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Workshop on Effects of Management on Forest Soil Carbon: A Report

December 5-7, 1994
Fort Collins, Colorado

Serita D. Frey

Workshop Organizers:

Richard Birdsey
U.S. Forest Service
100 Matsonford Road
Radnor, PA 19087

Steven Winnett
U.S. Environmental Protection Agency
2122, 401 M Street, SW
Washington, D.C. 20460

Doug Fox
U.S. Forest Service/TERRA
315 W. Oak Street, Ste. 101
Fort Collins, CO 80521

Report prepared by:

Serita D. Frey
Research Associate
Natural Resource Ecology Laboratory
Colorado State University
Fort Collins, CO 80523

Abstract

Summarizes presentations given at a workshop sponsored by the USDA Forest Service and U.S. Environmental Protection Agency, and hosted by The Terrestrial Ecosystems Regional Research and Analysis (TERRA) Laboratory. Specific workshop objectives were to: (1) review available information concerning the effects of forest management on soil carbon and (2) use available data to generate estimates of changes in soil carbon following forest disturbance and regeneration at the regional level for major forest types in the United States. Participants agreed that insufficient data are currently available from which to estimate, with confidence, the impact of disturbance on soil carbon for all major forest types. Available evidence indicates no net change in soil carbon, on average, following disturbance.

The Author

SERITA D. FREY, is a Research Associate with the Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, Colorado 80523.

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Contents

Background

At the 1992 United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro, the United States and other countries signed the Framework Convention on Climate Change. The treaty calls for "stabilization of greenhouse gas concentrations...at a level that would prevent dangerous anthropogenic interference with the climate system..." and commits participating countries to report greenhouse gas emissions and carbon (C) sinks. In response, several agencies of the U.S. Government have worked together to produce an inventory of greenhouse gas emissions and C sinks in the United States (U.S. Environ. Prot. Agency 1994).

In developing the inventory for the United States, the Environmental Protection Agency (EPA) and USDA Forest Service conducted joint and individual analyses of C dynamics (emissions and flux) for forest lands of the United States. Using Forest Service inventories of private and public lands (Powell et al. 1993), the agencies developed baseline inventory projections and simulated the effects of alternative management policies on C sequestration in forested systems. The role of forest soil C sequestration was considered especially important and uncertain.

EPA and the Forest Service both used the Forest Service's TAMM/ATLAS model to simulate changes in forest inventories for baseline and alternate management policy scenarios. Two different C accounting models were used to explore management impacts on C dynamics. Differences in model assumptions regarding how soil C behaves in response to forest management resulted in a wide range of estimates for total C storage on public and private timberland in the United States (Fig. 1a). The EPA model, FCM (Forest Carbon Model), assumes that soil C changes very little in response to harvest, regeneration, and prolonged regrowth of forests, whereas the Forest Service model, FORCARB, assumes that 20 percent of the soil C is depleted after clearcut harvest, then increases with regeneration and growth thereafter (Moore et al. 1981; Houghton et al. 1983, 1985; Birdsey et al. 1993).

