SOIL (LEFT), BIOCHAR-AMENDED SOIL (MIDDLE) AND BIOCHAR (RIGHT).

PHOTO: C.C. CHENG

BIOCHAR FOR SOIL RECLAMATION, AND MORE!

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Al Gore, Tim Flannery, Bill McKibben, and James Hanson agree: biochar is a promising tool for tackling climate change. Recently, the potential usefulness of biochar in soil reclamation and carbon sequestration has begun to generate a great deal of interest, and some recognize that if reclamation is carried out properly with sustainable biomass, then mine soil can be used as a potential sink for CO_2 (Shrestha and Lal, 2009). The addition of biochar to reclaimed soils not only sequesters carbon, but has the potential to improve soil quality and other key physical and chemical conditions necessary for successful revegetation.

Biochar is charcoal made from biomass by "baking" it with low or no oxygen (pyrolysis), with the specific intention of applying it to soil. Once in the soil, biochar is highly resistant to microbial degradation, and remains for much longer periods of time than the original biomass it was made from, thus producing carbon sequestration that potentially contributes to reductions in atmospheric greenhouse gas levels. The biomass used to make biochar should be sustainably obtained from existing waste streams such as crop residues in agriculture and the food industry, process waste materials such as biosolids, materials from solid waste streams, residues from saw mills, and pulp and sludge from paper production. Biochar can be obtained as a by-product of producing energy from such biomass sources.

Biochar production systems are currently being designed at a variety of scales, from cook stoves used in Africa and now Haiti, to gasifiers for heating barns or greenhouses, to large industrial waste management pyrolysis plants. The International Biochar Initiative (IBI) states that biochar technology should be sustainable on a cradle-to-grave basis. Waste biomass that currently does not have any other use is a logical first choice for feedstock. Sometimes such waste streams even entail tipping fees and/or represent economic and environmental burdens. Good examples are farm animal manures and yard and wood waste, in certain locations. Often, biomass waste is left to decompose, and the carbon it contains returns to the atmosphere as CO_2. Burning waste makes this process occur a lot faster. If such waste biomass is used to make biochar, the carbon can be "locked up" while energy is produced. The pyrolytic process used in creating biochar also produces beneficial by-products such as heat, syngas, and oils that can be captured and used. This is illustrated in the following diagram.

However, biochar represents much more than a carbon-rich material that can be buried in the soil, sequestering carbon for hundreds to thousands of years. Recent research has shown that soil-applied biochar improves crop yields in agricultural settings, and the material shows several properties that could make it a beneficial soil amendment in land reclamation projects. These properties include sorption of a variety of soil chemicals and impacts on soil water retention.

PLANTS GROW BETTER WITH BIOCHAR

Compensating for nutrient deficiency is a typical challenge in reclaiming degraded sites. To spur and sustain plant growth over time requires fertilization and subsequent nitrogen fixation by legumes. The addition of soil amendments such as biosolids, compost, manure, mulch, lime, or ash can increase macro- or micronutrients, affect pH, reduce erosion, and improve soil water-holding capacity to stimulate biomass growth and subsequent carbon sequestration. The beneficial properties of biochar witnessed in agricultural trials provide results that are clearly applicable to reclaiming degraded sites.

Much of the work on biochar has been carried out in tropical soils, which are acidic and very poor in nutrients, not unlike some active and abandoned mine-site soils. Although biochar is not a fertilizer itself, the application of this material to soil has been shown to improve crop yields and soil fertility, often through increasing soil pH (i.e. it has a liming

Biochar Research

Institutions currently involved in biochar research (this list is not necessarily exhaustive):

NSERC Strategic grant: McGill University in collaboration with the University of Western Ontario, the University of Saskatchewan, and the University of Waterloo: production and soil testing of biochar effect on crop growth.

University of Toronto: biochar application in forest environments.

Queens University and Fleming College's Centre for Alternative Wastewater Treatment (Lindsay, ON): Biochar for use in soil reclamation and wetlands.

Blue Leaf Inc. (Drummondville, QC): commercial scale agricultural field testing of biochar.

Saskatchewan Research Council: production and use of biochar from livestock and agriculture residues.

