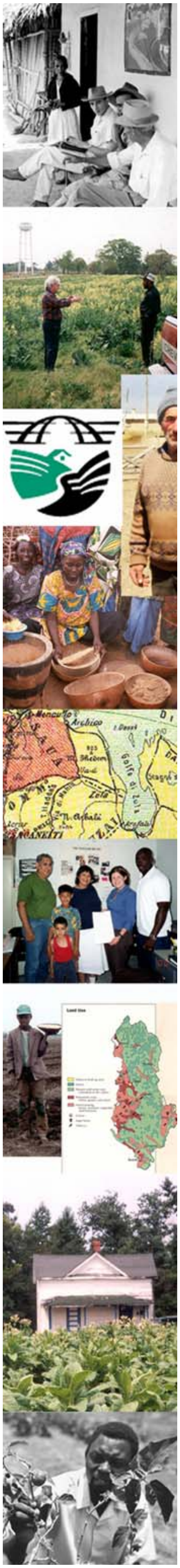

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TENURE BRIEF

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TROPICAL LAND USE CHANGE AND SOIL CARBON: Implications for REDD Policies

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The release of soil carbon due to changes in land use can be a major source of greenhouse gases. This brief illustrates the distribution and scale of soil carbon in the humid tropics, an area with high concentrations of carbon soil stocks. The brief further analysis the impact that various land use changes have on these stocks, and the implications for climate change.

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THE RELEASE OF SOIL CARBON due to a change in land use, such as clearing a forest to cultivate crops, is a major source of greenhouse gases. Since it is easier to measure carbon in visible vegetation than it is to measure carbon stocks below ground, much focus on the release of carbon due to changes in land use has tended to emphasize the role of above ground carbon stocks.

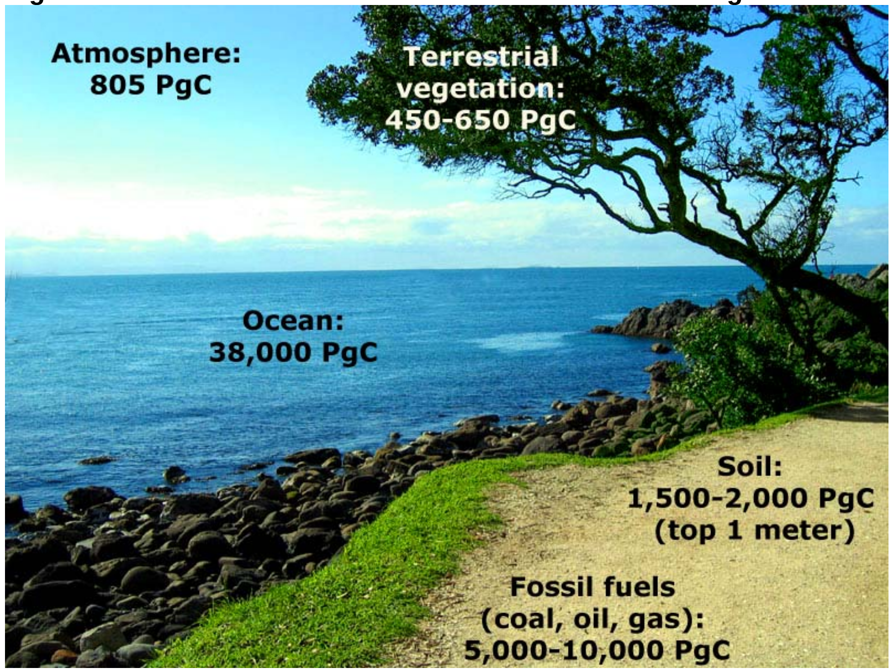
Globally, however, as shown in Figure 1 (next page), soil carbon stocks below ground are up to three times greater than vegetation carbon stocks. This large carbon stock in the soil, if released, can significantly accelerate climate change. Conversely, sequestering carbon below ground can help reduce the damaging effects of climate change.

To aid policy-makers designing REDD (reducing emissions from deforestation and forest degradation) and other projects, such as carbon-oriented payments for ecosystem services, it is necessary that we understand the extent of below ground carbon stocks—and the effect that land use change has on these stocks. This knowledge can help accurately identify the amount of carbon emissions that can be avoided by forgoing certain changes in land use; it can also help quantify potential benefits gained by carbon capture through measures such as re-foresting.

With this goal in mind, this brief summarizes a meta-analysis of 144 recent studies that attempt to account for below ground carbon stocks in the tropics. The brief then illustrates the impact that various land use changes have on these below ground stocks.

Comparing loss

Figure 1. Estimates of total carbon stocks as of 2005 in Pg.



Source: Houghton 2007.

Due to high rates of solar radiation, temperatures and precipitation, the humid tropics contain large stocks of carbon in the soils. Globally, from 1850 to 2000, changes in land use were responsible for 156 Petagrams (Pg) of carbon being released into the atmosphere (one Pg=109 metric tons) (Houghton 2007). Estimates show that approximately 60% of this came from the tropics.