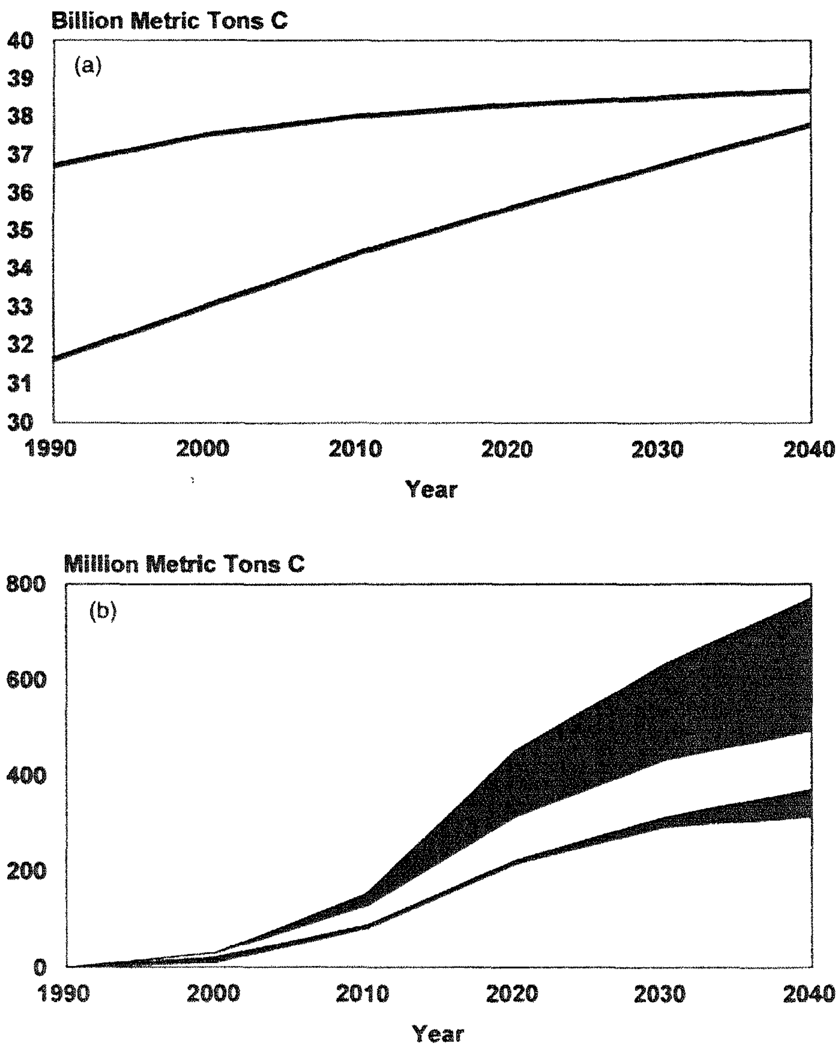


Figure 1.—Total carbon storage on U.S. public and private timberland: range of model results for (a) the base case scenario and (b) increases relative to base case for two tree planting scenarios. Each scenario (high enrollment vs low enrollment) represents projected spending on tree planting activities (Birdsey and Heath 1993, Turner *et al.* 1993; Turner *et al.* In press).

Because of the scientific uncertainty regarding soil C dynamics, EPA and the Forest Service together reported a range for total C storage that is quite large after 2010 for the alternative policy scenarios (Fig. 1b). Due to the uncertainty represented by the range, and in the absence of scientific consensus, the U.S. Government decided not to report soil C in the national inventory (U.S. Environ. Prot. Agency 1994). Soil C dynamics also were omitted from the U.S. Climate Change Action Plan (Clinton and Gore 1993) and from the report to the Framework Convention on Climate Change detailing plans to reduce net emissions (U.S. Gov. 1994).

The C in forest soils is a larger pool of C than that in tree biomass, both domestically and globally; therefore, changes in soil C could play a large role in national C inventories, whether in baseline projections or in policies designed to increase C storage. These dynamics are not currently considered, and analysts and policy makers are interested in determining what role soil C may play in greenhouse gas issues.

