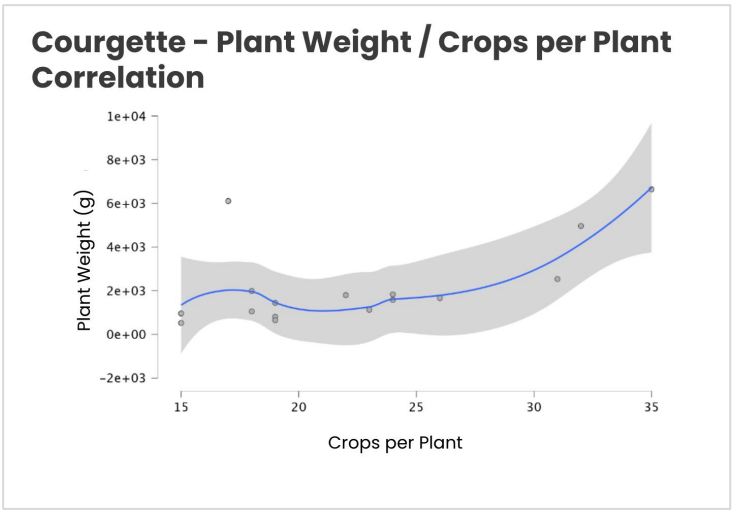
Analysis

Both variables produce results with relatively low statistical significance.

The Control group performed significantly worse that all preparations. Compost performed the best with a >300% increase in Plant Weight and 44% increase in Crops per Plant compared to the control group.

There was a strong correlation between Plant Weight and Crops per Plant with all results lying with 1 standard deviation of the mean.

The Biochar Compost performed worse than the Compost, potentially due to the high organic matter already present in the soil.



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Trial 3b - Maize

Setup

Organic grower Mike Warrick experimenting with Sweetcorn. The plot was small and only allowed for 16 plants with no room for replications of each application. Soil was a fertile silt loam with high SOM from to regular application of home-made compost.

Grower	Mike Warner
Location	Llandrindod Wells, Powys
System	Outside, strip beds, non-commercial, organic. Bed size
Crop / Variety	Sweetcorn, Sundance F1
Sowing date	10/04/2021
Planting out date	11/05/2021
Harvest date	15/09/2021
Preparations	Biochar - 15t/ha - 3.3kg Biochar Compost - 30t/ha - 7.7kg Compost - 30t/ha - 7.7kg
Replications	0
Plants per preparation	4
Total number of plants	16

__1.__ Molinia biochar applied to the soil, cultivated to 20cm by hand. __2.__ Planting out of 16x healthy seedlings in mid-May. __3.__ Grower manually recorded crop yields after picking over the cropping period. __4.__ Harvest and measurement of plants in September.

Results

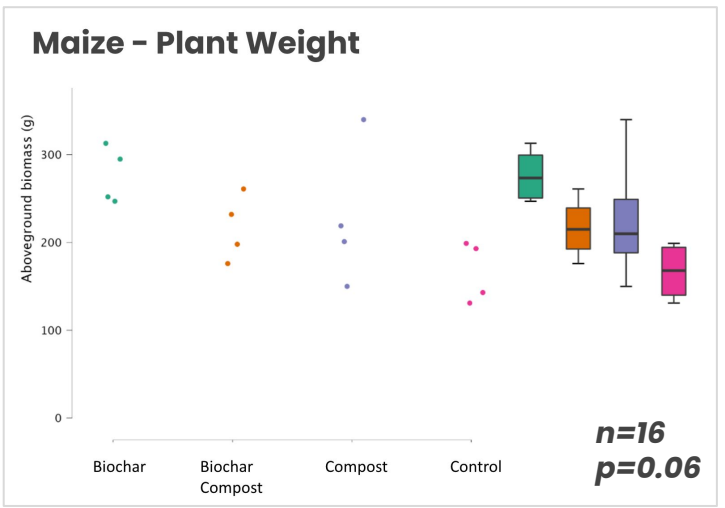
Two variable were measured during the trial - total above ground biomass of the maize plant (Plant Weight) and the total fresh biomass of the cobs per plant (Crop Weight).

