The Carbon Cycle: A Well-Known Tale is Full of Holes

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All of us—biotechnologists and farmers, climatologists and fishermen, seismologists and hang-gliders—work within an environment whose most basic characteristics seem wholly familiar. Though complex in detail, the principles at the heart of the global system, the forces at work in the atmosphere and biosphere and the overall features of the endless recycling of chemical elements are very well known. One of the simplest examples is the carbon cycle. It includes many subsidiary circuits, but broadly reflects the fixing of carbon into organic form through photosynthesis and its release into the atmosphere by respiration and fire. Inseparably linked with the story of oxygen, and neatly encapsulated in an elementary diagram found in schoolbooks the world over, the carbon cycle is thoroughly understood.

Not so. Recent research, and freshly recognized contradiction, indicate that our knowledge, particularly of carbon lodged in nonliving organic matter, is seriously incomplete. One indication has come from the discovery of a major pool of previously unknown organic compounds in the oceans. It consists of macromolecules such as cutans and suberans from the cell walls of higher plants, and algaenans from microalgae, all based on networks of long, saturated, hydrocarbon chains that are highly resistant to microbial and chemical degradation. As the pool of these substances is twice the size of that of atmospheric carbon dioxide and carbon biomass above ground, the role of the seas in the carbon cycle is now obscure when hitherto it was considered well delineated.

It was in light of this disquieting lacuna in knowledge that Christian Sonntag of the University of Heidelberg (Germany) and Richard Zepp of the U.S. Environmental Protection Agency (Athens, GA) brought participants together in Berlin recently for a Dahlem conference. Focused solely on the role of nonliving organic matter in the Earth's carbon cycle, the conference was intended to review ignorance and research needs not through conventional paper reading but through the Dahlem tradition of intensive, carefully structured discussion.

And the relevance to biotechnologists? Immediately, none, perhaps. Yet for those involved in pursuits such as bioremediation, or in efforts to promote nitrogen fixation by microorganisms or to enhance photosynthetic efficiency in plants, it must be sobering to confront our newly limited understanding of the terrestrial context within which such work is conducted.

Consider just a few of the unknowns that came to light during the Dahlem conference. First, there is charcoal, which represents a significant pool of carbon on the surface of the planet. Although its potency as an absorbent for organic substances is familiar enough, its stability to biological degradation is simply unknown. In models of carbon cycling in the soil, charcoal is usually treated as inert, and thus largely ignored. This may well be a serious error.

Second, textbooks will tell you that nonliving organic matter is preserved in anoxic marine sediments because it cannot decompose in the absence of oxygen. Again, this is almost certainly untrue. Microbial degraders undoubtedly decline in efficiency in the absence of oxygen. However, sulphate and other substances can still provide sufficient oxidizing capacity to promote decomposition. Recent studies indicate that, for a wide range of biological substances, rates of breakdown are very similar under anaerobic and aerobic conditions.

A third puzzle concerns limits on the productivity of the oceans. The answer is not the availability of carbon itself. Yet whatever regulates the proliferation and dynamics of plankton clearly has a direct influence on the cycling of carbon too. Recent evidence indicates that not only nitrogen but also iron plays a role. But the picture is far from clear. That is why, this fall, a team from the Moss Landing Marine Laboratory (Moss Landing, CA) has been conducting an extraordinary experiment in the equatorial Pacific. Having added iron salts to a 20 km by 20 km patch of the sea's surface, the researchers have monitored productivity, chlorophyll, iron, and major nutrients both within and outside the treated area. We await the result.

There are similar uncertainties about nonliving organic matter in the soil storehouse for an estimated 10^{15}g carbon, about twice as much as in the atmosphere and three times as much as in living plants. As pointed out by one Dahlem participant, Jerry Melillo of the Marine Biological Laboratory (Woods Hole, MA), politicians and others are beginning to ask how this massive pool will respond to global change—whether, for example, it will increase in size and function as a sink for carbon from the atmosphere, or conversely diminish and act as a net source of atmospheric carbon. Ingenious soil-warming experiments, now being conducted by Melillo and his colleagues in Harvard Forest in central Massachusetts, may shed light on these conundrums.

Dahlem conferences often reveal ignorance in the course of reviewing knowledge. But this was exceptional. In highlighting the yawning gaps in our understanding of one of the great fundamentals of terrestrial dynamics, the Dahlem organizers have performed a rare service for the scientific and wider communities. ///