Getting Back to the Garden

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DANNY DAY AND BOB HAWKINS

Growing levels of anthropogenic carbon dioxide (CO_2) emissions and related global warming are challenging the world to find new sources of energy that do not contribute to the increase in atmospheric greenhouse gases. Ideally, such sources would be renewable and sustainable, which implies that they should not be based on fossil fuels. In principle, biomass can meet these requirements, and thus is gaining popularity as a fuel source. It is sometimes considered to be carbon neutral, because the carbon emitted as CO_2 during combustion came from the atmosphere by way of photosynthesis, but that calculation should take into account a complete cycle, which means that biomass equal to the amount harvested must be regrown.

There is already an urgent need to intensify agricultural production to secure food supplies for the world's increasing population, and using biomass for fuel will require a further boost in agricultural production. Yet intensive agriculture may deplete soil minerals and other nutrients, thereby jeopardizing the future production of biomass. So although biomass is renewable, it is not necessarily sustainable.

Eprida is developing an energy-efficient method of converting agricultural waste biomass into hydrogen and char, a product that returns nutrients and minerals to soil. Our plant can process 25 kilograms (kg) of biomass per hour. Used in a closed-loop cycle, the process, a hybrid of pyrolysis and steam-X (X = oxygen, hydrogen, or CO_2, depending on feedstock) gasification, can boost biomass production beyond currently attainable levels, and so sequester carbon from the atmosphere. The hydrogen is generated in a mixture known as syngas, which can be used to produce electricity, purified to run a hydrogen fuel cell, or converted into substitutes for products now made from fossil fuels, such as Fischer-Tropsch diesel, methanol, and dimethylether.

The uniquely designed char can be used directly as a soil amendment. Alternatively, it can be combined with water, ammonia, and CO_2, as well as with sulfur and nitrogen oxides found in the exhaust emitted from coal-fired power plants, to form fertilizer; in this reaction, the pollutants are converted into ammonium bicarbonate, ammonium sulfate, and ammonium nitrate. These compounds are created and stored in the char, thus producing a slow-release nitrogen fertilizer we call ECOSS (enriched carbon, organic slow-release sequestering). If only CO_2 is removed from the gas stream, ECOSS is a mixture of 56.4 percent ammonium bicarbonate and 43.6 percent charcoal. One hundred kg of biomass yield 73.4 kg ECOSS and 8.35 kg of hydrogen.

We believe ECOSS has significant potential for use in a net carbon-negative fuel cycle, in part because some of the world's most productive agricultural soils contain elemental carbon. For example, in the chernozems (black soils) of Europe's northern steppes, as much as 45 percent of the soil organic matter (SOM) consists of black carbon. This carbon originated from vegetation fires and is several millennia old—up to 4000 radiocarbon years older than bulk SOM.

The use of charcoal as a soil amendment is an ancient practice. Indigenous peoples of the Amazon were using charcoal to enrich their soil more than 1000 years ago. Since then, however, this technology has been lost or forgotten. Charcoal-based fertilizer has now reemerged as a possible solution to major problems facing agriculture and energy production. The renewed interest was significantly spurred by the efforts of the late Wim Sombroek, who championed research on a Brazilian soil termed *terra preta*. This soil, named for its black color, is the most fertile soil in the Amazon. *Terra preta* soils were produced by a pre-Colombian civilization, and have been carbon-dated to between 80 BC and AD 1540. Phosphorus and calcium are normally scarce in the very acidic oxisols and utisols predominant in the Amazon basin, but *terra preta* contains extraordinarily high levels of these elements and has an almost neutral pH.

A distinctive feature of *terra preta* is the refractory nature of its SOM. In hot, wet climates, organic residues and SOM usually decompose quickly, and cultivation accelerates that decay. In contrast, *terra preta* soils are rich in SOM. Charcoal is believed to be responsible for its extreme persistence: recent research has shown that the *terra preta* soils' cation exchange capacity (a measure of nutrient retention capability) correlates linearly with the organic carbon content of the soils.

Before the introduction of mineral fertilizers, SOM was the main source of plant nutrients. It appears that loss of SOM, which liberates nutrients and CO_2, is the leading cause of soil degradation. Without continuous fertilization, nutrient-poor Amazonian upland soils show no potential for agriculture beyond the three-year life span of the forest litter mat. The persistent SOM resulting from the addition of charcoal improves soil's water infiltration, water holding capacity, structural stability, cation exchange capacity, and biological activity, while serving as a CO_2 sink.

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Although the subject is not completely understood, research seems to confirm that application of charcoal can greatly improve soil quality and thereby boost crop production. Charcoal is not merely elemental carbon: it contains polyaromatic backbone molecules and may have nanometer-sized pores that can affect chemical reactions.

One of the biggest effects of charcoal is that it reduces available aluminum and acidity. Because charcoal increases soil retention of water and nitrogen, runoff is reduced and nitrogen is prevented from leaching into groundwater and surface water. Most charcoal also contains significant amounts of potassium, itself a fertilizer, and phosphorus, calcium, and magnesium. These amendments stimulate symbiotic microbes such as mycorrhizal fungi, filamentous fungi, and actinomycetes, and generally support a more active microbial community.

The effects of charcoal on the biological, chemical, and physical properties of soil are undoubtedly complex, but the incontestable sustained fertility of *terra preta,* as well as its historic use in Japan and its current use in many other countries, is a strong incentive to study its effects. In some instances, glomalin, a substance secreted by arbuscular mycorrhizal fungi, and charcoal play an important role in creating long-lasting soil aggregates. The stability of charcoal with microbial interaction allows it to promote and create microenvironments in which SOM and dissolved organic matter are converted into stable humic matter. Tiny granules of charcoal thus may act something like ocean reefs—they provide a substrate around which organic material and life-forms can coalesce. Charcoal has other beneficial characteristics: it can reduce fertilizer runoff, it is an adsorbent for soil-damaging herbicides and pesticides, it neutralizes the natural toxins in decomposing organic materials, and it removes a germination-inhibiting chemical from seed surfaces.

Any new farming technique should be optimized for the local ecology and for local needs before it is implemented. We need to know much more about what happens when a charcoal-based fertilizer is placed in the ground, on both small and large scales, and impacts need to be quantified when charcoal is used in conjunction with other agricultural practices and systems. Eprida's tests indicate that the addition of char to soil can indeed increase essential nutrients and help to maintain the optimal pH for plant growth. The level of these benefits is determined in part by the nature of the biomass starting material and by the charring conditions. In one series of tests, the surface acid concentration of the char product reached a maximum when the process was run at a fairly cool 400° Celsius, and this resulted in maximum ammonia adsorption during the manufacture of ECOSS. In other situations, different conditions may be preferable.

Our research continues, but indications so far are that our process not only removes substantial amounts of carbon from the atmosphere but also does it in a way that is financially and environmentally sustainable—even before any carbon sequestration credits are counted. The time seems ripe for large-scale demonstration projects.

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"I can't see the forest for the trees, Henderson. Have the trees cut down."