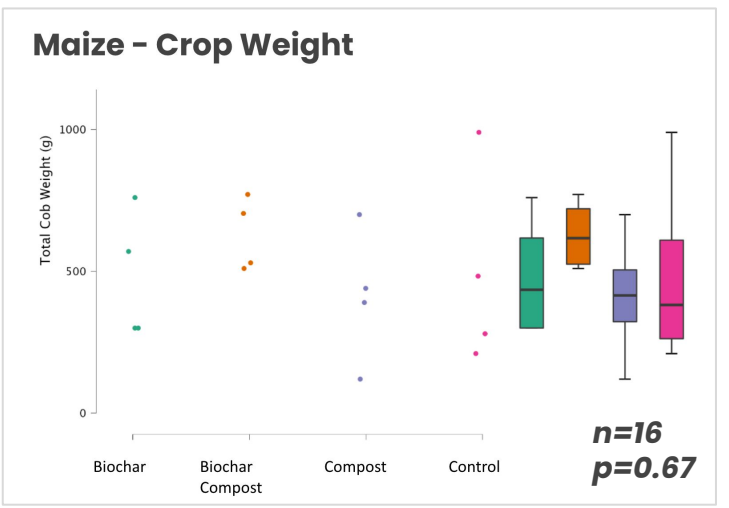
All seedlings reached maturity with no significant insect or disease pressure.

Crop Weight was calculated during the trial by the grower once the sweetcorn had reached maturity.

Plant Weight was measured by cutting plants at ground level and weighing on a calibrated mass balance accurate to 0.1g

Data was analysed using ANOVA statistical package in JASP v0.16





Preparation	Number of mature plants	Average Plant Weight (g)	Average Crop Weight per Plant (g)	Plant Weight vs Control	Crop Weight vs Control
Biochar	4	277	483	66%	-2%
Biochar Compost	4	217	629	30%	28%
Compost	4	228	413	37%	-16%
Control	4	167	491	0%	0%

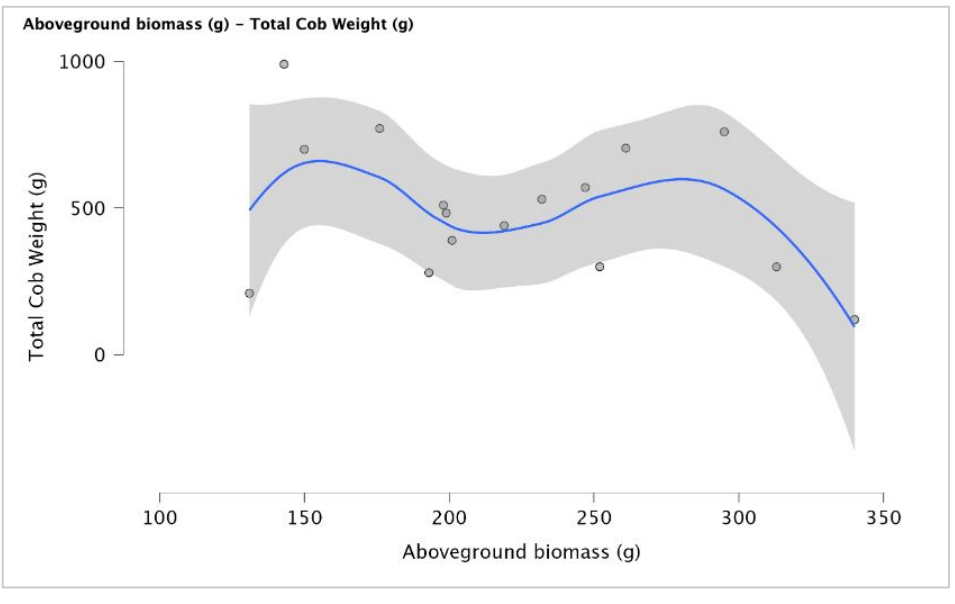
Analysis

The limited space available to conduct the trial had serious impact on the reliability of the results.

The Biochar application improved the Plant Weight yield by 66% (medium confidence) with the control group performing worst overall.

The Crop Weight was found to be poorly correlated to the Plant Weight, implying that a large plant did not necessarily mean a higher crop yield.

Biochar Compost was found to increase the crop yield by 28% (very low statistical significance) with Biochar producing a lower yield than the Control.



The results indicate the non-controlled variables had a more significant effect on yield than the applications. This could be improved by increasing the size of the sample, but maize cob yield may be considered an inappropriate indication of application effectiveness.