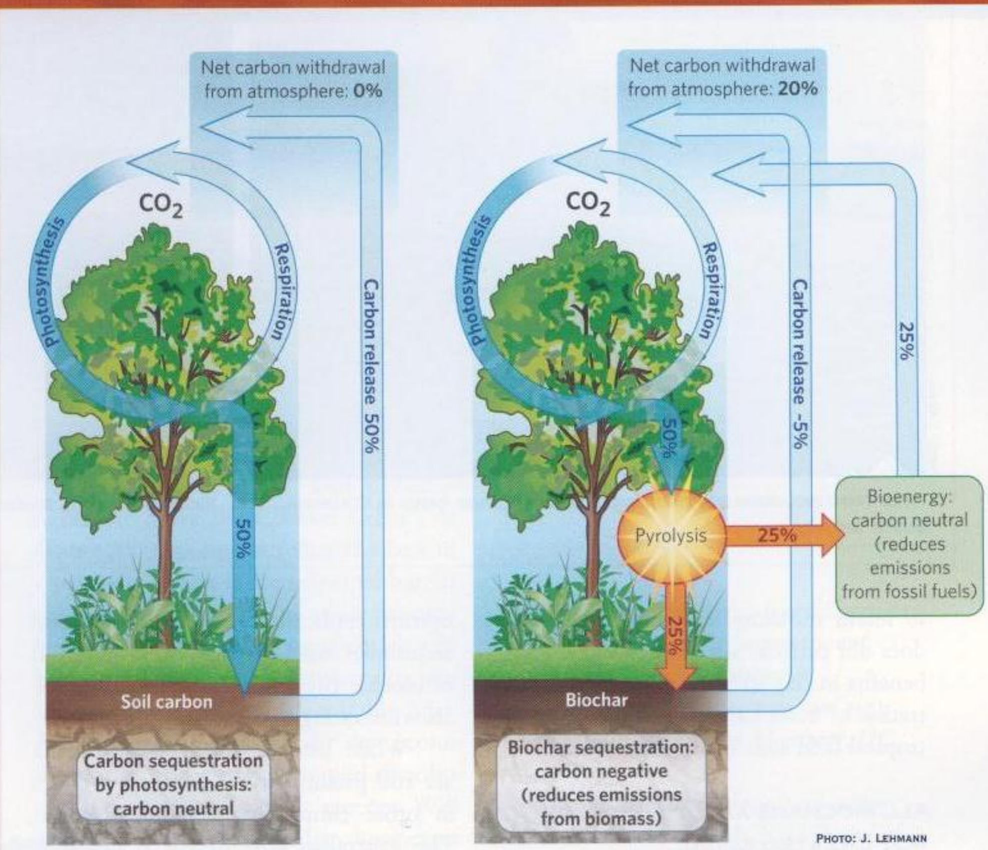

Photo: J. Lehmann

Biochar has been termed as potentially "carbon-negative", since part of the carbon in biomass feedstocks is transformed into a stable material which remains in soil on the long term, while improving soil such that more atmospheric CO_2 is fixed by better growing plants.

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effect), and thus produces greater nutrient availability. Biochar has also been shown to reduce nutrient (including nitrogen) leaching in poor tropical soils, most likely due to greater nutrient retention. In agricultural fields that have become saturated with phosphorus due to the over application of manure, there is interest in testing whether applying biochar could help reduce runoff and leaching of phosphorus. Similarly, some pot studies have shown that the use of biochar can improve nitrogen-use efficiency. All of these applications point to the potential for using biochar to improve revegetation of reclaimed sites while reducing the movement of soil-applied nutrients into water bodies.

Since biochar surfaces gradually become weathered, or "activated", after its addition to soil, the beneficial effects on crop growth have been observed over several years after single applications. Perhaps the most striking example of the durability of biochar effects on soil fertility is the *terra preta* soils of the Amazon. These are soils enriched with charcoal and nutrients which still remain highly fertile hundreds to thousands of years after they were formed. Other potential, under-studied beneficial effects of biochar include the promotion of favorable microbial interactions. Biochar has been shown to favor biological nitrogen fixation and root colonization by mycorrhizal fungi, but its effects on soil biota in general are not yet well known. The reclamation of existing and abandoned mine sites, and other post-industrial landscapes, can provide useful laboratories for testing physical, chemical, and financial aspects of introducing biochar to nutrient-poor soil environments.

Biochar is a precursor to activated carbon

Activated carbon is a highly efficient sorbent for a variety of organic and inorganic molecules. In tests where biochar was compared to activated carbon for its ability to sorb agrochemicals (mostly herbicides) and heavy metals, it performed similarly in many cases, and sorbed more of these chemicals than un-charred organic matter or "resident" soil organic matter. Biochar can also sorb polycyclic aromatic hydrocarbons (PAH) and other allelochemicals that inhibit seed germination; for example, just think of boreal forest species that require fire (and thus the production of charcoal) in order to germinate and colonize soil. It has also been hypothesized that the sorption by biochar of compounds that are inhibitory to soil bacteria may impact nitrogen cycling in the soil. Although results from projects where biochar has been applied to soils undergoing reclamation have yet to be reported, it will be useful to find out if biochar can "inactivate" harmful soil chemicals and thus promote plant establishment.

Water retention by biochar

Sustainable land reclamation efforts aim to re-establish the capability of the land to capture and retain fundamental resources, such as soil water retention, which is essential to life. Biochar is generally highly porous, has very low bulk density and has been shown to improve water holding capacity in sandy soils. It may prove to help with water retention in degraded or incipient soil with low clay and organic matter contents, thus facilitating plant establishment and survival. Heavier textured soils are better suited

Photo: J. Major

Field trial including different biochar application rates in Colombia, South America.

Photo: B. Husk

Incorporation of biochar to soil for a field trial in Québec.

to retain moisture, and biochar usually does not provide any moisture retention benefits in clay soils. Greater surface infiltration of water has also been observed in tropical field soils with added biochar.

