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Biochar Use in Agriculture: The Economic and Environmental Benefits

Written by:

Luke Breedon NSch

October 2024

A NUFFIELD FARMING SCHOLARSHIPS REPORT

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"Leading positive change in agriculture. Inspiring passion and potential in people."

Title	Biochar Use in Agriculture: The Economic and Environmental Benefits
Scholar	Luke Breedon
Sponsor	Alan and Anne Beckett
Objectives of Study Tour	1) Assess the current levels of biochar production and ascertain why is it being produced 2) To understand the benefits and drawbacks of different methods of use of biochar in different systems How carbon plays a part in biochar use in agriculture, horticulture and forestry
Countries Visited	Belgium, Germany, Sweden, United States, New Zealand and Australia
Messages	1) Global biochar production is on the increase, largely as a GHG gas removal tool and partially funded by the carbon credit market 2) The cost of biochar currently still outweighs the direct financial benefits in the short term; however, opportunities exist for farmers to get involved with industry as they are often either the producer or close to the production of feedstocks, and the end user of the product 3) The potential for regulatory and social pressure on increased emissions reduction in agriculture could make biochar production and use on farm a viable prospect Further research and publication of methods could help to inform farmers and those in the sector on best practice when looking at use of biochar

EXECUTIVE SUMMARY

Anthropogenic use of biochar can be dated back two millennia, however, only in the last couple of decades has significant research been undertaken to find out why, and whether the practice can bring benefits to modern day agriculture and other industries. It is estimated there are now more than 30,000 scientific publications on the topic with meta-analyses showing astounding results. Crop yield increases of 10-42%, increases in P availability by a factor of 4.6 and reduction in non-CO2 greenhouse gas emissions by 12-50% are just a few. These derive solely from the addition of biochar to soil, with many more potential uses showing equally impressive results. So why has the biochar industry not commercialised to the same degree? This report looks at the environmental and economic benefits and drawbacks of biochar and asks if these have contributed to its comparatively slow uptake.

It has been understood for many years that producing biochar can remove carbon dioxide from the atmosphere, a practice that has now been proven essential for the globe to reach minimum warming and emissions net zero. It is estimated by the International Biochar Initiative that biochar production could be responsible for removing 6% of global emissions per year, with further savings from its cascade of uses. Only in the last few years has this had any financial reward attached to it with the adoption of voluntary carbon markets, now fuelling a growing production industry and alleviating somewhat the high price of the biochar product.

More and more farm scale trials are being conducted, with varying results. This has highlighted some of the key approaches towards biochar use; not all biochar is created equal and that there are certain scenarios where it will have the greatest impact. Farmers and growers need to be increasingly aware of what it is they are using due to significant variations in feedstock, production parameters and inoculation as each could make or break a project. To make this worse, policy and guidance have not been developed in line with production, leaving potential users erring on the side of scepticism when considering projects.

On-farm production is on the rise however, as often feedstocks may be sourced on farm or locally and end use may be within animal, arable or grower sectors. Here we can see increased economic benefits through heat or energy generation, as well as the ability to offset farm-based emissions and growing opportunities for carbon trading.

Biochar should not be considered the "silver bullet" it once was, but a nature-based tool that through a considered approach can deliver economic benefits in the right scenario, and environmental benefits in almost every application.

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Please note that the content of this report is up to date and believed to be correct as at the date shown on the front cover.

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1: INTRODUCTION

Despite growing up in rural East Kent, surrounded by orchards, arable and vegetable farming, a career in agriculture wasn't even on my career advisor's radar. A National Diploma in Countryside Management from Hadlow College led to my first job aged 16 as a gang-master on a local top fruit farm. I then went on to study Rural Land Management at the Royal Agricultural College and after a two-year stint working on farms in Australia, I took a job with what was then The Co-operative Farms. Several years were spent at the Down Ampney unit near Cirencester, and several changes of management took place, eventually working as Assistant Farm Manager for Velcourt Ltd.

In 2021, in partnership with my wife Helen, we started Slate Hill Charcoal, where we produce high quality, local and sustainable barbecue charcoal. It was when the gradings and fines of our charcoal started piling up that the interest in biochar was sparked, and the ties it had to my previous career in agriculture. The potential to improve carbon sequestration on-farm, as well as soils, animal health and emissions seemed like an incredible opportunity to combine the two industries. Helen and I now produce charcoal, biochar and biochar kilns from our home in North Wiltshire where we live with our daughters, India (5) and Ava (3).

My Nuffield scholarship has offered an unforgettable experience and an incredible sense of agency to discover whether biochar could or should play a part in the future of agriculture.

Figure 1: Author with charcoal/biochar retort (Author's own)

2: BACKGROUND TO STUDY

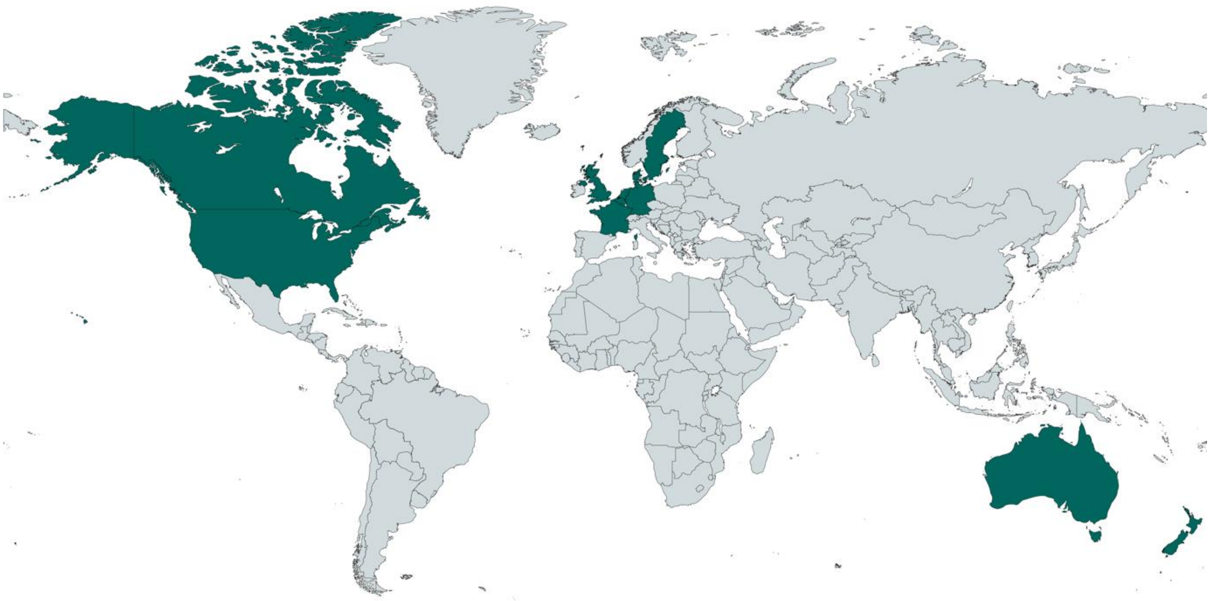
"Biochar is going through a renaissance."