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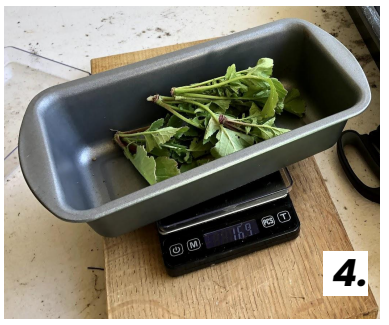
Trial 4 – Radish (Yr 1 & 2)

Setup

Upland famer Tony Davies manufactures the biochar and compost used for this trial on his farm above Rhayader. He conducted a pot trail with radish in soil taken from an adjacent field. Plants were grown outside during warm weather and regularly watered.

	Year 1	Year 2
Grower	Tony Davies	
Location	Rhayader, Powys	
System	In pots, outdoors in sheltered location. 10 seeds sown and thinned to 5 seedlings after 2 weeks.	
Crop / Variety	Radish, Scarlet Globe	
Sowing date	17/05/2021	26/05/022
Harvest date	17/07/2021	22/07/2022
Preparations	Biochar - 20t/ha - 26g per pot Biochar Compost - 40t/ha - 53g Compost - 40t/ha - 53g	Biochar High - 40t/ha - 54g/pot Biochar Med - 20t/ha - 26g/pot Biochar Low - 5t/ha - 7g/pot
Replications	4	4
Plants per preparation	20	20
Total number of plants	80	80



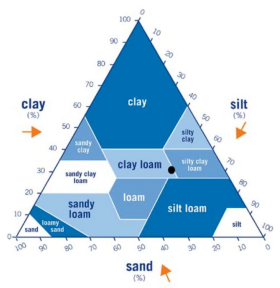
1. *Farmer and manufacturer of the biochar and compost Tony Davies.* ***2.*** *Pots after planting outside in sheltered space.* ***3.*** *15cm pots holding 1.3kg of soil, each with 5x thinned seedlings. 4x replications of each preparation giving total of 16 pots.* ***4.*** *Above and belowground biomass measured with balance accurate to 0.1g.* ***5.*** *Significant variation in yield. Left Biochar Compost, Right control.*

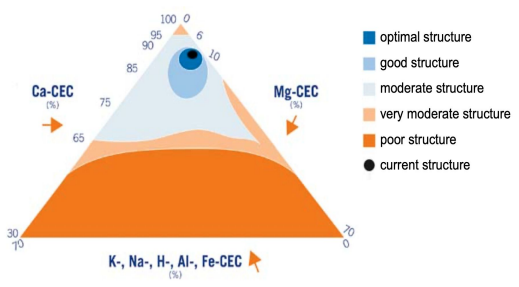
Results Yr1

A single variable of total wet weight biomass, including leaf and root (Plant Weight) was measured 60 days after sowing with mass balance accurate to 0.1g.

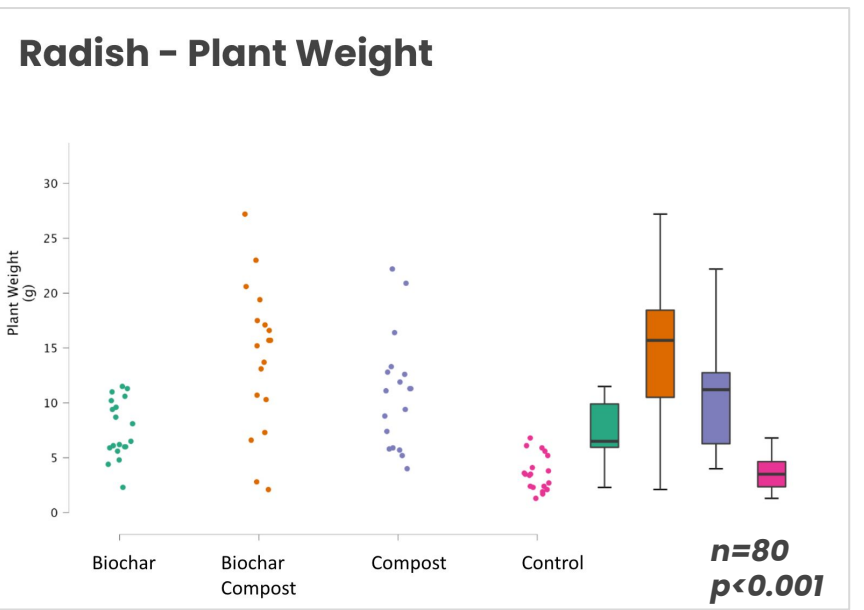
Around 15% of the crop had slug damage. There was no correlation between insect damage and application of the preparations and this has not been controlled for in the data analysis.

