Carbon Storage with Benefits

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joy of finding new facts or overturning old ones is no longer transmitted to students.

As well, clinical departments have expanded geometrically as medical schools compete with private hospitals by amassing huge clinical programs. The few scientifically oriented faculty in clinical departments have been diluted to irrelevance by pure clinicians. No wonder that few medical students are choosing to follow paths in basic research.

The research emphasis of NIH has gradually shifted. The primary focus is no longer on acquisition of knowledge in basic biological mechanisms. Current emphasis on "translational research" relegates basic science to a back burner. What has been lost is the conviction that progress in medicine rests ultimately on a fundamental understanding of physiology. Individual curiosity-driven science has been replaced by large consortia dedicated to the proposition that gathering vast amounts of correlative data will somehow provide the answer to life's fundamental questions.

Is it likely that the best and brightest medical students can be funneled into settings where they can reinforce each other and be inspired by brilliant mentors? If it were to happen, it would require NIH to support teaching and research at a concentrated depth in the basic sciences to open the eyes of medical school graduates to the joy of scientific study.

There is a lesson from this golden era of NIH: Ambitious young physicians juxtaposed to cutting-edge basic scientists can themselves make fundamental discoveries. Hopefully, this lesson will help to reconfigure the future.

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AGRICULTURE

Carbon Storage with Benefits

Biochar—a material related to charcoal—has the potential to benefit farming as well as mitigate climate change.

Saran P. Sohi

Biochar is the solid, carbon-rich product of heating biomass with the exclusion of air (pyrolysis or "charring"). If added to soil on a large scale, biochar has the potential to both benefit global agriculture and mitigate climate change. It could also provide an income stream from carbon abatement for farmers worldwide. However, biochar properties are far from uniform, and biochar production technologies are still maturing. Research is beginning to point the way toward a targeted application of biochar to soils that maximizes its benefits.

Biochar variation. The diverse properties of biochar have led to widely varying results. A more systematic understanding is now emerging, helping to define its value in crop production and carbon storage.

Incentives for using biomass to mitigate climate change currently focus on replacing fossil fuels in combustion. Biochar production seeks a different route to carbon abatement. By stabilizing carbon that has already been captured by plants from the atmosphere into a form resembling charcoal, it can prevent the carbon from degrading and returning to the air. A key attraction of biochar is that it can enhance the fertility and resilience of crop land. If biochar production could be made profitable through its use in agriculture, this would distinguish it from costly geoengineering measures to mitigate climate change.

At least one-third of net plant growth globally is thought to be now managed by humans (1). Diverting a few percent of this growth into biochar production could sustainably expand biosphere carbon stocks by a gigatonne [10^9 metric tons (t)] each year (2). In contrast, the addition of fresh or composted plant material would have a small effect on carbon storage: Only around 10% of the carbon becomes stabilized (3) and after reequilibration, higher levels of organic inputs to the soil are matched by more decomposition. Conversion of biomass to biochar through pyrolysis creates a product that is highly resistant to biological attack. The finite capacity of soils to store decomposing organic matter therefore does not apply to biochar. Exactly how long biochar remains stable in the soil is still not completely resolved, however.

Calculations show that cleanly creating biochar from diffuse, seasonal sources of biomass such as rice husk should provide a clear carbon benefit. However, biomass can often equally be used to create bioenergy and displace the use of fossil fuel. For biochar to become the better option, the efficient stabilization of carbon into biochar must be combined with the recovery of energy from pyrolysis gases and residual heat (2, 4). Pyrolysis systems that connect continuous biochar production (for example, in rotating kilns) with power generation from coproducts remain scarce.

Without financial incentives for carbon abatement by stabilization, biochar has to be worth money in the soil. However, biochar materials are diverse (see the figure), and maximizing the benefits gained from their use depends on matching them to the right situation (5). This diversity is the reason for the startling variety of results from early observational studies that aimed to demonstrate benefits to plant productivity. Although one study reported an eightfold increase in crop yield through the use of biochar (6), a meta-analysis of 16 glasshouse and field studies showed a mean impact of only 10 to 15% on plant productivity (7). The highest productivity increases were seen in soils of medium texture and low pH.

