Biochar for climate change: Is it a viable strategy?

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- Biochar acts as a way to make use of grown biomass sources (such as bioenergy crops) as well as waste biomass sources (including crop and animal residues)
- Biochar preserves more carbon content than other biomass processing techniques and as such has potential to act as a good carbon store
- Climate-positive effects linked to biochar use can be unreliable, application-specific and potentially damaging if biochar is used non-strategically

Introduction

Many believe the future of agriculture is in finding innovative ways to combine on-farm benefits, such as boosting crop yields or livestock productivity, whilst also reducing or reversing negative environmental impacts. To this extent, the recent 2020 "Agriculture Bill" highlights subsidies available for farmers who act to protect the environment and reduce environmental impacts. Biochar has been noted as a possible route towards achieving such goals both within the agricultural sector and further afield. The benefits associated with biochar are potentially numerous but can be highly varied based on both the original biomass/feedstock source and the methods used in its creation. Essentially biochar is a carbon-rich organic product similar to charcoal made via specific heating/burning of biomass in a low oxygen environment. The concept of biochar is linked to the discovery of dark earth soils within the Amazon region (where biomass burning practices occurred in farming over thousands of years) where increased crop fertility in these areas was observed. Whilst initially considered a way to increase growth, following their discovery in the 1500s, later research demonstrated that these soils also successfully store and sequester carbon, storing ~2.7 x more carbon than traditional soils. Biochar can be made from various biomass sources including woody and herbaceous plant materials (biochar with higher carbon content and soil stability), agricultural by-products such as manures (biochar richer in nutrients, lower in carbon and higher in salinity and risk of forming toxic compounds), food wastes and industrial wastes, with sources providing differing biochar characteristics. The biochar method of production also affects its composition, with methods including; pyrolysis (which can be slow or fast and performed at cooler or higher temperatures), gasification and hydrothermal carbonisation. These combined elements of biochar variability make studying and using biochar complicated. The main benefits of biochar can be seen in their incorporation into soil management where they have been suggested to affect soil physical and chemical makeup, soil biota, water infiltration and retention, nutrient retention, pH, N efficiency and have roles in the remediation of polluted soils. The effectiveness of biochar is significantly impacted by the soil starting conditions, local climate and method of application to the soils which they are applied, but can potentially be long-term in effect due to decomposition times ranging between 100-1000 years. Currently, there has been growing interest in the application of biochar as a negative emission technology (NET), with NETs being involved in sequestering (removing) carbon dioxide (CO_2) from the air and being a good tool in reducing the effects of climate change.

Beneficial climate effects

The main benefit of biochar is that it utilises biomass in a way where carbon is locked-in and stored compared to outright combustion (slash and burn), natural decomposition and other waste management options which involve the release of CO_2 and other greenhouse gasses (GHGs) into the atmosphere. Biochar has been indicated to retain up to 50% of its initial carbon content compared to 3% in traditional burning and 10 – 20 % via decomposition. Recently, it was noted that biochar production and use as a soil additive was predicted to act to reverse CO_2 emissions and that it could lead to maximum global net reductions of 1.67 tonnes of CO_2 equivalent emissions per tonne of feedstock used, with this reduction being based on a combination of the direct and indirect beneficial effects discussed below. It was also noted that biochar produced from woody biomass tended to give higher emission reductions due to containing higher energy which can be captured towards counterbalancing production emissions produced when heating/burning the biomass to make biochar. Other studies which have looked at utilising biomass sources sustainably without impacting habitats, soils or food security through the negative growth of biomass (which involves biomass being grown despite the land having more sustainable uses for crops or livestock) suggest biochar could offset 12% of the human produced CO_2 equivalent emissions per year. This would occur through a combination of storing more carbon in soils, producing usable energy during burning and avoiding the methane (CH_4) and nitrous oxide (N_2O) emissions given off if the same biomass was to decompose normally or be burnt. Whilst this was only demonstrated to be 2% higher than the 10% reductions possible on using the same biomass sources, as direct bioenergy products via burning, the other less direct benefits of biochar production as soil amendments in low fertility soils could further boost their viability (see indirect benefits). Other direct climate effects apparent with biochar soil addition includes the reduction of N_2O emissions from soils, with data suggesting 38% reductions are possible due to the promotion of soil bacterial breakdown of N to N_2 instead of N_2O (though these reductions are only seen for a year after application). As well as this in a recent study looking at the atmospheric CO_2 removal levels needed to maintaining global warming below 1.5 °C, biochar production from forest and crop residues and its use in soils was noted to have the potential to account for 10% of these required CO_2 reductions via both direct and indirect benefits. Furthermore, the study noted if extra crops were grown specifically for biochar production as well as these residue biomass' being used, the produced biochar could increase CO_2 reductions to cover up to 15-35% of the 1.5°C CO_2 reductions needed.

