BIOCHAR

Understanding the massive global potential for biochar to simultaneously reduce atmospheric CO_2 and regenerate soil

A climate restoration whitepaper

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Climate warming and degradation of soils

Anthropogenic emissions of carbon dioxide (CO_2) are causing an unprecedented change to the earth's natural systems. The burning of fossil fuels coupled with increased, and increasingly unsustainable, agriculture and associated deforestation has caused a combination of rising global temperatures, ocean acidification and a global degradation of soils on an unprecedented scale.

It is estimated that modern agriculture has caused the release of approximately 110 to 220 billion tonnes (Gt) of CO_2 since 1850[i]. This equates to between 30 and 60 Gt of carbon. Of the approximately 130 Gt of carbon that has been released over the last 12,000 years most has been released within the last 200 years (refer to Figure 2).

The atmospheric concentration of CO_2 reached 415 ppm in 2019 and continues to rise (1H2020). This equates to approximately 800 Gt of carbon or 3,000 Gt of CO_2. If we were to reduce this all the way back to the estimated pre-industrial level of 280 ppm then we would require a total reduction of about 260 Gt leaving a pre-industrial 540 Gt of carbon in the atmosphere.

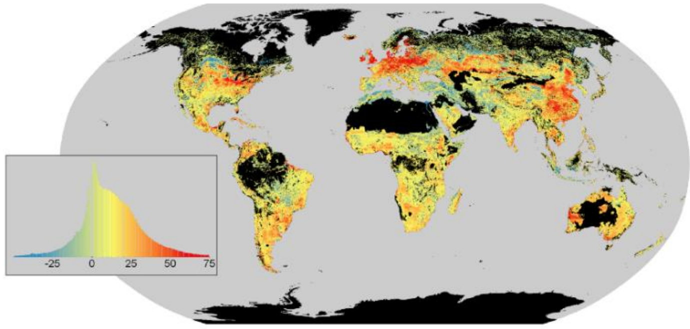


Figure 1 - Global Soil Organic Carbon (SOC) change in the top 2m. The legend is a histogram of SOC loss (tonnes C)[1]

Most countries are still not making enough progress towards achieving their Paris Climate Change Agreement targets[ii]. This means that we have done little to diverge from "business as usual" which the IPCC terms the 'Representative Concentration Pathway 8.5' or RCP 8.5 [iii]. Figure 3 below shows the current rising trajectory of atmospheric CO_2 concentration. Rapid removal of CO_2 from the atmosphere is clearly necessary to minimise the well documented damage that is occurring due to excess CO_2 in the atmosphere.

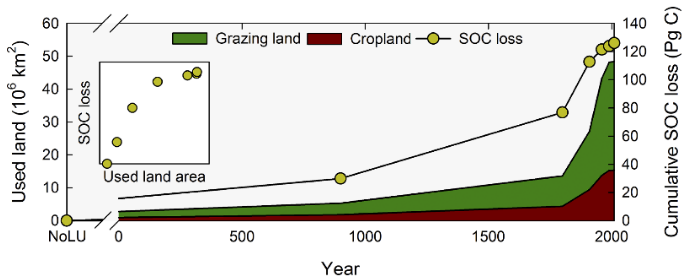


Figure 2 - Soil Organic Carbon losses since 10,000 BCE [1]

Interestingly, without human intervention, the world is very slowly removing CO_2 from the atmosphere through a number of natural carbon sequestration processes, including by mineralisation and the creation of new plant mass. On a geological timescale these processes will naturally return the natural CO_2 balance to the world. Unfortunately, that is too slow for mankind.

This paper addresses the acceleration of carbon sequestration through the restoration of degraded soils, achieved by recreating a global, multi-billion tonne store of carbon within those soils, resulting in a reversal of the soil damage and an enhancement of the productivity of the remediated agricultural lands.

"Fertiliser leaching has serious environmental and economic repercussions. When fertilising crops, keeping precise timing and regulating nutrient levels are critical for plant health. High levels can "burn" crops, while low levels mean that crops will struggle to grow, and repeated applications of low levels of fertiliser can be laborious. In addition to the loss of resources and reduced crop yields, excess runoff from nitrogen and phosphorus fertilisers can pollute surface water and groundwater, especially in high rainfall areas."