Evidence suggests that the first anthropological use of biochar was in the South American rainforest around 2000 years ago, at the very least. The "Terra Preta" (Amazonian dark earth) found here was discovered in the 1960's and is composed of charred organic material, food waste, manures, pottery shards and bones and is believed to have provided the basis for an agricultural system that fed a civilisation of thousands. However, natural biochar resulting from wildfire, or perhaps historic controlled burning by humans, can be found in some of the most fertile soils on earth: the Chernozems found across the North American prairies and Eurasian Steppe. Although some of these soils have become a tradable commodity, it is not until relatively recently that we have started to investigate how different biochars interact with our soils.

Figure 2:Terra Preta soils (left) compared to more common rainforest soils (right) from Glaser, Bruno & Haumaier, Ludwig & Guggenberger, Georg & Zech, Wolfgang. (2001. The Terra Preta Phenomenon: A model for sustainable agriculture in the humid tropics. Die Naturwissenschaften. 88. 37-41. 10.1007/s001140000193

It is estimated that there are now around 30,000 research papers about biochar, with the majority written since 2010. This indicates the level of interest in the subject within the scientific community, however if you ask the average farmer what biochar is, you may be greeted with a blank expression. Laboratory trials have been commonplace, but most field scale trials have only commenced within the last couple of years. There are several reasons for this, which I will explore in the following chapters.

3: MY STUDY TOUR



Date	Location	Comment	CO2e
March 2023- April 2024	UK	Various face to face and online meetings with farmers, biochar producers, machinery manufacturers, consultants and academics	0.1t
March 2023	London and Vancouver, Canada	Pre-CSC and CSC organised by NFST	2.4t
June 2023	France, Belgium, Germany, Sweden, Denmark and the Netherlands	Drove to the European Biochar Industry Consortium conference in Helsingborg, Sweden meeting various other businesses and projects on the way.	1.5t
October 2023	United States	Drove across 9 states visiting various industry experts, farmers, projects and manufacturers.	2.53t
February 2024	New Zealand and Australia	Drove around the North Island of New Zealand and NSW, QLD, VIC, SA	5.95t
Totals:	*Travel: 86 days*	*Miles driven: 13,000*	*12.56t*
As the production of biochar is as much about the atmospheric carbon removal it offers, I have calculated the Carbon Dioxide equivalent produced by my study tour. This will be in-set by me personally producing the required amount of biochar. This process has also allowed me to focus on areas where I can reduce my emissions, such as hiring an electric car for all the travel in North America. Further calculations can be seen in Appendix 1.			

4: BACK TO BASICS

The UK Biochar Research Centre defines biochar as: "the porous carbonaceous solid produced by the thermochemical conversion of organic materials in an oxygen-depleted atmosphere and which has physiochemical properties suitable for the safe and long-term storage of carbon in the environment and, potentially, soil improvement."

Most definitions now follow a similar format, with the key points being that biochar:

- Is produced through **pyrolysis**, or heating in a low oxygen environment
- Is produced from **organic material** that is free from contaminants
- Offers long term **storage of carbon**, and as such cannot be burnt or fully combusted

One of the simplest examples is charcoal, a carbon-rich solid produced from wood, but the key difference is that charcoal is produced as a fuel to be burnt whereas biochar is produced for the storage of carbon and potential benefits it brings in its dozens of uses.

The properties of biochar vary considerably dependent on feedstock, production parameters and end use: however, generally all will have a high level of carbon at between 35%-95%, a low level of volatile components such as Polycyclic Aromatic Hydrocarbons, and a very large surface area compared to mass. This surface area could be compared to a "carbon sponge" where a myriad of micro and macro pores in the carbon provide a wide range of benefits related to adsorption.

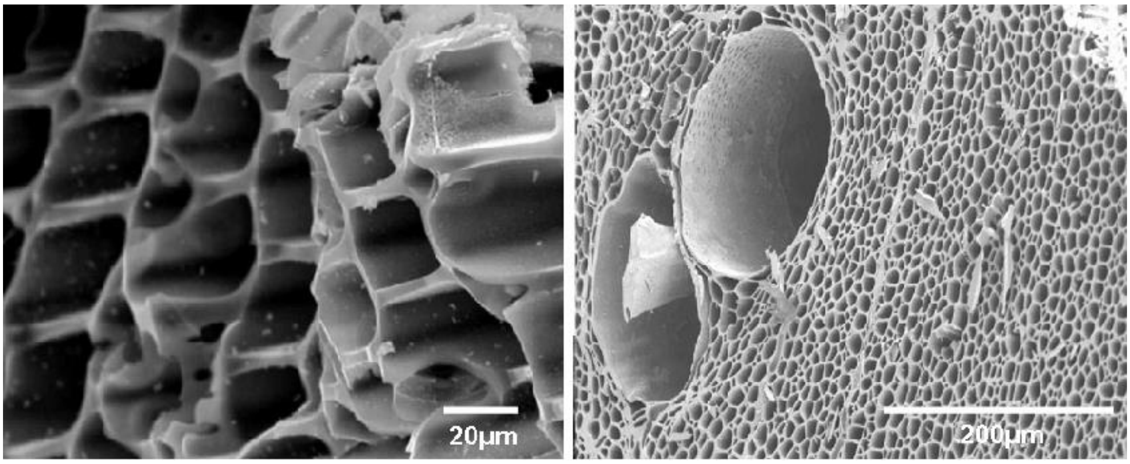


Figure 3: Biochar pore structures under an electron microscope. Thies, Janice & Rillig, Matthias. (2009). Characteristics of biochar: biological properties. Biochar for Environmental Management: Science and Technology. 85-105.