Many of these early studies used readily available charcoal, which is one form of biochar. Increasingly, biochar with particular properties is selected to address an identified soil constraint, such as water storage or flow, pH or retention of crop nutrients, or even a biological purpose (8). Suitable screening methods allow biochar to be compared for properties such as physical and material sta-

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bility, macroporosity, release of entrained ash, and labile carbon (*9*–*11*).

To understand the long-term value of biochar addition for both soil improvement and carbon storage, methods to assess and predict biochar durability and changes in its properties are required. Beyond real-time observation (*12*) and experimental manipulation (*13*), insight can be gained from the study of old wildfire charcoal as a naturally aged analog (*14*). Focusing effort toward these strategic goals could later explain much-studied but less predictable effects on native soil carbon (priming) and nitrous oxide emission.

Positive effects on soils and crop production cannot alone confirm the viability of producing and deploying biochar, however. In many situations, there will be limited technology options for pyrolysis and constraints on affordable or available feedstock (*2*). Strategies for deploying biochar must also consider the practical and logistical issues of storage, transport, and incorporation into soil.

Doses of application should reflect such constraints. In the United Kingdom, for example, the projected break-even cost of deploying biochar from fresh or clean waste biomass exceeds $150/t, suggesting that only annual doses at the lowest experimental rates would currently be economic (*15*). Understanding the relative merits of regular low-dose applications as part of a nutrient management regime, versus larger one-off applications, is therefore a priority; establishing protocols for the safe use of biochar derived from low-cost waste streams is another.

Future applications may include broadacre crops, high-value vegetable production, and management of liquid manures, and there is already niche usage in horticultural growing media and fertilizer products. Such diverse modes and scales of deployment require a generalized understanding of biochar function. Using biochar to enhance existing products, even as a relatively minor ingredient, could build familiarity and reliable supply chains for potential future scale-up. Other functions of biochar worthy of consideration include provision of compounds that promote plant growth and resistance to disease (*16*, *17*) or the modification of nutrient dynamics at the plant–soil interface (*18*). There may also be synergistic effects between biochar and manure (*19*), compost, and fertilizer.

Integrated understanding of biochar function and deployment will support expanding use patterns that are economic and environmentally attractive. Over decades, the use of biochar could create soils that in management and function begin to resemble the fertile terra preta (famed charcoal-rich soils in Amazonia). Full realization of these benefits requires rewards and incentives at a national level that reflect the global value of both agriculture and climate.

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CANCER

Can One Cell Influence Cancer Heterogeneity?

Genetic lesions allow mature brain cells in mice to revert to immature forms that can give rise to tumors.

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Gliomas are the most common form of malignant brain tumor in adults and have generally poor clinical outcomes. Patients with the most aggressive form of glioma, glioblastoma multiforme (GBM), have a low 5-year survival rate (*1*). Progress has been made in characterizing the genetic lesions and cells of origin in GBM, both of which may contribute to disease pathogenesis. On page 1080 in this issue, Friedmann-Morvinski *et al.* (*2*) show that differentiated neuronal cells and glial cells in the mouse brain can revert to less mature states upon acquiring these genetic lesions. Thus, multiple different cell types in the central nervous system, and not just neural stem cells, can be transformed into GBM in an animal model that recapitulates important aspects of the human disease.

The cellular background (the chemical modifications of chromatin, or the epigenetic state) in which a transforming genetic lesion occurs (cell of origin) may contribute to the complexity of cancer. The potential importance of the cell of origin and the transformability of multiple cell types raises questions about hierarchical relationships between cells and the properties of tumor-initiating cancer stem cells (thought to be cells within a tumor that can self-renew and give rise to heterogeneous populations of cancer cells that constitute the tumor). In mouse models of glioblastoma, genetic lesions introduced in both neural stem cells and more mature glial cells may lead to tumor formation (*3*, *4*). Although glial progenitor cells and differentiated astrocytes both have the potential to contribute to GBM, the tumors develop differently, depending on the cell of origin (*5*). Specific subtypes of human GBM show some relation to normal brain cell types (*6*) based on gene expression, suggesting that the cell of origin may influence the final GBM subtype.

Friedmann-Morvinski *et al.* examined this possibility in mice using a highly targeted method (stereotaxic injection of lentivirus vectors into cells that allows transduction of oncogenes or deletion of tumor suppressor genes) to induce genetic lesions in specific central nervous system cell types in vivo. The

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