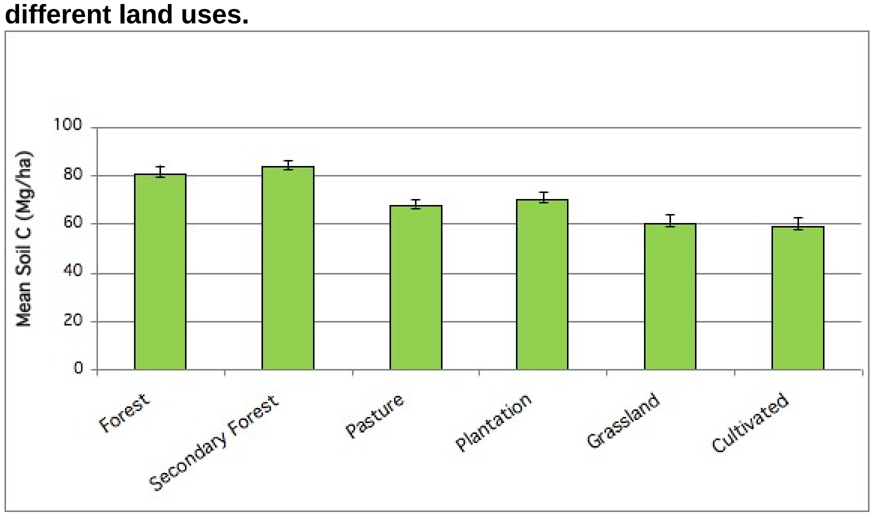
The many studies of soil carbon in the tropics have different ways of measuring amounts of carbon. Also, these studies take measurements at different depths, ranging from a few centimeters to several meters. Our meta-analysis standardized the measurements from the various studies to a depth of one meter. In this way, we can begin to accurately compare the potential loss of soil carbon stocks when forests are converted to other land uses.

Generally, the amount of carbon stored in soils results from the rate of organic carbon inputs from plants and other organisms as balanced with the loss of carbon through microbial decomposition, leaching and erosion. Different land management practices can accelerate these pathways of loss, leading to higher carbon emissions.

Figure 2 shows mean soil carbon stocks under different land uses. Forests and secondary forests have higher soil carbon stocks compared to pasture, tree plantations, cultivated land, and grassland. Generally, therefore, clearing a forest to cultivate crops will result in high emissions of carbon to the atmosphere. Indeed, one study estimates that cutting down a forest for cultivation can result in as much as a 50% loss of soil organic carbon in the top 20 centimeters of the soil after 30-50 years.

To understand general gains and losses in soil carbon stocks, we calculated the rate of change in soil carbon per year and in total carbon stocks after a change in land use. Table 1 illustrates the general trends when land is converted from one

Figure 2. Comparison of mean soil carbon stocks to 30 cm under different land uses.



type of use to another. As can been seen, when forests and secondary forests are converted to grassland or cultivated cropland, soil carbon is lost and released to the atmosphere. The studies we reviewed further detailed the consequences of clearing forests for these and other uses.

When converting forest to cultivated cropland, soil aggregates that store carbon are broken up, and carbon is more easily decomposed and respired. Typically, the result is a decrease in soil carbon of, on average, approximately 22 MgC/ha. One study showed an average loss of approximately 30% of soil carbon, while another study showed a 50% loss of topsoil carbon.

A primary reason for the carbon emissions once forest land is cleared for cultivation is the loss of litter accumulation. Even if a forest and the newly converted cropland have similar productivity, much less of the crop production is returned to the soil since most of it is harvested. Furthermore, soil carbon continues to decline following this conversion because significantly fewer litter inputs leach into the soil.

While the mean soil carbon stocks shown in Figure 2 would indicate that a conversion of forest to pasture should result in a carbon loss, this is not as straightforward a tale as when converting forests to cultivated cropland. It is true that when forest is cleared for pasture a considerable amount of above ground carbon in the vegetation is lost. Yet, unlike when clearing forest for cropland, this does not necessarily mean that there will be a loss of soil carbon. As seen in Table 1, our analysis of the studies shows that there is no net change in soil carbon stocks with conversion of forest to pasture.

In fact, following the conversion of forest to pasture there are instances where soil carbon may increase. Many tropical pasture grasses have deep roots, which contribute to below ground carbon pools. In contrast to cropland, pasture grasses continuously maintain a cover of vegetation on the soil, and the high productivity and turnover rates add organic matter to the soil, especially below ground. One study showed that soil carbon may tend to increase in areas receiving 2000-3000mm/yr of precipitation. Conversely, some studies do report losses of soil carbon in pastures due to their heavy use.

Soil carbon sequestration

Our analysis shows general trends of soil carbon decreases following conversion of forests to many other types of land uses, especially cultivated cropland. Can this loss of soil carbon be reversed? Would the re-establishment of forests following agricultural use (both cultivation and pasture) lead to soil carbon increases over time?

Table 1. General trends of changes in soil carbon from one land use (Time 1) to a different land use (Time 2).

