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The Effect of Changing Land Use on Soil Radiocarbon

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Most carbon budgets require greening of the terrestrial biosphere as a sink for some of the excess carbon dioxide produced by fossil fuel burning and deforestation. Much of this storage is thought to occur in soils, but running counter to this conclusion is the observation that cultivation has reduced the agricultural reservoir of soil humus. Radiocarbon measurements in agricultural soils lend support to this browning of agricultural lands. Moreover, the loss is from the fast cycling portion of the humus.

Soil contains about three times the amount of carbon that was present in the preindustrial atmosphere. This study uses soil radiocarbon measurements to explore the dynamics of soil carbon loss associated with agriculture, a significant source of atmospheric CO_2.

In a survey of 1100 paired soil analyses (*1*), agriculturally modified topsoils averaged 25% less carbon than their native counterparts. As cultivated soil now contains about 180 gigatons of carbon (GtC) (*2*), this loss has added 60 GtC to the atmosphere and may have contributed as much as 0.5 GtC annually during the 1980s (*3*). There are a variety of reasons why disturbed soil might have less carbon than its native counterpart. These include reduction in the annual input of plant residues, increased decomposition as a result of elevated soil temperature, aeration, and extra moisture (*4*). In addition, plowing increases surface area, which accelerates soil carbon respiration (*5*). Although erosion is another way in which soil carbon could be lost from the profile, it should not change the carbon concentration. Only the thickness of the topsoil would be diminished. Further, carbon losses from the soil due to erosion are much less than losses due to oxidation (*4*).

As we have shown in a previous paper (*6*), based on radiocarbon data, the carbon in soil can be divided into fast and slow turnover time pools. We suggest that the carbon lost from agricultural soils must have come from the fast cycling pool. If so, then this loss should be matched by a decrease in the $^{14}C/C$ ratio of bulk soil carbon. The logic is as follows: The evolution of radiocarbon in the surface of natural soil can be modeled by the assumption that 25% of the carbon resides in a slow-turnover pool with a $^{14}C/C$ ratio averaging 0.63 of that for preindustrial carbon (*6*). Because of its slow turnover, no significant bomb ^{14}C has entered this reservoir. The remaining 75% of the carbon resides in a fast turnover pool with a mean replacement time of 25 years. A 3:1 mix of these two end-members yields a time history that passes through the median of the available radiocarbon measurements on bulk carbon from uncultivated topsoil collected at various times and places over the globe (Fig. 1). If the 25% loss were to have come entirely from the fast cycling carbon pool, then the fast:slow proportions would be changed from a 3:1 mixture to a 2:1 mixture. Although agricultural soil has a lower radiocarbon content than native soil, the deficiency is even greater than expected for a 25% loss (Fig. 1). Rather, the best fit curve corresponds to a 1:1 mixture of slow and fast cycling carbon pools. To accomplish this would require that two-thirds of the fast cycling carbon pool be lost (that is, 50% of the total carbon). In constructing these curves, for simplicity we have assumed that the carbon loss occurred largely before the nuclear era (1958 to the present). Were the calculation to assume, instead, that half was lost after 1958, the results would change only very slightly. The shape of the best fit curve through the cultivated soil suggests that the turnover time for the fast cycling carbon pool in cultivated soil carbon is 25 years, the same as for native soil.

The greater than expected $^{14}C/C$ reduction for mean cultivated soil may be, in part, the result of mechanical stirring by plowing. For most soils, the $^{14}C/C$ ratio decreases with depth, approaching values that are 30 to 50% lower than the prenuclear atmospheric ratio at the base of the profile. We attribute this drop to an ever-decreasing fractional contribution of the fast turnover carbon with depth. But, because plowing homogenizes only the upper 20 cm of soil, its impact would not be expected to be large.

Data on carbon content and $^{14}C/C$ ratio on a native soil from New Zealand (*7*) are

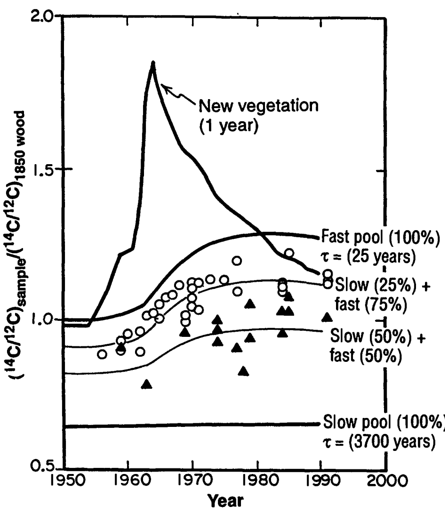

Fig. 1. Plot of radiocarbon versus time for the bulk carbon in topsoils (*8*). The natural soils (open circles) have higher radiocarbon values than the cultivated soils (solid triangles). The thick solid lines represent new vegetation, a fast (25-year turnover time) carbon pool's, and a slow (3700-year turnover time) carbon pool's responses to atmospheric bomb radiocarbon. The thin lines designate mixtures of fast and slow cycling carbon. A 75% fast and 25% slow mixture provides the best fit for the natural soils, but a 50% fast and 50% slow mixture provides the best fit for the cultivated soils.