5: BIOCHAR USE

The uses of biochar can be split into two sectors; for the removal and storage of atmospheric carbon and for the benefits that the physical product can bring to various systems. There are several characteristics which make biochar a useful product:

- The **high surface area** of between 200-2000m2/gram
- A slight **electrical charge**
- Often a **higher pH**
- The ability to **tailor the composition** both pre- and post-production
- The **inert** nature of carbon
- The **valorisation** or reduction in volume of waste material

These make biochar an attractive prospect for many industries, with agriculture and horticulture being the first, middle and sometimes last step in the cascade of its use.

5.1: Inoculation

Within agriculture we want biochar to become a nutrient battery, capable of storing and making available nutrients that might otherwise have been lost through leaching or lockup. It may also increase the water-holding capacity of a soil or substrate, provide an attractive site for funghi or microbes and increase the friability of an otherwise poor-quality soil. In all these we should remember the analogy of a carbon sponge. It will need "feeding" to reach its potential and has been shown to have negative results if not properly inoculated before use.

Methods of inoculation can be both natural and engineered, with many providing services before the product's end use. In Sweden, Malin and Magnus Axelsson have developed an aquaponics system that uses approximately 50mm pieces of biochar alone as the growing substrate alongside a comparative system using traditional granite gravel. Tilapia fish provide the nutrients in both systems, with their food and water being the only input. The results are clear, with all the plants in the biochar system considerably outgrowing those in the gravel. The biochar can then be further used in soil. Several companies are developing synthetic fertilisers with biochar as an ingredient. Lukas Van Zweiten and his team

Figure 4: Biochar coated urea, poly coated urea, pelletised Oat biochar with urea (Author's own)

from the New South Wales Department of Primary Industries are trialling oat char, washed with phosphoric acid and combined with urea to increase plant uptake and reduce the traditional losses associated with the fertiliser product.

5.2: Soils

Adding biochar to soil is the traditional method of use and is still the largest sector globally. The large amount of research that has gone into this area has highlighted how well inoculated biochar added to poor quality soil can dramatically improve yield through a combination of both nutrient and water holding capacity. Biochar can hold 5 times its own weight in water. These qualities are often demonstrated in their use in low yielding tropical soils with high sand or mineral content, low organic matter or potential toxicity. However, there are other areas which could benefit from the application of inoculated biochar. In the Blackfoot Valley of Montana, the USFS, TNC, Blackfoot Challenge and private landowners have come together to trial a high compost ratio biochar on irrigated pasture with clear results.

Figure 5: Compost and biochar trial plots on a Montana irrigated pasture (Author's own)

The pasture in the foreground has had around 1inch of compost and biochar applied, spurring on considerable new growth compared to the existing grass in the background. It should be noted that the soil depth on this pasture was only around 3 inches before reaching compacted rock, and as it had not received any additional fertiliser other than grazing for 6 years, the compost fraction may be the catalyst in this scenario. Time will tell whether the biochar and compost plot will outperform the compost-only plot with a reduction in nutrient and water leaching. The cattle in this pasture clearly enjoyed the fresh growth.

Soil amendment with certain inoculated biochars has also been shown to increase the Cation Exchange Capacity of a less fertile soil both physically as a proportion of the soil due to its own negative charge, and over time as the biochar ages. Redox potential also increases, meaning the soil has better oxygen availability and is less likely to become anaerobic.

There are other instances where biochar mixtures have been applied to relatively fertile agricultural land and still had a beneficial impact. Often this can be associated with the liming potential of certain biochars. In Griffith, NSW, Russell Burnett and Frank, a Broccolini farmer, trialled a biochar and sea mineral extract on one of Frank's beds in 2016. In the first year, which was remembered as a particularly wet one, Frank estimated that he saw a yield increase of 15%, and still refers to the plot as the "biochar bed" as its one of his best.

Figure 6: The author and Broccolini farmer Frank in Griffith, NSW (Author's own)

However, there are also instances where the application of biochar has made little to no difference in the yield of a crop. Dr Donna Udall from the CAWR at Coventry University managed an Innovative Farmers trial where cattle were fed biochar, the manure collected and pot trials using ryegrass were conducted. There was no notable difference in the grass growth in the pots, however Dr Udall commented that this only highlights the complex interactions involved and that further research would be beneficial. Trials that have added raw biochar to reasonably good quality soils have found a negative impact in the first one or two years and the biochar adsorbs nutrients, with significant benefits only being shown in the long term. If you were to apply well-inoculated biochar to good quality land with higher-than-average soil organic matter and nutrient indices, then it is unlikely that you would see much of an economic benefit over applying a compost or manure in the short term.

In some of the long-term trials and especially the sites where Terra Preta has been found, there is evidence of a negative priming effect on the soil from the introduction of inoculated biochar. This stabilises the soil organic matter and according to Professor Annette Cowie from the University of New England "protects new organic matter through formation of micro aggregates". At sites in the Amazon rainforest this has led to the soil volume and soil organic matter increasing over time, further than just the original additions, with the extra volume being mined periodically as a commodity.

Rates of application tend to vary depending on the mixture of biochar and other components, but few trials have seen a benefit of applying more than ten percent of the volume of soil, with many showing results from smaller first applications. Depending on the feedstock and production, mineralisation of the majority of biochars is slow, sometimes very slow, with the official figure being set at 100 years, but evidence available of thousands. This means that a "slowly, slowly" approach to application is possible, building up to a more beneficial level over time. One way to do this is by utilising the already established practice of manure spreading, as discussed below.