Data was analysed using ANOVA statistical package in JASP v0.16





Soil was taken from mole hills in adjacent field previously used for potato cultivation. Soil texture analysis showed clay loam with good structure. Organic matter of 10.3%, very high N values of 11,000 kgN / ha and pH of 5.8. Measurements performed by NRM, fertiliser manager suite.

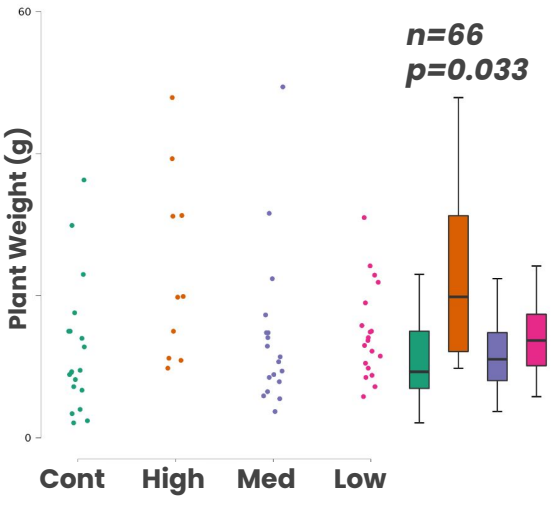


Preparation	Number of mature plants	Average Weight (g)	Weight vs Control
Biochar - *20t/ha*	20	7.6	111%
Biochar Compost *40t/ha*	20	15.2	323%
Compost - *40t/ha*	20	10.9	203%
Control	20	3.6	0%

Results Yr2

During the second year three different rates of pure biochar were applied to the same soil to grow Radish. Germination was good and plants grew to a larger average size than Yr1.

Results showed good statistical significance with highest biochar rate producing ~90% more biomass than the control.



Preparation	Number of mature plants	Average Weight (g)	Weight vs Control
Biochar High - *40t/ha*	10	23.6	91%
Biochar Medium - *20t/ha*	19	14.7	19%
Biochar Low - *5t/ha*	18	14.2	15%
Control	19	12.3	0%

Analysis

Pots trials growing globe radish in poor quality hill soil amended with biochar and compost were conducted over two years. The results in both years showed that the addition of either biochar or compost **improved the yield significantly vs the control**.

Year 1 had generally low yields due to slug damage and under watering, with each application improving performance vs the control. In Year 2 with better growing conditions the **highest application of biochar (40t/ha) produced the highest yields (~90%).**

Soil analysis revealed a very low P concentration in the soil (0.5kg/ha - with a UK average of between 4 and 7 kg/ha). Biochar is known to be a source of P (depending on the input substrate)

Furthermore biochar is know to have a liming effect which may have been beneficial to the crops growing on very acidic soil (pH 5.8)

Combined Results

Results

In total 13 experiments comparing Biochar, Biochar Compost and Compost applied at several rates were completed at 4 farms over 2 years.

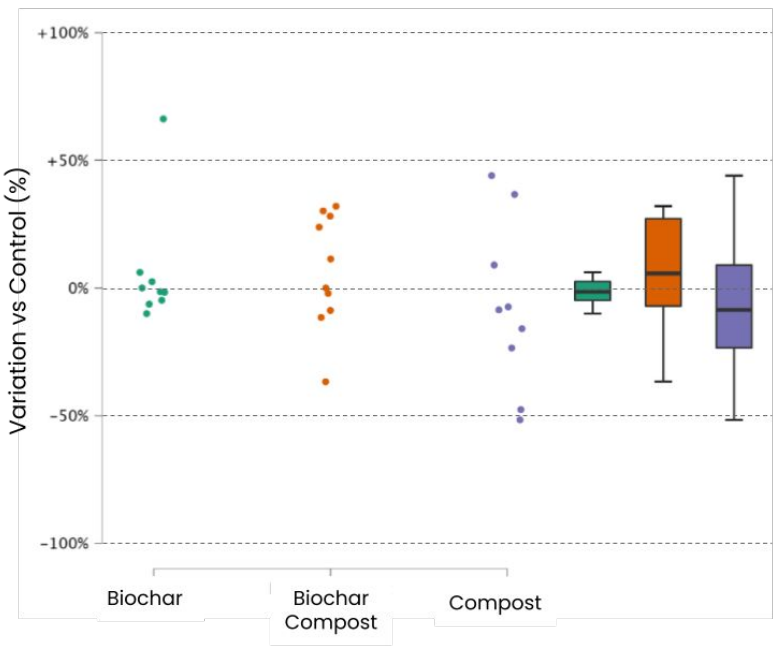
A meta analysis was conducted for 12 of the compatible experiments to compare the applications against the control group. The results are displayed in the table and chart below with averages in crop performance weighted for the number of plants in the trial. They indicate that:

