ECOLOGY

Managing Soil Carbon

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Restoring soil carbon is essential to enhancing soil quality, sustaining and improving food production, maintaining clean water, and reducing increases in atmospheric CO_2. Short-sighted farming practices have resulted in loss of an estimated 4 ± 1 gigatons (Gt) of carbon from soils of the United States, and 78 ± 12 Gt from the world's soils, a large fraction of which ended up in the atmosphere (*1*). Soil carbon loss has come principally from plowing that turns over the soil, making it susceptible to accelerated erosion (*2*). This is exemplified by the Dust Bowl era in the United States and is a serious issue in most developing countries (see the figure).

Although some carbon is sequestered (*3*), accelerated water erosion is responsible for net emission of about 1 Gt C/year (*4*). Leaving crop residues after harvest increases the carbon content of soil and controls erosion, but the benefits are lost if the biomass is plowed under, because microorganisms quickly degrade residue C to CO_2 (*5*). Essential nutrients that adhere to soil organic carbon (SOC) disappear with its depletion. Thus, farmers require more fertilizer, irrigation, and pesticides to preserve yield. Water quality can deteriorate when less SOC is available for natural filtering.

No-till agriculture (in which seeds are implanted without turning the soil with a plow) reduces the loss of the SOC pool (*6*–*8*), while conserving soil water and inhibiting weeds. Soil C enhancement would improve agronomic productivity (*9*) and resource-use efficiency of impoverished soils. The beneficial effects of enhanced SOC cannot be fully replaced by increased levels of fertilizer, especially in soils of the tropics (*10*). No-till, in combination with mulching and crop rotation to enhance the SOC pool (*11*–*14*), is also a viable strategy for sustainable management of soils of the tropics in general and those of sub-Saharan Africa in particular (*15*). No-till would decrease silt in rivers and lakes, which would lower transport of SOC and pollutant-laden sediments to aquatic ecosystems and reduce hypoxia, as in the Gulf of Mexico.

Of all cultivated land (1379 Mha globally), no-till is currently practiced on only 5% of the world's cropland (*16*). Rapid adoption of no-till farming in South America is attributed to cooperative agricultural extension education efforts (in which university staff work with the farming community), use of crop residue for mulch rather than for fodder or fuel, and development of systems to make no-till farming work. The success of no-till sowing of wheat after rice in the South Asian rice-wheat belt is encouraging (*17*).

Soil erosion due to agriculture practices in the drainage basin of Madagascar's Betsiboka River. [NASA Photo STS51A-34-40]

However, intense plowing of water-saturated soil (puddling) for the rice crop and lack of residue mulch because of prior removal or burning at the time of sowing wheat minimize benefits. Furthermore, expansion into Africa and Asia remains a challenge, because crop residues are removed from the land, and animal waste is primarily used as fuel not as fertilizer. Identifying economic, clean, and healthy sources of household cooking fuel remains a challenge in developing countries.

Topsoil is even used for bricks to meet the demand for housing. Farmers in India, for example, sell topsoil to 1-m depth for up to Rs 60,000/acre (U.S. $1300/acre). Identifying alternate material for brick making is a high priority, but finding agriculturally marginal lands from which soil can be mined to deeper depths may also be needed. Using topsoil for brick making must be banned.

No-till agriculture, together with leaving crop residue in fields, does have costs. The yield may be lower in poorly drained and compacted soils and in places where springtime soil warming is slow. Initially, more fertilizer may be required, but, as SOC increases, the soil becomes more productive, requiring the same or even less fertilizer. Crop residue left in the fields would not be available for animal feed, energy production, biofuels (ethanol or hydrogen), or other uses and may increase incidence of pests and pathogens.

Implementing a program to increase SOC requires that governments mandate no-till agriculture or provide financial incentives to farmers. The United States has a large subsidy program (*18*) to preserve soil quality. Whether current funding is sufficient to pay for SOC restoration is unclear. However, developing nations lack such opportunities and institutions. Subsidy programs must be consistent and long-lived, because carbon gains are easily reversed. Creative policies that combine short- and long-term incentives, extension programs, education, and changes in public norms will be required. Aid programs should place far greater emphasis on subsidizing and providing technical and other assistance for soil restoration. As an option that wins globally and locally, adoption of no-till farming deserves attention now.

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18. For example, the Conservation Reserve Program pays farmers up to $50 per acre per year for retiring highly erodible land from cultivation.
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