Land Management Options for Mitigation and Adaptation to Climate Change

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Abstract

In the long term, the strategy for sequestering carbon on land must be to increase the carbon density of all lands through management. But in the short term, the fastest way to reduce carbon emissions and increase carbon sinks on land is to stop deforestation and expand the area of forests. Such activities reverse historic trends, but "the forest transition" (Area 24:367–379, 1992) observed in many countries suggests the reversal may be under way. In the end, the choice is not between forests and agriculture (or energy or fiber) because a habitable Earth and a stable climate require both.

Keywords

Agriculture • Bioenergy • Carbon • Carbon emissions • Carbon sequestration • Competition for land • Deforestation • Forests • Land management • Land use

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Definition

This chapter discusses broadly the management of land for mitigation of, and adaptation to, climatic change. Mitigation includes activities that reduce emissions of carbon to, or increase removals from, the atmosphere. Adaptation refers to uses of land that are compatible with climatic change, for example, increased agricultural yields.

Managing land for mitigation of, and adaptation to, climate change will require a reversal of long-term global trends in land management. To date, land management, globally, has released 200–300 Pg C to the atmosphere, largely from deforestation for agricultural production. This long-term net release approaches the amount released from combustion of fossil fuels, although currently the emissions from land-use change are only ∼15 % of total anthropogenic emissions. The good news is that this global reversal of deforestation has already begun in many regions, and forests are accumulating carbon worldwide (Pan et al. 2011). The bad news is that the reversal is required in all regions at the same time that pressures for more food, fiber, and fuel are greater than ever before and are only going to increase in the future. If the management needs of the next 2–3 billion people are obtained the same way the needs were met for the last 2–3 billion, another ∼50 Pg C will be released from land before 2100. The need to reduce emissions and to increase the storage of carbon on land comes at a time when the use of land to produce food, fiber, and fuel already accounts for approximately half of the land's ice-free surface. Furthermore, the land required for these goods must now compete for lands needed for carbon sequestration and other ecosystem services. The competition for land, already intense, is growing only more so.

This chapter paints with a broad brush the areas under management today and current trends. There are an infinite number of ways to manage land, but this chapter focuses on two broad categories: croplands (distinguishing food, feed, and bioenergy crops) and forests or woodlands. The chapter is also strategic rather than tactical. That is, it features the options potentially available over large spatial scales and not particular forms of management practiced on the ground. The two questions lurking in the discussion are the following: (1) What are the needs for land, especially with regard to mitigation and adaptation? (2) Are there trade-offs or synergies among these needs? Towards the end of the chapter, the issue of scale is raised.

The Distribution of Land Cover Today and Recent Trends in Carbon Storage

The trend in land cover over the last ∼150 years is obvious (Fig. 46.1, top): managed lands have increased, and unmanaged lands have declined over time. Areas devoted to food, feed, fiber, fuel, and settlements have increased, but carbon