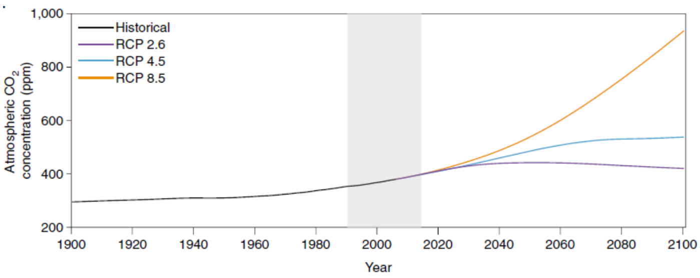


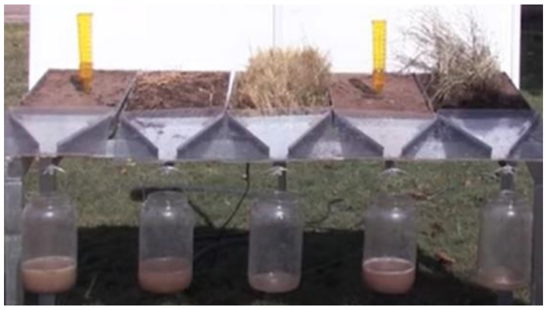
Figure 3. Projections of atmospheric CO_2 for RCPs 2.6, 4.5 and 8.5. RCP 2.6 most closely estimates the emissions required to meet the Paris Climate Change Agreement targets [6]

Impacts of **soil degradation**

The impact of soil degradation is far-reaching. The effects of this have been observed in the physical and chemical conditions not only in affected soils but also in the environment downstream of the land. These are far-reaching and diverse. Soil degradation is initiated through intensive agriculture, particularly monoculture, which draws nutrients out of soils to grow the crops but traditionally without replenishing these nutrients correctly. The use of synthetic fertilisers to replenish nutrients often has an adverse impact on the soil biota, causing massive loss of the subsurface species which work symbiotically with plants to help them grow strong and healthily.

There are many species living in healthy soils[iv] including micro-organisms (bacteria, fungi, archaea and algae), soil animals (protozoa, nematodes, mites, springtails, spiders, insects, and earthworms) and plants living all or part of their lives in or on the soil. Larger animals feed on this soil life and make up the food chain for predators. Killing the soil causes a long tail of destruction down the food chain.

Dead soils do not hold water. Heavy machinery makes this worse through compaction, and both tilling and periods of no crop cover between harvesting and replanting can accelerate soil run off graphically demonstrated in a USNIFA video[v].



It has been estimated that 75 Gt/y of soil[vi] is eroded from arable lands worldwide. The inability of soil to hold water reduces drought resistance of crops in arid areas, and in areas with heavy rainfall water often flows straight off the land without any retention either causing or exacerbating flooding downstream. The water runoff takes a layer of soil with it which contributes to the silting up of rivers and estuaries and also removes some of the expensive fertilisers[vii] which may have been applied to overcome the lack of nutrients – forming a vicious circle as yet more fertilisers are added. This process can cause eutrophication and dead zones in rivers and the coastal regions into which they discharge.

Dead soils do not help crops to grow strong, and ever more pesticides are required to help fight off disease – something which is far less prevalent in plants grown in healthy, living soils.

A related problematic activity is the burning of agricultural biomass to ash. Although it captures various minerals it can generate significant smoke and haze (China has banned the burning of rice straw to reduce the negative effects of the smoke), and there is also the risk of fires spreading to adjacent fields and forests.

It doesn't have to be this way. Already many farmers have discovered the benefits of various soil restoring practices and are reversing carbon loss. However, many more including the industrial-scale operations (which will continue to be required in helping deliver the world's food supply), are still using carbon releasing practices and have not yet adopted tools to restore soil health.

One solution that is almost universally applicable is the use of biochar as both a soil enhancer and carbon sink.

Adding biochar **as a cure to enhance soils**

> *"Biochar first came into broad public awareness through the example of the Amazon, where the hypothesis is that Amazonian inhabitants added biochar along with other organic and household wastes over centuries to modify the surface soil horizon into a highly productive and fertile soil called Terra Preta, which is in direct contrast to the typical weathered Oxisol soils in close proximity. Biochar is exciting to many people because of its role in such soil-building processes. Those who have used biochar for several years may obtain tangible positive results, but they may not have solid concepts and theories about how it works. Biochar is a heterogeneous and chemically complex material and its actions in soil are difficult to tease apart and explain mechanistically." viii*

Biochar can provide a cascade of ecological, social, and agricultural benefits on the way to the soil. These can include water cleaning, nutrient and pollutant capture, greenhouse gas mitigation and animal welfare benefits. When biochar arrives in the soil many of these services continue along with improving soil health, significant and measurable stable carbon sequestration and potentially increasing labile carbon storage.