Indirect climate benefits

During the production processes of biochar two bioenergy products are also produced in the form of syngas and bio-oil. The relative fractions of each of these is dependent on the production methods (temperature, method of heating etc). In certain instances, the energy available from the syngas produced can act to self-sustain the biochar formation reducing fossil fuel inputs or it can be used in turbines to directly produce electricity. Bio-oil has the potential to be used as a further carbon deposit that has been shown to increase carbon sequestration up to 1.7 x when combined with biochar or act as an independent carbon store if pumped into geological formations. Bio-oil requires refining before it can be utilised as a direct energy source reducing any potential GHG emission reductions, however, it can function as a temporary carbon store through its incorporation into resins, adhesives, asphalt, slow-release fertilisers or pesticides for example. Similarly to bio-oil-based geological sequestration, there have also been recent models suggesting the positive climate impacts of storing biochar underground in unused mines where it can act as storage and potentially a future energy supply.

Generally, biochar soil applications tend to act to reduce the need for fertilisers through a variety of mechanisms including acting as a liming agent. The decrease in nitrogen leaching (up to 13% in certain conditions) and an increase in nitrogen uptake efficiency, demonstrated by crops following biochar addition, have multiple indirect climate benefits. Benefits include the reduction of free nitrogen for conversion to N_2O and reduction of fertiliser requirement, the production of which itself acts to emit GHGs. Furthermore, certain types of biochar (mostly manure-based) can act as long term slow-release phosphate fertilisers and could act to recycle what is a finite and dwindling resource. Other manure-based biochar mixes could act as high nutrient/low-leaching horticulture products giving an increased monetary value to livestock farmer's waste products whilst reducing climate-related leaching effects at the same time. Biochar acts well in this slow release role due to its composition allowing strong sorption and binding of several compounds and also gives it further functionality in the recycling and recovering of otherwise wasted resources in applications such as human/animal waste treatment. Biochar has even been suggested for incorporation into landfill covering strategies as it can oxidise methane reducing its GHG impacts. Similarly, it has been suggested to have potential effects in reducing methane impacts on incorporation into animal feed in ruminants. Finally, an indirect application of biochar on climate change could be seen in its potential to replace peat moss as a horticultural substrate as it duplicates many of the desired properties whilst having reduced GHG emission impacts compared to CO_2, CH_4 and N_2O emissions associated with the disturbance of natural peatlands.

Limitations and detrimental climate effects

Despite biochar's discussed benefits, there are several caveats and potential negative co-effects to be considered in any future applications. Whilst biochar tends to stabilise and improve soil physical properties with roles in preventing erosion, this is often soil specific with the incorrect application leading to increased wind erosion effects. Black carbon is a particulate with human and environmentally toxic effects that can be produced during