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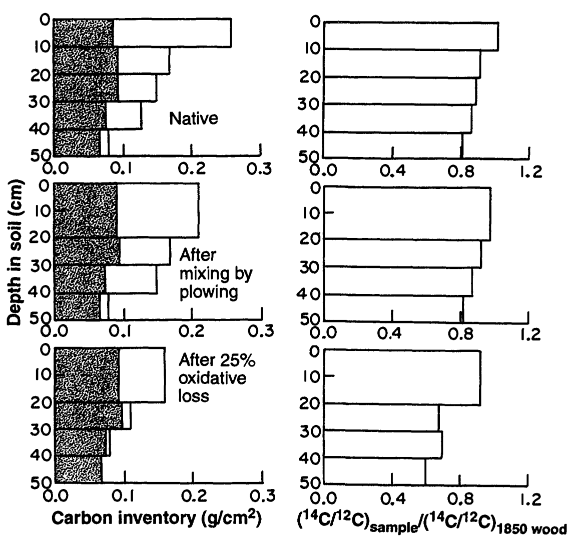

Fig. 2. Hypothetical evolution of native New Zealand soil carbon and radiocarbon subject to changing land use. The top figures illustrate the native radiocarbon ratios and carbon inventories, both of which decrease with depth (*6*). Also shown is the partitioning between fast turnover (unshaded region) and slow turnover (shaded region) carbon pools. The fast pool has a $^{14}C/C$ ratio of 1.26 and the slow pool a ratio of 0.63. The middle figures show how a farmer's plow would homogenize the upper 20 cm, thus decreasing the observed $^{14}C/C$ ratio and carbon inventory for the surface soil. The bottom figures show how the $^{14}C/C$ ratio and carbon inventory change with a 25% loss of carbon, all from the fast-turnover pool.

consistent with the hypothesis that a combination of plowing and oxidation of the fast cycling carbon pool are the cause of the downward shift in $^{14}C/C$ ratios observed for agricultural soil. To test this hypothesis, we considered what would happen if a native New Zealand soil was mixed to a depth of 20 cm and 25% of the carbon was oxidized (Fig. 2). Through mixing with underlying material, the $^{14}C/C$ ratio for the upper 10 cm of soil was reduced from a native value of 1.08 to 1.02 and the soil carbon inventory in this layer was reduced from 0.26 to 0.22 g/cm^2. We assumed that the increased oxidation took place in the fast cycling pool with an e-folding time of 25 years, eventually removing 25% of the soil's carbon. As a result, after a few decades, the $^{14}C/C$ ratio in the upper 10 cm of the soil dropped to 0.94 and the bulk carbon to 0.16 g/cm^2. The predicted $^{14}C/C$ ratio of 0.94 agrees with the observed average value for cultivated soil collected in 1975.

In summary, the observation that the $^{14}C/C$ ratios for agricultural soil are lower than those for native soils is consistent with a reduction in the amount of humus stored in these soils. Part, but not all, of the radiocarbon reduction can be attributed to preferential oxidation of humus in the fast cycling pool relative to that in the slow cycling pool. These observations suggest that as much as 60 GtC (10 years of fossil fuel CO_2 production at the current rates) could be sequestered if agricultural soil across the globe could be engineered back to its original carbon content.

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Crustal Thickness on the Mid-Atlantic Ridge: Bull's-Eye Gravity Anomalies and Focused Accretion

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Spreading segments of the Mid-Atlantic Ridge show negative bull's-eye anomalies in the mantle Bouguer gravity field. Seismic refraction results from 33°S indicate that these anomalies can be accounted for by variations in crustal thickness along a segment. The crust is thicker in the center and thinner at the end of the spreading segment, and these changes are attributable to variations in the thickness of layer 3. The results show that accretion is focused at a slow-spreading ridge, that axial valley depth reflects the thickness of the underlying crust, and that along-axis density variations should be considered in the interpretation of gravity data.

The source of bull's-eye–shaped mantle Bouguer anomalies (MBAs) on the Mid-Atlantic Ridge (MAR) has been debated since they were first observed in 1988 (*1*). The MBA represents a simple correction of the observed gravity field for the effects of topography at both the sea floor and the Moho, assuming a constant crustal thickness (6 km) and constant densities [1030 kg/m^3 for seawater, 2730 kg/m^3 for crust, and 3330 kg/m^3 for mantle (*2*)]. Three possibilities for these anomalies have been proposed (*1*, *3*–*5*): (i) that they provide a window into the dynamics of the underlying mantle and are evidence of central upwelling plumes; (ii) that they may be attributable to along-axis crustal thickness variations; or (iii) a combination of the two. A seismic measurement can distinguish between these possibilities by providing an independent estimate of crustal thickness. Any of these explanations would indicate that magmatic accretion is focused (*3*) on the slow-spreading MAR. In focused accretion, the middles of segments are

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