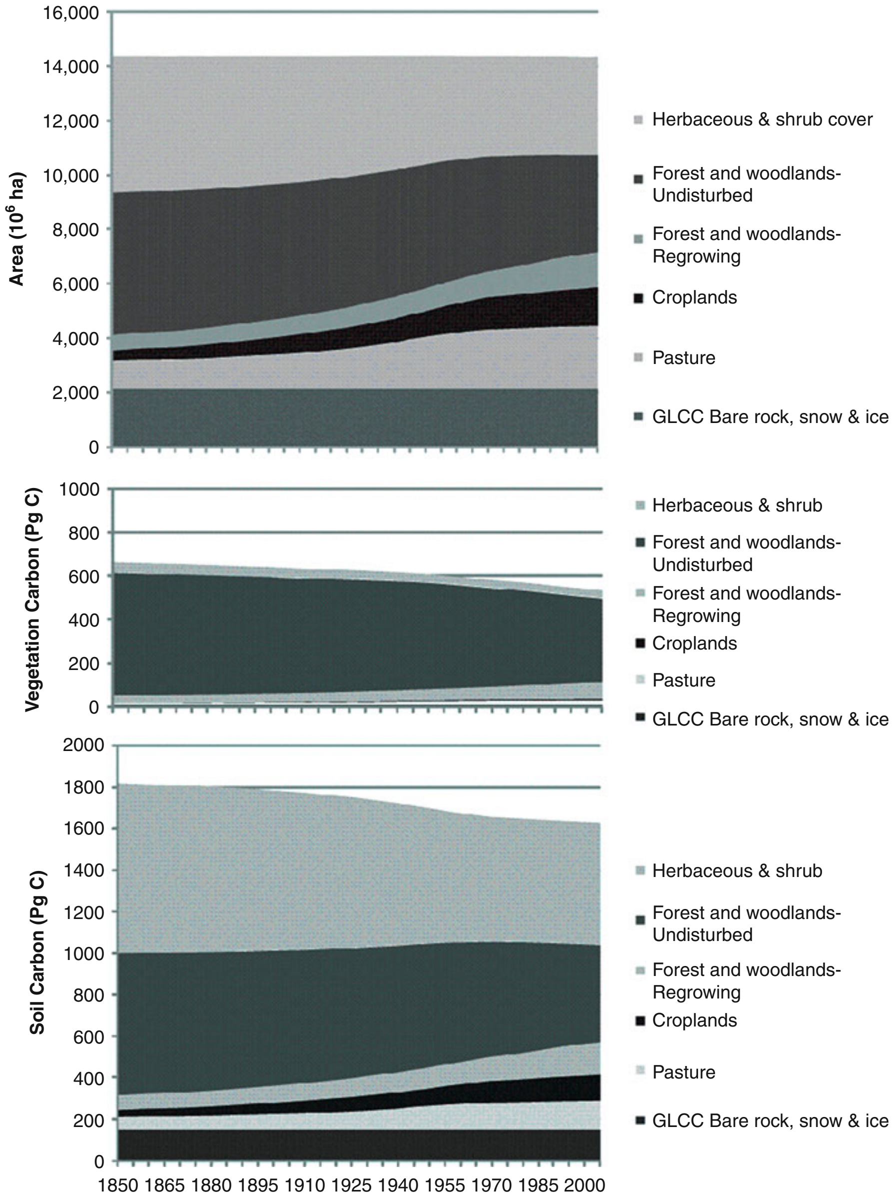

Fig. 46.1 Areas (*top*) and carbon content of vegetation (*middle*) and soils (*bottom*) in major land covers of the world. Areas of secondary forests, croplands, and pastures have increased since 1850, but the amount of carbon held in terrestrial ecosystems has declined, especially as a result of the loss of forests

storage and ecosystem services have declined as a result. If lands are to be used to sequester carbon, these trends will have to be reversed.

Managed lands do not always lose carbon, of course. Protected areas are managed, yet they preserve carbon stocks. Some forms of agricultural management increase the organic carbon in soil, and forests managed for long-term wood products could, in theory, increase the storage of carbon on land. Nevertheless, the overall trend, globally, has been for land management to release carbon to the atmosphere.

Estimates of the area managed, or at least influenced by direct human activity, vary. The area currently occupied by croplands and pastures is 4,400 million ha (Houghton 2012) or about one third of global land area. Forests now cover ~3,850 million ha currently or 28 % of the land, and many of these forests are managed. Estimates of the fraction of land surface directly affected by people vary from ~40 % to >75 %.

Reconstructions of land-use change suggest the amount of carbon on land today is 200–300 Pg (1 Pg = 10^{15} g) C less than was present initially, largely as a result of the conversion of forests to agricultural lands (Houghton 2012). Most of the loss has been from forest biomass, while the loss of soil carbon as a result of cultivation is estimated to have contributed ~25 %. Rates of change have been accelerating, such that the reduction in terrestrial carbon stocks since 1850 (Fig. 46.1) is greater than the reduction attributable to human activity for all of time before that date.