All biochars are not created equal

There is a pressing need to establish a testing and classification system for biochar, since its characteristics can vary widely, depending on how it is made and what it is made from. The IBI currently hosts a workgroup to tackle these questions. However, in order to really determine the most important characteristics of biochar, a wide variety of materials will need to be field tested. The characteristics of ideal biochar for each reclamation project will likely differ; hence, the concept of "designer biochar", or biochar materials produced to maximize benefits in specific soils and soil management systems.

Biochar projects

In terms of economic feasibility, it will be desirable to have a waste stream suitable for pyrolyzing that is located near the biochar application site. If the heat or fuel generated during pyrolysis can be used on site, it will be even better. Reclamation projects could make use of small-scale, mobile, pyrolysis units, which are being developed in several countries. Field studies where biochar is used in land reclamation projects should ideally provide data on all potential value streams of biochar, including waste management, energy production, soil improvement, and soil carbon sequestration. Also, many practical aspects of biochar use remain to be determined, such as optimal application rates and application techniques. Seed coatings, or the addition of biochar to hydroseeding mixtures, are also interesting approaches to be tested.

While biochar projects in Canada are still preliminary, policy and projects in other countries are more advanced. The Australian government is investing in projects in New South Wales aimed at assessing biochar by field testing carbon sequestration in soil and benefits to soil health. The Richmond Landcare group, also based in New South Wales, is hoping to invest $AUS 12 million in a production unit to create biochar from green waste. In the United States (US), provisions were made for biochar in the Carbon Offset Bill introduced to the Senate in November 2009. Passage of this bill will provide support for biochar projects to qualify for carbon offsets, as well as research and development funding for the US Department of Agriculture to implement biochar production and utilization projects. Projects designed to enhance carbon sequestration in reclamation soils are also underway in US academic research institutes and agencies such as Ohio State University and West Virginia University, national laboratories such as Oak Ridge National Laboratory, Pacific Northwest National Laboratory, and Los Alamos National Laboratory, and non-governmental organizations (NGOs) such as The Nature Conservancy.

Biochar in Canadian reclamation

Degraded lands, such as abandoned mine sites, typically have altered soil profiles and severe reductions or losses of soil organic carbon. When original topsoil is saved, stored, and reused in reclamation, subsequent revegetation results in the accretion of soil organic carbon to the restoration of the mine site ecosystem (Shrestha and Lal, 2009). Reclamation projects that restore sites to undisturbed natural landscapes with sustainable biomass, essentially contribute to carbon sequestration. The net balance of carbon input (plant litter) depends upon the levels of carbon loss (decomposition); therefore, carbon storage gains require increasing the amount of carbon entering the soil as plant residue. The introduction of biochar can be a useful tool to augment this process.

Biochar added to topsoil storage piles to mitigate the loss of nutrients, and later during the reapplication of topsoil in final reclamation phases, should increase soil carbon levels far above decomposition rates, thus potentially increasing sequestration as well as soil enrichment; however, this still has to be tested. Nevertheless, an opportunity exists for the reclamation community to advance biochar research within projects across the country. In some aspects, transitions from agriculture to revegetation schemes on mine sites or brownfields appear to be seamless; however, more field work in controlled experimentation is needed to observe how biochar types derived from different biomass sources will function in reclaimed soil environments.

Looking ahead

As a soil amendment tool in land reclamation biochar has promise. Finding suitable organic waste materials as feedstock for the creation of biochar might require establishing creative partnerships with local communities and groups, such as community colleges, agricultural research agencies, recyclers, composters, farmers, foresters, and solid waste handlers. Reclaimed derelict sites could be re-dedicated to sustainably growing feedstock for biochar production. An additional dimension for reclamation projects is the potential for carbon sequestration and offsetting. The Chicago Climate Exchange, in partnership with other organizations and agencies, is developing a protocol to trade credits of carbon sequestered in reclaimed mine soils (Shrestha and Lal, 2009). Even without biochar, trading of carbon credits can provide incentives for mine owners to adopt management systems which increase carbon sequestration in reclaimed soils.

Biochar is rapidly gaining interest in Canada; several regional groups have been formed in addition to the *Canadian Biochar Initiative*. Research projects are underway at several Canadian universities, and some Canadian companies are developing pyrolysis technology. Awareness of biochar amongst our policy makers remains low, but it is expected that increased interest in this material and reported results from field studies could help to change that. The feedstock derived from various waste streams is available, and the technology to manufacture biochar is known, including the capture and reuse of syngas and oil by-products. Research and development and subsequent marketing of "designer" biochar is wide open for enterprising individuals or firms.

In his recent book, "Our Choice – A Plan to Solve the Climate Crisis", Al Gore (2009) points out that the lack of a price on carbon is the principal barrier to capitalizing on the promise biochar holds for providing an inexpensive and highly effective way to sequester carbon in soil. When, and not if, a stable price for carbon is established, the economies of biochar production and distribution will quickly emerge. Will Canadian businesses associated with land reclamation be ready? ■

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