5.3: Animals

One of the best ways to inoculate a biochar is using animals directly or indirectly. Adsorption of potentially wasted nutrients such as ammonia can bring benefits to the animal system as well as to the next use of the biochar.

Although several people I met on my travels mentioned anecdotal evidence of biochar use in animal bedding, I struggled to find many instances where it was being used commercially. Use in both cattle and poultry systems would appear to bring considerable benefits for emissions reductions and animal health. Mick and Darren Jones from Woodtek Engineering in Welshpool, UK, produce commercial biochar kilns, but also farm beef cattle. By adding biochar and woodchip fines to his indoor cattle bedding Mick is feeding what he calls his "microbial factory", where indoor ammonia is significantly reduced, and the resulting spreadable manure product has increased yield, growing season and quality and reduced pests and dependence on antibiotics. Soil tests on fields have shown triple-fold microbial levels on those with the biochar manure applied for the last three years.

Figure 7: FYM with biochar and woodchip fines from Mick Jones's cattle sheds (Author's own)

Charcoal has long been used as a sorbent for toxic compounds internally in humans and animals, but usually as a treatment rather than a preventative. Several studies have shown that feeding biochar as part of a regular diet can alleviate symptoms associated with poor quality feed such high levels of mycotoxins, and in many cases improve yield (weight and products), quality and overall herd health. Some have gone as far as to measure the levels of methane produced by cattle, with reductions of between 7-40%. Again, few farm scale trials have been undertaken, although several are currently underway. One potential concern of farmers and nutritionists mentioned was whether the high potential adsorbency of biochar could affect beneficial medicines. Kelpie Wilson, a founding board member of the USBI from Oregon says that this is likely the case, but that in theory by feeding biochar fewer antibiotics would need to be used, and that the level of adsorbency would only be high whilst the biochar was in the animal's system.

Figure 8: Oregon Biochar Solution's biochar mixed with crushed clinker is used as a landfill capping to limit emissions and adsorb contaminants (Author's own)

5.4: Beyond Agriculture

It is not just agriculture that the biochar production market is focussing on. Trials using biochar as an additive in road surfaces have found reduced rutting and offsets of environmentally damaging materials. Charcoal is already well-known as a water filter material, but more recently sewage sludge biochar has been shown to be a sorbent of PFAS (forever chemicals) in liquids such as landfill leachate. In Stockholm the local authority converts residents' garden waste, producing heat for a district heating network and biochar that is used in urban tree planting systems. Trees planted in this way have a much higher survival rate as the previously problematic road runoff water serves a valuable purpose watering the vegetation, with the biochar storing this water through drier periods. A leading carbon strategy research foundation, The Ithaka Institut, famously published the article "*The 55 Uses of Biochar*" to highlight some of the extraordinary research that has been conducted.

6: BIOCHAR PRODUCTION

As you can see from the definition of biochar, it is produced from organic materials heated in a low oxygen environment. This is usually in the process known as pyrolysis. In the conversion process, most of the volatile compounds in the feedstock are removed as a gas or a liquid, leaving a high carbon product behind. An example of this is a burning match, where the flame that surrounds the wooden match, or feedstock, shields the process from ambient oxygen in the air, leaving a stick of mainly carbon remaining. As the wood is heated, the volatile compounds are gasified and then combusted as they react with air, fuelling the pyrolysis process further.

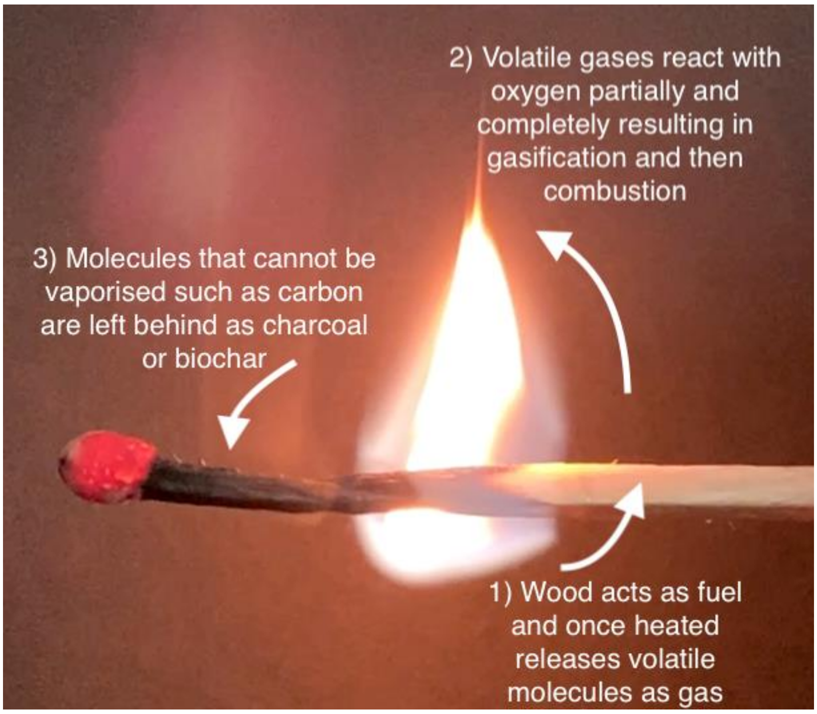


Figure 9: The thermal decomposition of a match showing pyrolysis, gasification and combustion (Author's own)

6.1: Technologies

Although the process is a relatively simple one, the production systems seen on my travels varied considerably with several factors governing the design.

1. **Scale and volume**
   Processing plants are available in the form of batch and continuous flow kilns, with batch machines producing between 10-200kg/day and costing from £0-£3000. Continuous technology is constantly evolving but on average could produce 1500kgs/day and cost between £800,000-£6,000,000.
2. **Feedstock**
   Moisture, handling and the potential for harmful emissions will dictate the kind of system that can be used.
3. **Location and mobility**

Centralised fixed plants can take advantage of heat and energy but will incur haulage of feedstock and/or biochar. Mobile kilns can be taken to the feedstock.