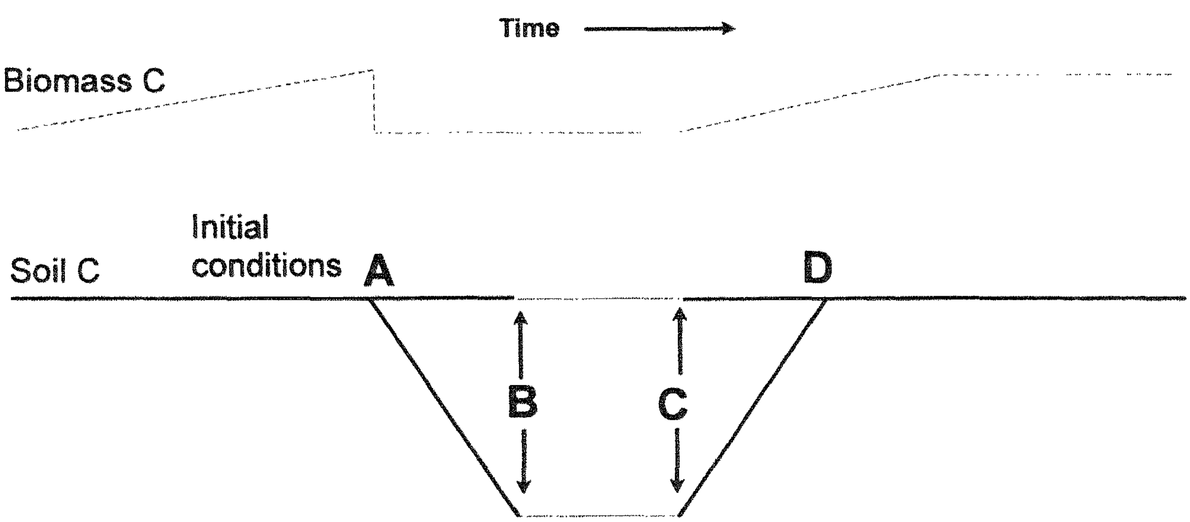
Workshop Objectives

The overall goal of the workshop was to reach consensus among workshop participants on the effects of forest management on soil C dynamics. **Specific objectives were to: (1) review available information concerning the effects of forest management (including afforestation and land clearing) on soil C and (2) use available data to generate estimates of changes in soil C following forest disturbance and regeneration at the regional level for major forest types in the United States.**

To facilitate discussion, a conceptual model of the impacts of forest disturbance and regeneration on soil C was presented (Fig. 2). The model begins with the definition of initial conditions and estimates an average rate of change in soil C. A disturbance (clearcut, partial cut, fire) occurs at time A after which there may be some change in soil C over the period AB. Options after disturbance include reforestation or conversion to pasture or cropland. After the period BC, which would be zero in the case of reforestation, there could be further change in soil C over time period CD. After time D, another reference situation is reached in which soil C changes at some average rate.

Workshop organizers hoped that quantitative information (both published and unpublished) supplied by participants and compiled at the workshop could be used to obtain estimates of the initial and long-term changes in soil C following each type of disturbance. This information would subsequently be used as model input for establishment of a baseline estimate of C changes in U.S forests and to estimate the impacts of alternative management practices on C storage.

General Model of Forest Disturbance and Regeneration Effects on Soil Carbon



1. Define initial conditions (e.g. soil C in average 55-yr. old loblolly pine in the Southeast)
2. Define level of disturbance at point A (e.g. clearcut harvest)
3. Define activity from A to B (e.g. site preparation and regeneration)
4. Define activity from B to C (e.g. cultivation or pasture)
5. Estimate percent change in soil C over a time period from A to B (e.g. 20% loss over 20 years)
6. Estimate percent change in soil C over a time period from C to D (e.g. 20% gain over 55 years)
7. Estimate percent change in soil C after point D (e.g. .3% gain/year)
8. Suggest shape of curves AB and CD

Figure 2.—A general model of forest disturbance and regeneration effects on soil carbon.

Summary of Invited Presentations

The Global Carbon Budget

David Schimel first summarized Chapter 1 from the report of the Intergovernmental Panel on Climate Change (IPCC), which has generated interest in the global C budget and in developing a greater understanding of the relationship between C emissions and atmospheric concentrations of CO_2.