Land Use Time 2	Land Use Time 1					
	Forest	**Sec. Forest**	**Pasture**	**Plantation**	**Grassland**	**Cultivated**
Forest						
Sec. Forest	No net change		+			+
Pasture	No net change	-			No net change	+
Plantation			+		No net change	+
Grassland	-	-	+			+
Cultivated	-	-		No net change	-	

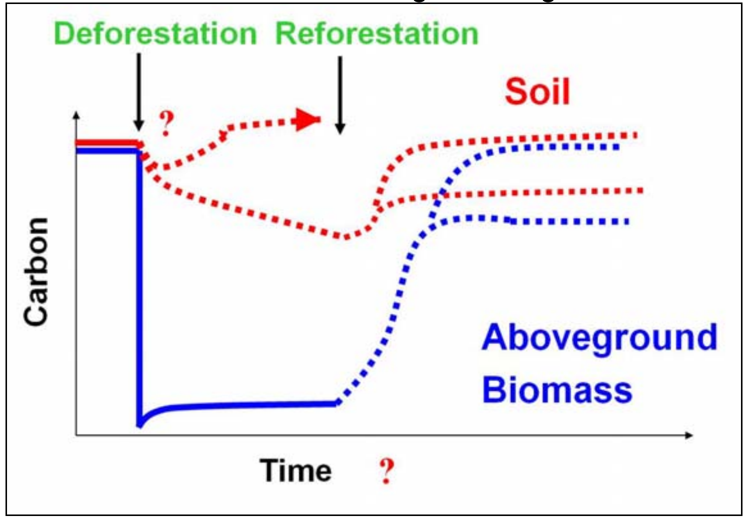
One study shows an overall increase in soil carbon in tropical and subtropical sites following the re-establishment of forests after agricultural use. Factors that are important in determining if a reforested site will gain or lose soil carbon (and how much) are climate, soil type, land use type, species planted, and time since conversion. Key factors for increasing soil organic carbon storage include:

- increasing input rates of organic matter
- slowing the decomposability rate of organic matter inputs
- placing organic matter deeper in the soil either by increasing below ground inputs or by enhancing surface mixing by soil organisms
- enhancing physical protection of carbon.

Figure 3 shows the impacts of deforestation and reforestation on carbon stocks below ground and above ground. Upon clearing a forest, the obvious effect is to immediately and significantly reduce the carbon in the above ground biomass (solid blue line). Upon reforestation, carbon increases in tree biomass, although the original values are not always reached (dotted blue line).

Below ground stocks are not as predictable. While soils can store as much carbon as tree biomass, a smaller percentage of this pool is affected by land use change. Soils can gain, lose, or show no net change (dotted red line) with changes in above ground biomass and land management. The fate of soil carbon after reforestation depends on how much was lost after the initial clearing.

Figure 3. The impact of deforestation and reforestation on soil carbon vs. carbon in above ground vegetation.



Challenges and opportunities

Despite the importance of soil carbon in mitigating greenhouse gas emissions, only a fraction of projects exist with the direct purpose of managing soil so as to sequester carbon. Of more than 150 bilateral carbon offset projects developed to date, approximately 30 are based on forestry activities and options related to land use designed to conserve and/or sequester carbon, or to substitute renewable wood products for fossil fuel-based products. Fewer than 10 measure soil carbon sequestration. This knowledge gap limits the ability of policy-makers to understand the potential benefits that land use policy can have on climate change.

One challenge faced by these projects is the complex response of soil carbon stocks to changes in land use, as illustrated in Figure 3. Accurately measuring sequestration in soils after there has been a change in the way the land is used can be difficult. Challenges include establishing a baseline of soil carbon stocks from which to begin monitoring, defining boundaries for measurement, and reconciling differences in methods of measurement.

While soils do not lose as much carbon as above ground tree biomass during deforestation, managing sites to conserve or accumulate soil carbon would increase a site’s total carbon benefits and reduce total greenhouse gas emissions. Soil carbon also is a very important component of soil fertility, so managing soil organic matter reserves has benefits that go beyond carbon sequestration.

Related reading

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Terminology

Carbon stocks: units of mass of carbon per unit area to a fixed depth (e.g., MgC/ha to 30cm is Megagrams of carbon per hectare down to 30 centimeters). MgC and PgC are commonly used units for soil carbon stocks. 1 PgC = 10^9 MgC.

Net primary productivity: net carbon gain by vegetation stored in biomass.

Secondary forest: forests regrowing on land that was originally cleared as a consequence of human impact on forest land. An example is forest regrowth on abandoned agricultural fields. Secondary forests do not include tree plantations (see below).

Soil organic carbon: plant, animal, and microbial residues at all stages of decomposition in soil.

Tree plantation: typically refers to a monoculture of trees planted and managed for harvesting or carbon sequestration purposes.

Turnover rate: a measure of the movement of carbon calculated by dividing the quantity of carbon present in a particular pool or reservoir by the flux rate for that element into or out of the pool.

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