In one sense, the losses of carbon in the past provide an opportunity for sequestration in the future. Most of the activities that have released carbon to the atmosphere might, with appropriate incentives, store it again on land. The restoration of forests on cleared lands could, in theory, restore 200–300 Pg C; but many of these lands are currently in use and unlikely to be returned to forests. Rather, the management of agriculture and forests will have to increase the carbon density (MgC/ha) on lands already managed. For example, if the forests of the Northeastern USA were to return to fully stocked timber stands, the biomass of the region would be increased by ~25 %.

Using Terrestrial Ecosystems to Stabilize the Concentration of Carbon Dioxide in the Atmosphere

Two activities have the potential to affect terrestrial carbon emissions at scales large and rapid enough to stabilize the concentration of CO_2 quickly: massive reforestation and a halt to deforestation. On the order of 200–300 × 10^6 ha of new forests could remove 1–1.5 Pg C year^{-1} from the atmosphere for a few decades. The area is large but not in comparison to current areas in croplands and pastures. The magnitude of 1–1.5 Pg C year^{-1} assumes, optimistically, an average sequestration rate in wood and soils of 5 Mg (1 Mg = 10^6 g) C ha^{-1} year^{-1}, whereas the lands available for such afforestation are unlikely to be the most fertile and productive.

Deforestation is responsible at present for annual emissions of 1–1.5 Pg C. A halt to deforestation, combined with a massive program of reforestation, could thus reduce C emissions by 2–3 Pg C year^{-1}. The reduction is more than half the rate at which carbon is accumulating in the atmosphere (~4 Pg C year^{-1}). Similar reductions of 1–2 Pg C year^{-1} in the emissions of C from fossil fuels, which are now nearly 9 Pg C year^{-1}, would stabilize the concentration of CO_2 in the atmosphere immediately. Additional reductions would be required over time to bring the concentration of CO_2 in the atmosphere back to 350 ppm, but the management of carbon on land could help stabilize atmospheric CO_2 concentrations in short order. It has the advantage of being technically achievable and cheap relative to other emissions reductions. Over the longer term, management will have to focus more on increasing the carbon density of lands already in use. Rates of carbon accumulation in trees and soil may be slower in established agricultural lands and forests than the rates associated with changes in forest area, but smaller increments over large areas can still have a substantial annual effect.

Both the area and carbon density of forests are increasing in many nations (Pan et al. 2011). Can these trends become global? And can they become global when the demands for food are growing, as well as the demands for meat, wood, and bioenergy? The rest of the chapter describes options for providing food, biofuels, and carbon storage for mitigation of, and adaptation to, climate change. Emphasis is given to competing and synergistic interactions of land use.

Stopping Deforestation

Almost all deforestation is for agriculture, including croplands and pastures. And most increases in agricultural areas in recent decades have been from tropical forests (Gibbs et al. 2010), particularly in South America and Central Africa, where large areas of forest remain. This circumstance is not encouraging. Deforestation of tropical forests releases nearly twice as much carbon per hectare as deforestation of temperate zone or boreal forests yet provides, on average, only half the agricultural yields (West et al. 2010). From 2000 to 2005 deforestation in the tropics added only 2.5 % to agricultural area yet contributed 39 % to carbon emissions from the tropics (DeFries and Rosenzweig 2010). If deforestation is to be halted, crop yields will have to increase in the tropics.

In fact, yields have been increasing. Over the last two decades agricultural production in developing countries increased by 3.3–3.4 % annually while gross deforestation increased agricultural areas by only 0.3 % (Angelsen 2010). The good news for the tropics is that the current low yields can be increased through intensification. The potential for increased yields (adaptation) can, in theory, work synergistically with decreasing deforestation (mitigation) (DeFries and Rosenzweig 2010).