He then presented an overview of the global C budget, the components of which include storage in atmospheric, oceanic, and biospheric reservoirs; fluxes between these pools and anthropogenic emissions from fossil fuel combustion, other industrial processes (e.g. cement manufacture), and changing land use, especially tropical deforestation (Fig. 3). Recent C budget calculations have indicated a potential terrestrial C sink attributable to several processes. Increased C storage in trees after regeneration of previously harvested forests and regrowth of abandoned agricultural land in the mid-latitudes may be one component of the "unidentified" terrestrial sink. Additionally, some experimental studies have shown enhanced plant growth with elevated levels of atmospheric CO_2. However, it is still unclear how this "CO_2 fertilization effect" will influence global C storage given the nutrient limitations of many ecosystems. Ecosystems with limited nutrients may show an enhanced growth response and thus increased C storage if coupled with nitrogen fertilization from deposition.

In addition to changes in C storage as a result of enhanced terrestrial plant growth, C storage in soil also has significant potential for change. Most terrestrial C is stored as soil organic matter, which is composed of different fractions with turnover times ranging from a few years to decades or thousands of years making interpretation of the role of soil C as a source or sink difficult. Recently, the Century ecosystem model was used to examine controls on C storage and turnover times in a range of forest and grassland soils distributed worldwide (Schimel et al. 1994). Results showed that soil C is positively related to soil texture, increasing as clay content increases and that soil C storage and turnover times decrease as mean annual temperature increases.

After the above discussion, Schimel presented results from a modeling exercise designed to examine the relationship between anthropogenic C emissions and atmospheric concentrations of CO_2. Modeling groups from around the world were given standardized emission scenarios and asked to use their respective models to project future atmospheric concentrations from given emission levels and also to determine the emission levels required to meet prescribed atmospheric concentrations. Comparisons indicated that increasing anthropogenic C emissions will result in increasing atmospheric concentrations of CO_2 and that stabilization of CO_2 levels below 750 ppmv will require the reduction of emissions below current levels.

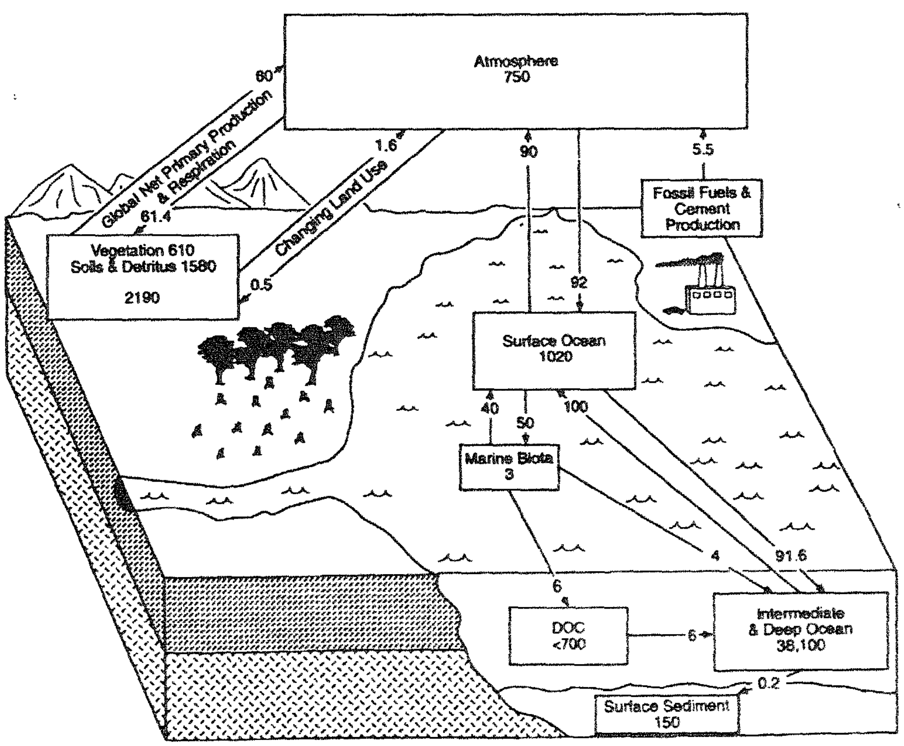


Figure 3.—The global carbon budget.