4. **End use of biochar**
   Certain properties such as consistent high temperature conversion or uniform particle size can only be achieved with certain processing plants. Fast and efficient trialling of different biochars may only be possible with a batch machine.
5. **Energy or heat capture**
   Heat exchangers and electricity production (except for some such as thermoelectric) are generally only suitable for fixed plant in a certain location such as near a district heating network.
6. **Collection of other pyrolysis products**
   Gas condensate (wood vinegar), tars, oils, syngas and even bio-methanol can be produced from pyrolysis if there are markets for them.

6.2: Feedstocks

One of the most important considerations for biochar use and production is “what is it made from?” Characteristics of the feedstock will be carried through into the biochar and influence any associated products. Traditionally this would have been hard or soft wood fibre, often as a byproduct of forestry or, as seen in countries such as the US, reducing wildfire fuel burden. However, biochar can be made from any organic material. Experiments have been conducted using bone char as a fertiliser and soil remediation agent as it is highly adsorbent and although it contains less fixed carbon than wood chars, does have higher levels of nutrients. Manures can also make an interesting product, with companies such as Onnu planning to convert 1.6million tonnes of poultry manure into farm-friendly biochar, reducing run-off from storage effluent, reducing the weight by 95%, sequestering carbon and utilising waste energy. The nitrate burden could become a nitrate benefit in the form of a more easily transportable nature-based fertiliser.

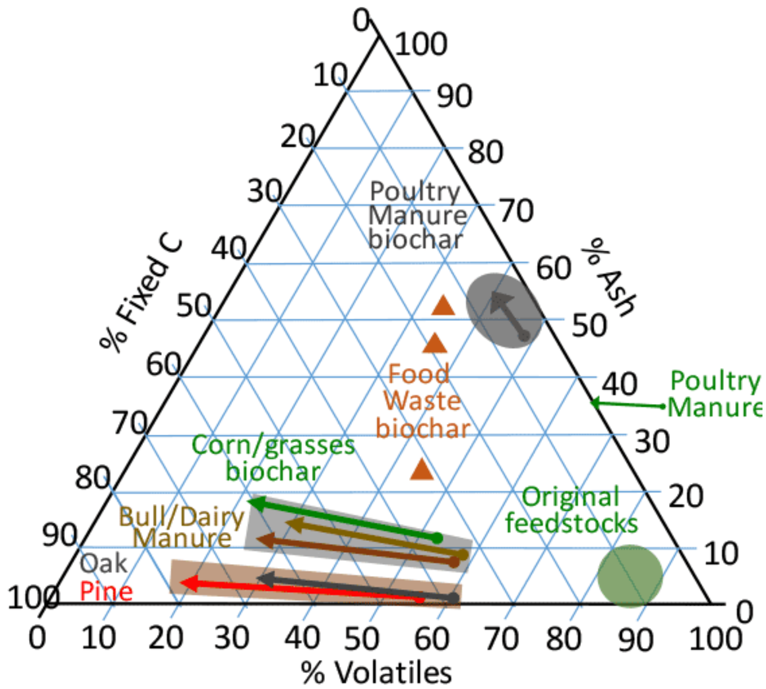


Figure 10: The relationship between feedstock and biochar constituents. "The Properties of Fresh and Aged Biochar" S Joseph, P Taylor, F Rezende, K Draper, A Cowie

As you can see from figure 10, different feedstocks can have very different post-pyrolysis compositions. This also provides the opportunity to tailor biochars to specific uses such as filtration or soil remediation.

The interest in producing biochar from sewage sludge is one of the fastest growing areas in the industry. This process does not produce the same value of waste thermal energy as others, and any heat or gas that is left from the pyrolysis reaction is often used to de-water the feedstock. The result is however that you can dramatically reduce the volume of waste to be transported and disposed of; sewage sludge biochar is free from pathogens and plastic, has some nutrient composition and does not leach. Heavy metals do still pose a problem, especially cadmium, as these are not removed at pyrolysis temperatures.

6.3: Scale of production

According to the EBI's latest European Biochar Market Report in 2023, 75,000 tonnes of biochar was produced in Europe, up 41% on 2022. This reflects the increase in mainly larger production projects, as much of the smaller scale production is not accounted for. This highlights a split that was evident throughout my travels, with little purposeful production on a medium scale due to inaccessibility of funding, carbon markets, biochar markets and machinery. Rowdy Yeatts from High Plains Biochar in Wyoming, US, has identified this and develops machinery that would be more suited to a large domestic or small commercial scale. Continuous flow biomass boilers have been available for many years and to design a system that fulfils this purpose whilst also producing biochar would seem to fit into a lot of agricultural scenarios such as poultry

Figure 11: Small scale production with Dale Redpath in Opotiki, NZ (Author's own)

Figure 12: Medium scale production with Rowdy Yeatts's RocketChar 301 continuous flow kiln in Laramie, Wyoming (Author's own)

production. Access to carbon credit markets at this scale is currently in development through Rowdy's Biochar Co-op and the UK Carbon Code of Conduct.

Figure 13: Large scale production with Pyrocal's commercial pilot plant in Toowoomba, QLD (Author's own)

While 75,000 tonnes may seem like a relatively high number for an emerging industry, if you consider that an application rate of 20t/ha would not be unreasonable, you can see how far production must go to fulfil a potential agricultural market. This brings about a "chicken and egg" problem, where the producers would like to sell biochar into the agricultural market, but biochar production is not currently at volumes large enough to create such a market to fuel more production.

Figure 14: Miles Pope's chicken manure, biochar and compost mixture, Auckland, NZ (Author's own)

Some of the largest producers of biochar globally are doing so by accident. High carbon boiler ash is a product of inefficient combustion found in many of the older biomass boilers that shares many of the same properties as purpose-made biochar, often with higher mineral contents. In New Zealand, Miles Pope has blended this with chicken manure and other soil conditioners to an extent that potato and onion farmers, ST Growers, have reduced their chemical fertiliser use by 40-50%. They now spread around 3000 tonnes of organic matter products a year, gradually building their soil carbon back to a sustainable level.