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biochar production, on an incorrect application of biochar to soils black carbon can be transported via wind erosion and is linked to both global warming impacts and lung and heart disease risks, though currently little research has been performed relating to biochar black carbon impacts. Sequestration of pesticides and insecticides is also known to occur with biochar application due to the high sorption nature. Whilst this can have beneficial roles in reducing leaching of chemicals it could also act to reduce their general effectiveness leading to over applications and increased crop losses associated with soil-borne pathogens and other pest impacts. There are further complications surrounding biochar through its effect on decreasing albedo (resulting in increased levels of solar energy being absorbed leading to warming effects) in some instances this can assist in crop seed germination (due to warmer soils) whilst other instances suggest that the increased warming can reduce any biochar climate benefits by 13-30%. Converting waste biomass to biochar stores increased carbon, however, it also requires an input of energy to be produced, depending on the scenario involved this energy input could act to negate the biochar carbon storage gains. A meta-analysis study found that the supply chain aspect and pyrolysis production of biochar could emit up to 1.04 tonnes of CO_2 equivalent emissions per tonne of feedstock. Whilst this was outweighed by the overall benefits in the study it has repeatedly been noted, across various studies, that in regions with high carbon intensity energy systems (countries reliant on coal etc) that combustion of biomass (as a bioenergy source) rather than conversion to biochar leads to larger emissions savings making biochar less attractive. This balance of CO_2 equivalent emissions and energy utilisation is a further limitation of biochar when comparing to other NETs such as “bioenergy with carbon capture and storage” (BECCS). BECCS tend to utilise the same biomass sources and potential lands available for growth as biochar, with BECCS demonstrating higher negative emission potential due to higher energy outputs in current UK assessments. In a recent study in Sweden, utilising biochar in a district heating plant, the importance of the availability of a market for the biochar produced was highlighted as essential for biochar energy production to be economically feasible. This may further affect the uptake of biochars compared to bioenergy crops where this consideration is not required.

Feasibility and future considerations?

Conflicting data and lack of long-term study across surrounding biochar effects make any LCA (the prediction based analysis tool used in most studies to assess biochar climate impacts) give relatively tentative results. Where comparisons of several LCA studies are combined climate benefits trends start to emerge, however, benefits connected with biochar soil applications are further confused by studies finding no benefits or even negative effects. Future considerations are needed to truly understand biochar application effects and model these before researchers could provide individuals with simple figures of a biochar's climate change impacts. This is largely due to previously mentioned biochar variability based on; starting biomass material, biochar production characteristics and interactions depending on the environmental soil conditions. This variability could, however, offer the ability to tailor a biochar to a specific soil to perform specific tasks but would require huge amounts of research to do so, reducing practicality for wide scale application. On searching the literature over 700 studies were found relating to "biochar" and "carbon sequestration" in the last five years alone, suggesting high interest in this area and a likelihood for rapid developments in the near future.

Summary

Interest in biochar application in soils as a negative emission technology is increasing rapidly. Currently, the majority of biochar data available is experimental or relies on predictions with few long-term on-farm studies performed to support potential benefits. Generally, the data suggests that biochar production and application could act positively towards mitigating GHG emissions globally, through a combination of direct carbon sequestration and other indirect

GHG emission reduction effects. However, infrastructure for the processing of biomass into biochar is currently limited and other NET strategies may actually be more beneficial. Where farm level biochar processing is concerned suggestions are that the impacts of this on reducing emissions, in the UK specifically, would be low, therefore it is unlikely to act efficiently as an on-farm technique. However, the benefits of biochar addition on agricultural lands are key in realising any benefit between the emission equivalent costs of producing biochar (in off-farm processing plants) compared to simply burning biomass. Furthermore, the mitigation effects of biochar can be lost if unstructured land-use changes occur which increase the growth of biomass feedstocks without careful consideration. Far greater information is required on the highly variable nature of biochar characteristics (based on starting material and production processing) and its interaction with differing soil conditions before more trust can be placed in utilising it as a climate mitigation tool or even as a soil amendment tool for farmers, unless a case by case analysis is performed first. Currently, there is a more secure understanding of the benefits of the utilisation of farming land toward bioenergy crops (when taking into account carbon land-use factors) and their ability to reduce climate impacts when grown strategically.