Regional Analysis of Carbon in Agricultural Soils

Ted Elliott, Keith Paustian, and Vern Cole discussed research they have initiated to examine the potential for C sequestration in agricultural soils of the Great Plains and Corn Belt Regions. They suggested that assessing the potential for C sequestration in agroecosystems requires an approach that facilitates integration of the complex interactions and feedbacks inherent in any natural system (Elliott and Cole 1989). Interactions between soil C, climate, management practices, soil type, and other edaphic factors are best synthesized using ecosystem-level simulation models (e.g., the Century model, Parton et al. 1987, 1993) that embody the current understanding of ecosystem function (Fig. 4). Data from process-level laboratory, greenhouse, and field studies are used to develop and modify existing models. For regional-scale analyses, spatially distributed driving variables (e.g., temperature, precipitation, and soil texture) are used as model input. Once a model is validated using data from regional site networks, it can be used to predict the impact of different management regimes and/or climate change on soil C storage. Additionally, such an approach facilitates identification of weak areas, and new process-level studies can be designed and implemented to fill this information gap.

Data from long-term agricultural field experiments are a valuable source of information regarding the effects of different management practices on soil C dynamics. Until recently, however, these data were not organized into a comprehensive database. In 1992, a project was initiated to collate existing long-term crop production and soils data from field experiments associated with state experiment stations, USDA-ARS, and Agriculture Canada experiment stations distributed across the Corn Belt and Great Plains Regions (Elliott et al. 1994; Paustian et al. 1995). Each site was also re-sampled to obtain a uniform characterization of soil organic matter. Samples were analyzed for total organic C and N, particulate organic matter, microbial biomass, mineralizable C and N, texture, and pH. These data are now being used to evaluate the effects of management on soil organic C and for Century model validation.

The Century model was previously used to simulate historical changes in soil organic C for a native grassland converted to a wheat-fallow cropping system and to predict potential soil C storage under possible scenarios of changed management and climate (Cole et al. 1993). Simulated C levels dropped from 45 Mg C ha^{-1} to 25 Mg C ha^{-1} over an 80-year period following conversion of native grassland to cropland. Recovery of approximately 3 Mg C ha^{-1} over a 50-year period was observed when plant C inputs were increased by changing the management system from wheat-fallow to wheat-corn-fallow or reseeding to grass. Simulations incorporating a doubling of