- Molinia **biochar** applied as a soil amendment had a **slight (8%) increase in crop performance** vs the control.
- Molinia **biochar** combined with sheep wool **compost** had a **moderate (15%) improvement** on crop performance vs the control
- Sheep wool **compost** showed a **slight decrease (-7%)** in crop performance vs the control

In general statistical significance of the results was low to medium with pot trials producing higher quality results than outdoor field trials.

Meta Analysis				Crop Performance vs Control		
Experiment	**Measurement**	**Statistical Significance**	**Number of Plants**	**Biochar**	**Biochar Compost**	**Compost**
Courgette	Crop Yield	Low	16	190%	0%	132%
Courgette	No. of Fruit	Medium	16	0%	32%	44%
Maize	Crop Yield	Low	16	-2%	28%	-16%
Maize	Total Biomass	Medium	16	66%	30%	37%
Radish Yr1	Crop Yield	High	80	106%	331%	198%
Cabbage Yr1	Crop Yield	Low	96	-5%	24%	9%
Cabbage Yr1	Crop Height	Low	96	-2%	-2%	-7%
Cabbage Yr2	Crop Yield	Low	61	2%	11%	-9%
Cabbage Yr2	Crop Height	Low	43	1%	2%	1%
Basil - Low Application	Crop Yield	Medium	257	-6%	-12%	-48%
Basil - Low Application	Crop Height	High	257	-10%	-9%	-23%
Basil - High Application	Crop Yield	High	250	6%	-37%	-52%
		Weighted Average		**8.20%**	**14.86%**	**-7.26%**

Meta analysis showing crop performance of each application vs the Control group for 11x experiments over two years.



Discussion

The experiments were designed to provide indicative results to assist farmers in making decisions about whether the application of biochar and compost made of sheep wool could improve the growth of vegetables of different types across a range of conditions.

With the results compiled, the following conclusions can be drawn:

1) Biochar and Biochar Compost had a strongly positive effect on plant performance when applied at rates between 20 and 40t/ha in low-quality soils during periods of water stress. This correlates well with existing studies indicating improvements in water holding capacity and improvements in Cation Exchange Capacity in such soils. This was demonstrated by the Radish trail in year 1 and 2.

2) Pure Molinia Biochar had generally low impact on crop performance across the sites (weighted average of 8.2% increase with range between -10% and +190% increase in performance vs the control). This result was repeated in both pot and field trials for all crops.

3) High application rates of Biochar and Biochar Compost used as a growing medium had negative impact on plant growth (average -44% effect on crop performance in basil trial). These products should therefore not be sold as an alternative to commercial composts or other well tested growing media.

4) Application of pure compost derived from sheep wool had a slight negative impact on crop performance across the experiments (weighted average of -8% range between -52% and +198%) due to likely deficiencies in key nutrients.

5) The performance of biochar and biochar compost was found to be greater in the second year than the first, indicating the the biochar remains stable in the soil and is likely to provide a stable structure for beneficial fungal and bacterial communities.

Further Research

- Understanding the effect of applying biochar manufactured from a wider range of locally available substrates (such as hedge clippings, coppice material and compost oversize) on crop performance.
- Perform a full Life Cycle Analysis to determine the net carbon sequestration potential of biochar manufactured on-farm in small and medium scale retorts, to better understand the climate mitigation potential of integrating biochar within the the farm system.
- Investigate the effect on N2O emissions and crop performance of using biochar to stabilise volatile animal waste streams (poultry and dairy manure).

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Supporting Images