6.4: Quality and standards, Temperature and Time

"Not all biochar is created equal"

This was heard consistently throughout my travels. Some even go to the lengths of saying that the term biochar should be revised, as the definition is too broad and that it now applies to too wide a variety of products, and that consistency was rarely replicable.

With the rapid increase in production volumes of biochar there has also been a focus on quality assurance, and therefore standardisation schemes. Several now exist, specifying the parameters of carbon, metals, minerals and nutrients, as well as the Hydrogen to Carbon ratio. The H:C ratio can illustrate how pure the biochar is, with a higher hydrogen component meaning that the feedstock may not have been converted at the necessary temperature or for the adequate time. This becomes especially important for uses such as animal feed.

Temperature and time in the conversion process go hand in hand with feedstock to dictate the type of biochar produced. Usually, temperatures of at least 300°C are needed to begin pyrolysis, with anything up to 500°C considered low temperature, and up to 900°C high temperature. Higher temperatures produce higher carbon biochars and more crystalline structures that should be more permanent but are harder to attain and require more specialist machinery.

6.5: Energy

Pyrolysis is an exothermic reaction, meaning that it produces heat. In most systems this will be used to fuel the process, with only minimal sacrificial fuel in the form of feedstock, electricity or petroleum products needed to get the process to a point where moisture is driven off and the expelled volatile gases can be combusted.

In small scale systems any excess heat is released as it would be hard to capture. Medium scale plant may utilise heat exchangers, thermoelectric generation or perhaps more expensive organic Rankine cycle electricity generation. Large installations may take advantage of district heating networks or direct uses such as controlled environment agriculture.

7: THE ROLE OF CARBON

When biochar is produced, a proportion of the carbon in the feedstock is converted to a stable form that can persist for centuries or longer. This means that the process is seeing considerable interest regarding the carbon removal and storage potential of the technology. Take a coppice woodland, where the trees have been photosynthesising for several years and "fixing" CO_2 in the atmosphere into carbon, if this plant matter was undermanaged and left to decompose then the CO_2 would be released back into the atmosphere. If this material undergoes pyrolysis, then around 50% of the carbon will persist in the resulting biochar with the rest being consumed or emitted in the process as carbon monoxide, cardon dioxide and methane.

Figure 15: The boiler (left) at Katunga Fresh in Victoria, Australia, heats the glasshouses during the winter, and the ORC generators (right) produce electricity during the summer. Both will be fuelled from the excess gas of the pyrolysis system. (Author's own)

"Biochar is an exit from the carbon cycle"

The basic carbon equation of biochar is as follows:

1) A tonne of pure carbon is equivalent to 3.62t of CO2 (CO2e)
2) Biochar has a carbon content of between 40-95% (144.8-3.349t CO2e)
3) Once the lifecycle assessment (LCA) has been considered then the true carbon removal value of 1tonne of biochar can be calculated

Feedstock, production and end use will all play a part in the longevity and permanence of this carbon removal, as well as factors such as exhaust emissions, and should be accounted for in an LCA to realise the true carbon figure.

There are several biochar focussed companies now stating that they are aiming for gigatonne level carbon removal by 2050 or even earlier. To put that into context, the UK produced 14 million tonnes of wheat in 2023, a gigatonne is 1000 million tonnes, larger than the global wheat yield of 785 million tonnes for 22/23. Even if machinery and infrastructure developed to meet this production then a vast amount of feedstock would be required. This increase in demand for biomass could dramatically change the way that both biomass and eventually land itself are competed for, and potentially lead to leakage within the carbon credit system.

7.1: Carbon credits and offsetting

The more recent interest in biochar production has been fuelled by the push towards net zero carbon emissions and companies taking action towards their carbon responsibilities. The IPCC has stated that to limit global warming to below 2°C by 2100 then carbon drawdown and removal (CDR) plays a part in all scenarios. This should be as an offset for emissions that cannot be reduced further, rather than as an excuse to continue business as usual. Agriculture is one of the sectors that will be impossible to fully decarbonise. Of the seven land-based CDR options, biochar carbon removal accounted for around 90% of all those delivered in 22/23. The fact it is a physical product means that that is attractive when looking at the measurement, reporting and verification protocols associated with carbon removal certificates. Carbon offset and removal certificates (CORC's) also require an appropriate end use of the product, so in future there may be increased pressure on producers to ensure this is being upheld.

7.2: Additionality

Additionality has become a cornerstone of quality carbon credits. To ensure that carbon has been removed from the atmosphere, it is essential that the process or action is "additional" to what would have happened if the carbon credit did not exist. For example, this could be financial, in that the action would or would not have occurred without the payment of a carbon credit, or regulatory compliance, where policy or law states that it must happen irrespective of any payment. This could be particularly relevant to biochar. If benefits of the product itself outweighed the carbon removal aspect, then it would not be additional. For example, if spreading biochar in poultry housing reduces ammonia and therefore foot marking, improving the profitability of the enterprise then this may be more fiscally valuable than the carbon credit.

8: BIOCHAR OPPORTUNITIES

Currently if you wanted to purchase biochar in bulk for agricultural or horticultural application it would be hard to justify with cost: benefit analysis. Prices for hard or softwood biochar are similar throughout the world, on average at around £400/tonne or £100/m3. Following guidance on application rates this could make it unrealistic for a one-time application in many projects outside of trials and research. It is anticipated that prices will come down with the expansion in production and developments in technology, but there is also a likelihood that the cost of feedstock could increase. This may offer opportunities to farms or estates with biomass available. Marcel Huber from Syncraft, a biochar machinery producer in Austria suggested that feedstock prices could triple before 2030. This will be more evident in Europe, where biomass is more limited than in countries such as the US or NZ.