Management of Crops for Food

Crop yields are a function of the intensity of management, and food production has become more intense over time, from hunting and gathering, to shifting cultivation, to permanent cultivation. The increased intensity can be defined in a number of ways, including per unit of time or land area as well as energy inputs, fertilizers, pesticides, and water. Emissions of N_2O, for example, usually increase as a result of fertilizer use. A parallel trend in crop production has been to centralize production, from local subsistence to global agribusiness. Indeed, the primary drivers of tropical deforestation seem to have switched in the last two decades from rural-based localized agents to urban growth and international agricultural trade (DeFries et al. 2010). Whether intensification of crop production in the tropics is sustainable and whether 7–10 billion people can be fed sustainably, with or without agribusiness, are questions outside the scope of this chapter. However, intensity of land management, by itself, does not lead to increased yields. On the contrary, overcultivation and overgrazing are major causes of degraded lands, which generally have low carbon densities.

The economics of intensification is not clear either. Greater yields through intensification of agriculture are expected to spare forests because tropical forests were the primary source of new agricultural land in the 1980s and 1990s (Gibbs et al. 2010). Yet the intensification of crop production has not consistently spared forests (Rudel et al. 2009). In fact, the increased profits from increased yields may actually lead to greater deforestation in the pursuit of still greater profits (Angelsen 2010). Put another way, the intensification of crop production increases the opportunity cost of forest conservation by raising the competitive value of agriculture. The argument that intensification of agriculture is a win-win proposition is perhaps not supported from an economic perspective.

Regarding meat production, the land surface can support more vegetarians than meat eaters simply because of the lower efficiency obtained in processing organic matter through an extra trophic level between plants and humans. Thus the best way to conserve land and reduce emissions of greenhouse gases from animal management is to reduce meat in human diets. Animals are a major source of methane and nitrous oxide, and the expansion of pastures into forests further increases the carbon footprint of meat. Regarding the question of *where* animal production is suitable, grazing is most competitive (i.e., appropriate) where soils and climate are poor for crop production (i.e., rangelands) but where animals may, nevertheless, forage at low densities.

Management of Crops for Bioenergy

Diverting crops from food to fuel raises food prices and tends to compensate for the loss of food production by increasing croplands elsewhere. Early analyses focused on the case for ethanol production from the US corn production. The displacement of food for fuel seems likely to expand cropland either into tropical forests (Searchinger et al. 2008) or into marginal lands that may be more sensitive to erosion when cultivated.

Another example of a negative externality in bioenergy production is the cultivation of oil palm plantations, most notably in Indonesia and Malaysia. The draining and burning of the peatlands in these forests emit large amounts of carbon. Furthermore, the use of palm oil for energy sets its price at the world market for oil and thus increases the price of oil palm. Bioenergy makes sense, from a carbon perspective, where the ratio of energy produced to energy consumed is large, such as with sugarcane or with plant residues otherwise wasted. The emissions from new palm oil plantations could be lowered if expansion targeted degraded lands or agricultural lands with low carbon stocks.

Expanding the Area of Forests

Using forests for either bioenergy or for carbon storage has much the same effect as using croplands for bioenergy. Such uses may lower the cost of reducing carbon emissions, but they add to the value of forests and woodlands and thereby raise the price of food crops and livestock. Model simulations have shown that tropical forests will be preserved, and forest-based bioenergy will be an effective mitigation option, only when two other conditions were met: (1) there is a price on greenhouse gas emissions and (2) crop yields continue to increase (Thomson et al. 2010). Using forests instead of croplands to supply bioenergy does not seem to ease the price of food. Whether from croplands or forests, the addition of bioenergy to the list of competing land uses raises the prices of the others. Furthermore, the use of forests for biofuels is projected to increase worldwide fuelwood demand by three- to sixfold over the next 50 years.

Management of Forests for Carbon Storage or Bioenergy

The use of forestry and wood production for mitigation has received considerable attention. Wood products substituted in place of non-wood products can reduce emissions as can the recycling of wood products. Forest management includes synergies and trade-offs between mitigation (carbon storage) and adaptation (harvested wood products and bioenergy). For example, the annual increment of wood (carbon) was lowest in those forests where carbon density (MgC/ha) was highest. One can either maximize the rate of carbon uptake or the amount of carbon held on a site but not both. Further, maintaining high stocking density (mitigation) may decrease stand-level structural and compositional complexity (adaptation potential). On the other hand, the Northwest Forest Plan in the Pacific Northwest (USA), initially implemented for biodiversity, increased carbon storage as well.

