Biochar by design

S. Abiven, M. W. I. Schmidt and J. Lehmann

Biochar has been heralded as a solution to a number of agricultural and environmental ills. To get the most benefit from its application, environmental and social circumstances should both be considered.

Biochar, a type of charcoal that is generated by heating organic matter under oxygen-limited conditions, has been hailed for the potential benefits it can bring to agriculture, the environment and climate. Biochar additions are thought to increase nutrient and water retention in soils, and thereby help to improve crop yields. It can also promote the recycling of organic waste and the remediation of soil contaminants. Importantly, from a climate perspective, biochar is very persistent in the environment, and so its application to soils can remove carbon dioxide from the atmosphere for long periods of time. Finally the production of biochar also generates biofuels, including bio-oil and syngas.

Not only does biochar have the potential to remedy a whole host of problems, it should also be cheap to make. However, biochar is not as universally beneficial as often assumed, and the outcomes of its application can vary widely depending on the agricultural and climatic circumstances. Here, we argue that rather than thinking of biochar as a one-size-fits-all soil enhancer, we need to focus on developing tailor-made biochar systems for individual applications that take into account soil type, climate and social setting.

Yields, carbon and context

Biochar applications affect crop yields and soil organic carbon levels in highly variable ways. The application of biochar to soils can boost crop yields by up to 60% or diminish yields by up to 30%, mainly depending on the type of soil to which it is applied[1]. The poorer the soil quality — that is, the lower the organic matter content and nutrient retention capacity — the greater the likelihood that biochar additions stimulate crop yields[2]. In addition, at a given location, the application of different types of biochar can lead to very different responses[3]: some types of biochar can increase crop production by over 100%, and others can reduce it by a similar amount.

Biochar represents a highly persistent form of carbon compared to uncharred plant material. As such, its addition to soils generally bolsters long-term soil carbon stocks[4]. Nevertheless, estimates of the mean residence time of biochar in soils vary from centuries to millennia, depending on the type of biochar applied, the environmental context (particularly climate and soil type), and even the experimental and analytical approaches employed. For instance, environmental conditions are generally kept constant and optimal for the microbial decay of biochar in laboratory experiments, whereas other factors, such as the influence of local plants, can contribute to the response seen in the field[5].

Even in settings and management regimes where biochar additions can make a difference to agricultural yields and carbon sequestration (Fig. 1), the socio-economic setting will determine the extent to which these rewards can be reaped. Socio-economic factors influence, among other things, the availability of biochar feedstocks, access to the technology needed to create the biochar, and investment capacity. So far, only a handful of studies have examined the costs associated with setting up biochar-based agricultural systems[6], owing to the scarcity of mature business cases. Economic analyses of a minimum but globally important set of case studies could yield insight into the feasibility of establishing biochar systems elsewhere.

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Figure 1 | Smouldering sugar cane in Kenya. Sugar cane bagasse residues are discarded and burnt as a waste removal strategy in western Kenya. These residues could instead be used as feedstock for biochar and thereby mitigate emissions from in-field burning.

Lessons learnt

The deficit in our understanding of the benefits that biochar can bring to crop yields and carbon storage stems in part from spatial and temporal constraints in the experimental set-ups used to study its effects. Much of what we know about crop yield responses to biochar additions arises from field experiments with at most 4 to 5 years of data, or from necessarily short-term glasshouse experiments. And most of our understanding of biochar turnover times stems from short-term laboratory incubations of only a few years. Long-term data on the turnover of substances comparable to some types of biochar do exist, most notably in the form of charcoal-rich soils in the Amazon Basin, termed terra preta, that have persisted for centuries to millennia. However, the applicability of these findings to other types of biochar remains uncertain.

What has become clear is that the environmental benefits can only be achieved in systems where organic waste management, the production of biofuels and the agronomic use of the biochar product are considered simultaneously. Biochar systems are likely to be successful in places where soils would benefit from biochar additions to improve water and nutrient retention, where organic wastes are easily accessible (and not diverted to other forms of waste utilization), and where economic conditions are favourable.

Tailored treatments

To make headway with this potentially promising tool, the global biochar research and development community should focus on a limited number of the most environmentally and economically promising biochar-based agricultural systems. In terms of readily available and environmentally beneficial types of biochar, that derived from poultry manure holds promise; the pyrolysis of poultry manure heats houses, offsets fossil fuel use, and generates a nutrient-rich form of biochar that can be transported out of agricultural regions that are already laden with excess nutrients. Once the most promising types of biochar and agricultural and socio-economic setting have been identified, a series of standardized field trials should be run across ecological and climatic gradients.

Ultimately, biochar should be made to target the objective in hand. For instance, to improve soil fertility, and so agricultural yields, a mean biochar residence time just three times that of the original biomass is sufficient. For carbon markets, a mean residence time in excess of a hundred years is more than sufficient to realize most of the carbon sequestration value[7]. And for a reduction in atmospheric carbon dioxide levels over geological timescales, a mean residence time of several hundred years to a few millennia is needed[4].

The application of biochar in Western agriculture dates back to the mid-nineteenth century[8], but may extend back even further back in time. By refining the research focus and developing targeted commercial platforms, biochar additions may continue to bolster agricultural yields and deliver environmental and climatic benefits in our time. ❐

S. Abiven[1], M. W. I. Schmidt[1] and J. Lehmann[2] are at [1]Soil Science and Biogeochemistry, Department of Geography, University of Zurich, 8057 Zurich, Switzerland, and [2]The Atkinson Center for a Sustainable Future, Department of Crop and Soil Sciences, Cornell University, Ithaca, New York 14853, USA.*
**e-mail: samuel.abiven@geo.uzh.ch*

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