Figure 16: Hawkes Bay in NZ was inundated with forestry residues in the last typhoon. Now saline, these are little use for anything, but biochar production in-forest could help with future issues. (Author's own)

Other changes could also influence this volatile market. The price range of carbon credits is significant, with biochar CORC's trading for between $100-$500/t CO2e, and financial additionality will have to be proven for these. In California, the Sitos Group has installed a biochar plant at ReGen Monterey, a landfill and compost site where they take the oversize screenings from compost production, mill them and convert them before mixing back into the compost. California has all but banned open burning of any kind, so grubbed vineyards must now be disposed of another way. The state will also shortly ban landfill of household organic waste. Steve McIntyre, who is on the board of the Sitos Group, runs Monterey Pacific, a vineyard contractor with 16000 acres of vines under management, and has been trialling the biochar compost mixture under new vine plantings for several years. Steve and Doug Beck, the lead agronomist at Monterey Pacific described how with the application, both grape yield and quality improved, as well as vine vigour and soil health on their 0.7% organic matter sandy soil. The application paid for itself in year one with a 2t/acre yield increase.

8.1: Integration

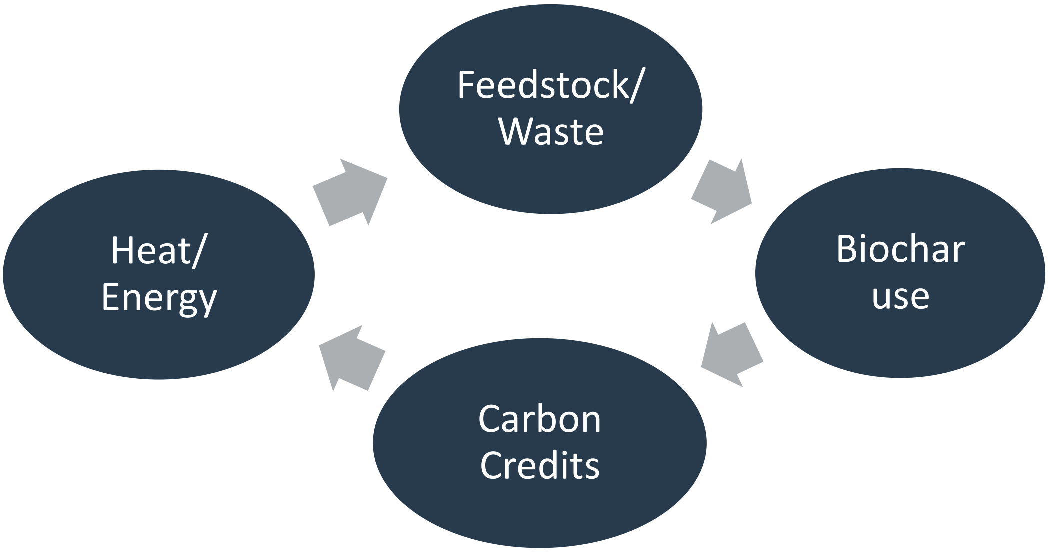


Figure 17: Key factors to consider for biochar projects to be economically and environmentally beneficial (Author's own)

With high prices and a long investment period there are certain situations that will benefit more from biochar. One thing heard repeatedly was that you need four things to fall into place for a system to work the best environmentally and economically: access to a feedstock, preferably a waste, an end use or uses for the biochar, the ability to market carbon credits and a requirement for heat or electricity.

8.2: Farm Emissions

Agriculture is increasingly coming under the spotlight for its emissions globally. Nearly half of NZ's GHG emissions come from livestock, and the previous government had progressed plans to introduce a pricing system on agricultural emissions that was only recently thrown out. The new government intends to put more funding towards finding solutions and technologies that reduce emissions.

Biochar, as a nature-based solution, ticks many of the boxes when it comes to reducing emissions. Not only is it a physical carbon store, but goes on to increase sequestration in its use, whether as a methane-reducing feed, capturing nutrients before they become pollution, reducing non-CO2 emissions from soil by 12-50% or producing more from the same resources.

9: DISCUSSION

Wherever I have travelled it has been clear that biochar in its use and production can bring both environmental and economic benefits. However, it is also clear that the economic benefits are far more dependent on individual scenarios, with an emphasis on the integration of the four key factors mentioned in figure 17 influencing any project. There are currently issues surrounding these that need to be addressed if farm-based production or widespread use is ever to happen. The Environment Agency classes biochar as a low-risk waste, as it is often made from a waste, and therefore has outlined protocols around its use (LRWP 61). Only ten tonnes are allowed to be stored at any one time, and only 1 tonne should be spread per hectare. This protocol is from 2012 and more is now understood about the characteristics and interactions of biochar. Several biochar producers I met also commented that there was a focus on other land-based CDR methods such as Direct Air Carbon Capture and Storage (DACCS) and Biomass to Energy with Carbon Capture and Storage (BECCS) which are currently expensive and can be energy intensive or allowing business as usual.

Whilst the environmental benefits outweigh the economic benefits there are questions to be raised over the funding of any projects. Some farmers I spoke to were strong believers that "if carbon came from the farm, then it should stay on the farm" which is especially appropriate when considering that both the feedstock and product of biochar are produced and often used on farm. Currently the carbon trading system is favourable towards the biochar producer, as they are the ones who are stabilising the carbon, but some farmers believed they should be entitled to some of the payment. Could there be more financial income from sequestering emissions in the future? It would certainly fall under the category of a public good, but it may be just as likely that emission reductions could be imposed via a tax or regulatory burden. There is certainly a point here that on-farm biochar production could be an interesting prospect in the future. Biomass boilers were commonplace on farms and estates whilst incentives were available, so perhaps carbon credits or carbon in-setting for the business could replace that incentive, with the beneficial product of biochar also being produced.

There are other benefits of biochar use that are harder to quantify. In the animal feed trials that have been conducted, even those that showed no positive result, there was often anecdotal evidence that herd "happiness" increased with biochar as a feed additive.

10: CONCLUSIONS

I have been fascinated to meet and visit such a wide range of people and businesses on my Nuffield scholarship. There are quite a few different motivations surrounding the biochar industry but out of all of them one came across the strongest; "*we need to utilise carbon drawdown and removal to reach net zero, and biochar is a shovel ready solution*".