A special case for climate-change mitigation with forests is Reduced Emissions from Deforestation and forest Degradation (REDD). Demonstration that a country has reduced carbon emissions through reduced rates of deforestation qualifies it for compensation depending on the price of carbon ($/ton). The policy applies in particular to non-Annex I (developing and transitional) countries in the UN Framework Convention on Climate Change (UNFCCC) and is likely to be incorporated in the next round of negotiations.

One of the concerns with REDD is the distribution of funds for reduced emissions. Will the funds make their way to those managing the forests? Who should best manage the forests? In some areas, local management is best. Greater autonomy at the local level may result in high carbon storage and livelihood benefits (Chhatre and Agrawal 2009), in part because forests provide key goods and services to local communities. The establishment of protected areas in Brazil has already helped reduce rates of deforestation and emissions of carbon. Nevertheless, the opportunity costs are real and will have to be paid either through a fund from Annex I countries or through the market. Even a high price on carbon may not be high enough to enable forests to compete with the profitability of some crops, e.g., oil palm bioenergy production. Furthermore, protected areas may not be as effective at reducing deforestation as community-managed forests. The good news is that protected areas including indigenous people or multiuses seem capable of providing both the global goals of biodiversity conservation and climate mitigation at the same time they support local livelihoods (Nelson and Chomitz 2011).

Implementation of REDD must also consider leakage through international trade in agricultural and forest commodities. Countries may be successful in reforesting locally because they have shifted to importing wood products from elsewhere (Meyfroidt et al. 2010).

Tree plantations raise additional concerns. Like forests, they may be used to sequester carbon or to provide fuel, but unlike forests, they may provide little in the way of ecosystem services (e.g., biodiversity). However, both plantations and bioenergy can be managed in a manner consistent with providing ecosystem services.

Scale of Management

At what scale should the competition for land be reconciled? Climate change must be addressed at the global scale because the atmosphere is well mixed, and climate affects all countries. Is the global scale also the scale for land-use management? In some ways it is: the best place for crops (in terms of yield per unit of greenhouse gas emissions) is currently in temperate zone and boreal lands rather than in the tropics (West et al. 2010). And globally, there is a spatial disconnect between global biomass production and consumption. Sparsely populated regions supply the demand of more densely populated regions.

Should every country have a goal to provide, sustainably, all of its needs for food, fiber, fuel, and carbon storage? Should every state or province? The current distribution of importers and exporters suggests this would be impossible. Every country cannot be expected to “grow its own.” The fact that food security is at the top of the agenda for most developing nations raises the question of whether national interests sum to the global interest or, more critically, whether a warming world will continue to sustain current levels of production. Droughts in the interior of every continent in recent years have contributed to the rise in food prices.

Watersheds may be the ideal management unit from a natural resource perspective. For example, Egypt may not have enough water for irrigation if Ethiopia and Sudan divert the Nile waters for their own agriculture. Amazonia is also a watershed large enough and unconstrained enough by development to be tasked with sustainable use of land for agriculture, wood, energy, carbon storage, and climate.

Trade adds a wrinkle to planning at any scale. With respect to greenhouse gases, the emissions involved in the production of goods are imbedded in those goods. Under the current rules of carbon accounting, the emissions are “charged” to the producer, but should they be?

Questions of scale are difficult not only because of geographical variations in such variables as soil fertility and growing season but also because of social issues such as equity and sovereignty. In any case, the appropriate ecological scale may be moot given the lack of infrastructure, even at national scales, let alone international or global scales, to administer land management decisions among these competing uses. We need to begin thinking about nationally and globally acceptable levels of resource use (Bringezu et al. 2011).

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