Biochar is a porous carbon formed by pyrolysing[ix] biomass. A high percentage of biomass comprises molecules containing carbon, including glucose, cellulose, and lignin. If this biomass is heated in a very low oxygen environment it reduces to a solid that retains all the minerals and around half the original carbon. The other half of the carbon is driven off as volatile organic components (VOCs). Some of these VOCs can be condensed into useful liquids, and the remainder can be burned to provide the energy to carry out the pyrolysis.

The most common method used to convert biomass into a suitable, useful nutrient is composting. This process retains the minerals, and the end product has its own valuable properties. However typically in composting at least 90% of the carbon is eventually lost to the atmosphere as CO_2. Furthermore, there is always the risk that the decomposition occurs in a low oxygen environment whereby methane can be created in place of CO_2 which has a far greater warming effect on the environment.

Note that biochar is not a replacement for compost or other fertilisers – instead, it should be used in conjunction with them.

From an agricultural and local land management perspective biochar is a soil improver, with a great many positive benefits for land management and almost no negative effects, as follows:

- Biochar is a neutralising agent and can improve acidic soils through regular application.
- Biochar is highly porous and so helps to absorb water, and any nutrients dissolved in the water, as well as releasing water slowly. This water retention characteristic also reduces soil and fertiliser runoff during heavy rain, and it improves crop drought resistance.
- Biochar improves the nutrient use efficiency of fertilisers, both synthetic and organic, and can therefore significantly reduce fertiliser application.
- Biochar's high porosity provides a home for the many diverse biota, increasing the concentrations of biota which helps raises nutrient levels and strengthen crop pest resistance.
- Biochar is a very long-term, stable solid store for carbon which can also reduce greenhouse gas emissions.

Biochar can be made at moderate cost either by small farmers in simple batch kilns, or industrially in continuous flow process using a variety of methods including rotary kilns, augers, multi-hearths, gasifiers, and other established technologies.

Adding biochar **as a cure to store carbon**

Plants take in carbon dioxide from the atmosphere and through photosynthesis they convert the CO_2 into new sugars, cellulose, and lignin, etc. to allow the plant to grow. This is the source of carbon that is used to create biochar. Importantly, in 2018 the IPCC recognised biochar as an important negative emissions technology[x].

The large deposits of biochar (Terra Preta) discovered in the Amazon basin are estimated to be more than 3,000 years old, and adding biochar made from biomass to soils today will create a new very long-term, stable store of carbon in solid form.

It is important to note that biochar should not be used as a fuel if it is to form a long-term carbon store.

A small proportion of carbon is naturally stored in soils during the decomposition process. We can accelerate this natural absorption pathway of soils and convert various carbon-negative and extractive agricultural practices into significantly carbon-positive, carbon storing processes (i.e. carbon dioxide reducing).

This is achieved by using the biomass already generated by the agricultural activities to make biochar. This works both at the smallest scale in batch processes for the smallest farms, and at industrial scale for the largest plantations.

Biochar has **global scalability**

There is more than enough land

The earth has a surface area of 510 million km^2, of which around 149 million km^2 is land. 30% or about 48 million km^2 is used today for agriculture, either grazing or cultivation.

The amount of biochar that is typically applied to land ranges between 1 and 15 tonnes/hectare (t/ha). There several precision agriculture projects applying up to 50 t/ha. The rate is only limited by the economics of production & supply and sustainable biomass resources. To put this into perspective, 10 tonnes of biochar spread evenly on each hectare of land would form a layer only 3 mm deep.

All agricultural land could accept some biochar. If we assume that we were to apply biochar to 30% of the agricultural land, or 16 million km^2, at a rate of 5 tonnes of carbon/hectare then we would sequester around 8 Gt/y of carbon, or the equivalent of 29 Gt/y of CO_2. By comparison we are currently emitting 40 Gt/y of CO_2 from human activities.

Whilst there are significant margins of uncertainty in the calculated figures, what these calculations certainly demonstrate is that the potential opportunity for land to sequester carbon is vast, and it is at the right scale to help reduce the atmospheric concentration of CO_2, if utilised. The calculations above assume a moderate application of biochar to only a third of all agricultural land and takes no account of the major deserts which could also accept huge quantities of biochar.

The limitation of this process to sequester carbon is not land, but the availability of biochar, sustainable sourced biomass, and its acceptance and adoption by the agricultural community.