- The biochar industry is in its infancy but with global focus on reducing emissions and reaching net zero it is set to grow considerably within the next decade.
- Interest in different uses of biochar is also growing as more industries focus on their green credentials, but agriculture and specifically soil addition will play the major part in the short to medium term.
- With the correct feedstock, production and inoculation, biochar can have an impressive impact on poorer quality soils, with yield increases of 10-42%.
- Other areas of agriculture and horticulture such as animal feed and bedding, tree and vine planting and water and waste management could all benefit directly from the production and use of biochar.
- Currently there are only a few systems where the economics of biochar use alone stack up, but with a potential fall in prices and focus on emissions this could change.
- On-farm biochar production could work economically and environmentally if the individual scenario is fulfils the right criteria.

11. RECOMMENDATIONS

From my research and these conclusions I have the following recommendations:

- Further field or farm scale research should be conducted into biochar use in various agricultural systems such as poultry bedding, animal feed, biochar as a hydro or aquaponics substrate and water filtration material
- The current carbon credit removal certificate methodologies should incorporate small and medium scale production alongside their industrial counterparts. This could be in the form of agglomeration to satisfy larger requirements or keeping carbon local and insetting related or nearby small business.
- A biochar association should be formed in the UK to provide a cohesive voice for standards, guidance and policy.
- A guide aimed at those using biochar at a farm level should be developed alongside DEFRA so that clear and consistent messages can be followed with the opportunity to provide feedback on results.

Figure 18: Biochar is constantly at work at Kelpie Wilson's home in Oregon, US (Author's own)

Thanks and Acknowledgements

Nuffield Farming Scholarships Trust provides an outstanding opportunity for those with a passion for a subject to explore and interrogate ideas and publish their results to an engaged and innovative community. I would like to thank everybody at NFST for giving me the opportunity to delve into this slightly less mainstream topic.

My most sincere thanks must go to my sponsors, Alan and Anne Beckett, for their unwavering support of the less "tried and tested". Sadly, Alan passed away before this report was written, but his and Anne's legacy of the Beckett scholar group shows the level of generosity, curiosity and fellowship that can inspire us all. Thanks to all those in the Beckett Group, and particularly to Steven Watkins and Doug and Pauline Harkin for making me feel a part of this great bunch of innovators.

During three and a half months of travel I was lucky enough to meet some amazing people. The biochar industry is filled with entrepreneurs, risk-takers, educators, innovators and even some agitators, but all have a common goal in bringing about positive environmental change. Thank you to all that gave up their time, experience, expertise and occasional spare bed.

Thank you to my wife, Helen, and children, India and Ava for encouraging me make the most of this opportunity, putting up with my biochar talk and keeping our business running even through the tough times.

Glossary and Abbreviations

BECCS- Biomass to Energy with Carbon Capture and Storage

CAWR- Centre for Agroecology, Water and Resilience, Coventry University

CDR- Carbon Drawdown and Removal

CEC- Cation Exchange Capacity

CORC- Carbon Offset and Removal Certificate

DACCS- Direct Air Capture with Carbon Storage

DPI- Department of Primary Industries, Australia

EBI- European Biochar Industry Consortium

GHG- Greenhouse Gas

IPCC- Intergovernmental Panel on Climate Change

LCA- Lifecycle Assessment

NSW- New South Wales, Australia

PAH- Polycyclic Aromatic Hydrocarbons

PFAS- Perfluoroalkyl and Polyfluoroalkyl Substances

USFS- United States Forestry Service

TNC- The Nature Conservancy

Appendix 1 - Carbon Calculation

Carbon Account for Nuffield Scholarship

Trip	CO2e	Biochar equivalent
Vancouver	2.4t	
Europe	1.5t	
US	2.53t	
IBI Symposium	0.08t	
New Zealand and Australia	5.95t	
Belfast	0.39t	
	12.85t	4.28t

Carbon Accounting for Nuffield Study Tour

Once you have identified your intended study tour visits it is possible to calculate the carbon emissions associated with your travel.

1) Calculate overland mileage associated with each visit

For any overland sections of travel you can use a widely available website such as google maps to calculate the mileage of each leg. This works for road, rail and bus travel.

2) Calculate flight mileage or use pre-determined figures

Some flight booking programs will provide you with the exact CO2 equivalent emissions of your flight. It would be preferable to use these as flight emissions vary with aircraft and carrier.

You can also use an estimated number provided for you by one of the many free carbon calculators available online. For example www.carbonfootprint.com. These will often have to option to input your departure and arrival point and work out the average emissions for a flight of that distance.

3) Calculate any other carbon sources

Although travel is the main cause of emissions, any other extraordinary parts of your study tour can also be calculated. For example considerable stays in hotels. Any regular activity that you would take part in in your life outside Nuffield doesn't need to be counted, for example phones and food. Putting a figure on these sources is subjective, however many carbon calculators will have an option for these.

4) Use a carbon calculator to work out total emissions

For example www.carbonfootprint.com is free and has plenty of options. Input your mileage, flights (where applicable) and extras and your carbon emissions in the widely recognised form of CO2 equivalent are calculated.

This is a useful tool to compare different modes of transport and can highlight areas where it may be possible to reduce emissions. Even relatively small changes such as hiring a slightly smaller car can have an impact.

Offsetting emissions

It is important to note that not all Carbon offsets are created equal, and unless verifiable for many years to come can in fact be worthless. Opt-in type schemes where you can check a box to offset travel should be checked before going ahead.

Afforestation projects and carbon reduction credits are examples of projects which have come under scrutiny for not delivering on the carbon sequestration figures initially provided or not proving additional to existing practices.

Biochar is an example of a stable carbon offset if the sequestration is additional. Biochar sequesters carbon that has been initially turned into biomass through photosynthesis, and when pyrolysed around half of this carbon is turned into a stable, recalcitrant form. When this is used for any other purpose except as a fuel it is considered sequestered for at least 100 years if not a lot more.

One tonne of 100% carbon is equivalent to 3.67 tonnes of CO_2. Most biochar is around 85% carbon when the hardwood feedstock is slowly pyrolysed at over 500 degrees Celsius. Once lifecycle assessments have been made, this figure can be anywhere from 2.2 to 3.1 tonnes CO_2 equivalent. For the purposes of this calculation the figure of 3 tonnes CO_2e has been used as the wood is very local and the biochar has not been transported.

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