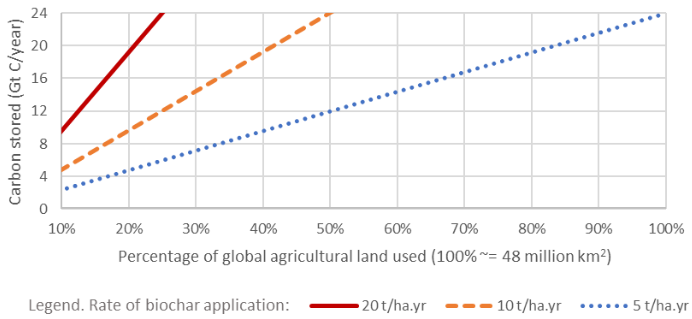


Figure 4 - Potential for storing carbon in soils

***Agricultural and forestry biomass** for making biochar*

The commercial agricultural and forestry industries are substantial. In all cases the commercially valuable part of the crop represents only a proportion of the overall crop mass – there remains a significant amount of biomass. Examples of biomass: harvesting grains creates straws and husk; timber harvesting produces biomass from branches, bark, and sawdust; and the fruit juice industry creates peels and every few years trees may be replanted. Some of this biomass also has value – some straw is used in raising livestock for example, but much of the biomass is either composted or burned. In both cases most of the carbon is then returned to the atmosphere as CO_2.

The global production of the top ten staple foods, including maize, rice[xi], wheat[xii], potatoes, etc. is about 3.4 Gt/y[xiii], and the timber industry produces about 5.7 Gt/y[xiv] totalling 9.1 Gt/y. We anticipate that a biomass equal to at least 20% of the product weights could be used to make biochar, i.e. 1.8 Gt/y. This could yield up to 0.5 Gt/y of biochar, and we anticipate the maximum potential to be much higher.

There is also huge additional potential from fast growing perennials such as bamboo and napier grass not accounted for in the above numbers.

Accelerating the uptake of biochar

There is a huge knowledge base about biochar, with established methods equipment for the production and application of biochar to enhance soils and improve crops. However, despite this knowledge biochar production is still not at a scale to significantly impact the level of atmospheric CO_2.

There is the potential to expand production massively. However, this needs a coordinated process of marketing; education of potential buyers (particularly at plantation scale); and the provision of capital to establish large scale production units, with local distribution networks; and there is a need for CO_2 emitters to buy carbon-negative offsets as a means of providing the capital to support a whole new global biochar industry.

Conclusions

Mitigation strategies aimed at reducing the amount of CO_2 emitted into the atmosphere are not yet showing any significant signs of success. Even in a best-case scenario where nations were implementing much more rapid changes emissions reduction alone will not be enough to prevent the atmospheric and oceanic CO_2 concentrations from reaching catastrophic levels.

CO_2 removal techniques will be necessary to actively reduce the amount of CO_2 in the atmosphere. Scaling up biochar production is one approach which can be applied to accelerate the natural rate of atmospheric CO_2 uptake in soils.

The amount of biochar that land can accept is more than can be made - the limiting factor in how much carbon can be sequestered using biochar is the amount of biochar which we are able to sustainably produce.

There is sufficient organic biomass from existing agricultural activities to be able to produce biochar at a rate equivalent to capturing at least 0.5 Gt/y of CO_2 (and possibly much more), which is the same order of magnitude as the 0.8 Gt of CO_2 emitted by the shipping industry.

Storing carbon equivalent to 0.5 Gt/y of CO_2 will not solve the entire problem of excess atmospheric CO_2 alone, but it would make a noticeable difference, and when considered in conjunction with the long list of on-the-ground improvements for agricultural business and the neighbouring environment, the case for action now is compelling.

Biochar is an affordable, and highly mutually beneficial method to store carbon that is available today.

Industrial scale support is required now.

About the **Authors**

Jerry Joynson is a former oil industry chemical engineer and co-founder of Herculean Climate Solutions.

Jerry, together with HCS co-founder Steve Willis, is seeking to help implement effective, massively scalable solutions to rapidly reduce the level of atmospheric CO_2.

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Trevor has been focused on promoting the benefits of biomass and since 1998 and of biochar since 2009.

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[vii] https://www.cleanearth.tech/agriculture/

[viii] How biochar works in soil: https://www.biochar-journal.org/en/ct/32

[ix] Pyrolysis is the thermal decomposition of materials at elevated temperatures in an inert atmosphere and involves a change of chemical composition. In general, pyrolysis of organic substances produces a range of volatile products and leaves a solid residue enriched in carbon, called char. Extreme pyrolysis, which leaves mostly carbon as the residue, is called carbonization. https://en.wikipedia.org/wiki/Pyrolysis

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