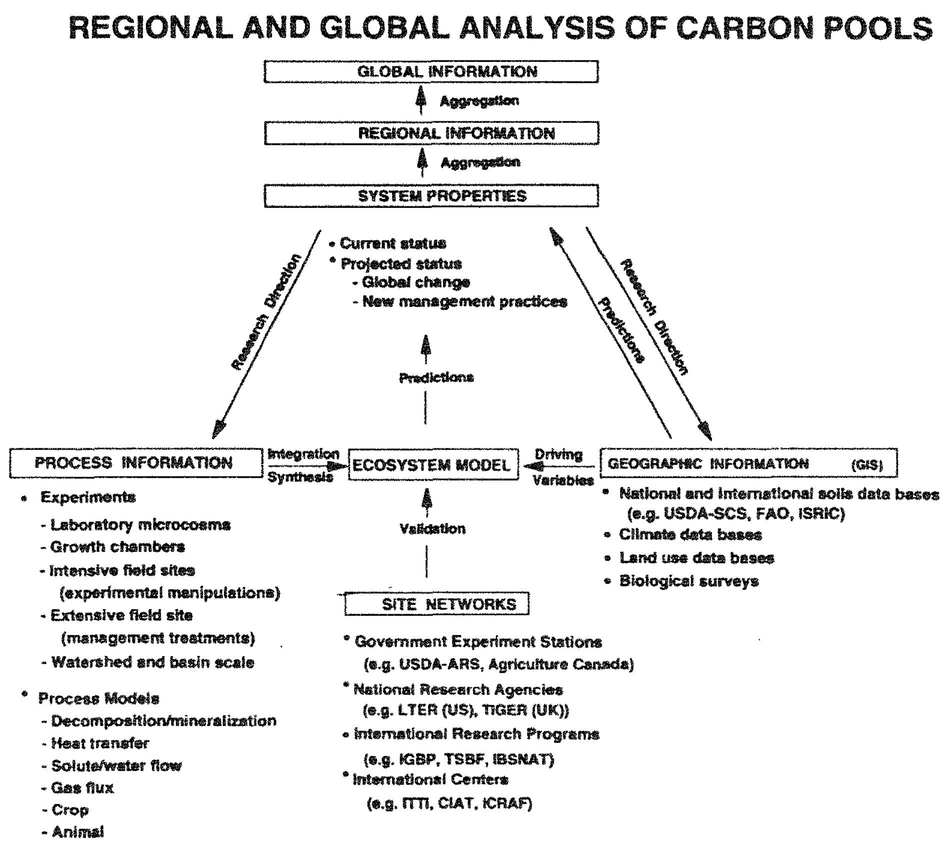


Figure 4.—Information requirements and structure for long-term and large-scale analysis of agroecosystems (Elliott and Cole 1989).

atmospheric CO_2 by 2040 (resulting in an increase of 3°C and 5 mm in mean annual temperature and precipitation) resulted in greater soil C levels in both annual cropping systems compared to the same systems under present climate conditions. These preliminary modeling exercises suggest that changes in management practices could result in C sequestration in agricultural soils.

Carbon in Forest Soils

Kristiina Vogt presented an analysis of soil C data from nearly 90 forested sites distributed globally (Vogt et al. 1995). When the data were grouped by forest climatic zone (boreal vs. temperate vs. tropical) she found that soil organic C was greatest in temperate sites (117 Mg C ha^{-1}) and lowest in boreal sites (62 Mg C ha^{-1}) with tropical forests being intermediate (90 Mg C ha^{-1}). Within each biome, the data were then grouped according to the dominant tree species present at each site. In general, soil C levels were higher for forests dominated by deciduous species. The amount of soil C, expressed as a percentage of the total C, also varied by biome: in boreal deciduous forests, 64 percent of the total C was in soil C compared to only 17 percent for coniferous forests. By contrast, approximately 50 percent of the total C was in soil C for both deciduous and coniferous forests in warm temperate regions. When the data were analyzed based on dominant tree species alone, soil C was found to be highest in mixed deciduous and coniferous forests compared to forests dominated by deciduous or coniferous species alone. Regression analysis of the data showed that climate, represented by minimum, maximum, or mean temperature, did not explain observed differences in soil C.

Soil classification and texture were also examined for their impacts on soil C levels. As a group, Ultisols had higher C levels relative to other soil orders, but within a given order, soil C levels varied by region with cold temperate forest soils having higher levels of C than warm temperate, boreal, or tropical forest soils (Vogt et al. 1995). Significant differences in soil C levels were also observed for forests with different site quality—low-quality sites (SQ = IV) had lower levels of soil C than high-quality sites of the same age (SQ = II) (data for *P. menziesii* in Washington; Vogt 1987).

Harvesting Effects on Soil Carbon

Dale Johnson summarized a review of the forest science literature in which he evaluated the effects of forest harvesting, cultivation, site preparation, burning, and fertilization (especially from nitrogen fixation) on soil C storage (Johnson 1992). He noted that the current paradigm in the forest soil science community is that soil organic C drops precipitously after a clearcut harvest. However, he found that most studies showed no significant change (±10 percent) in soil C after harvest, though individual sites could experience either a net gain or loss of soil C, depending upon residue management regimes (Fig. 5). Studies that looked at harvesting in combination with other treatments were excluded. When harvesting was considered in combination with subsequent cultivation, most studies showed large soil C losses (up to 50 percent).

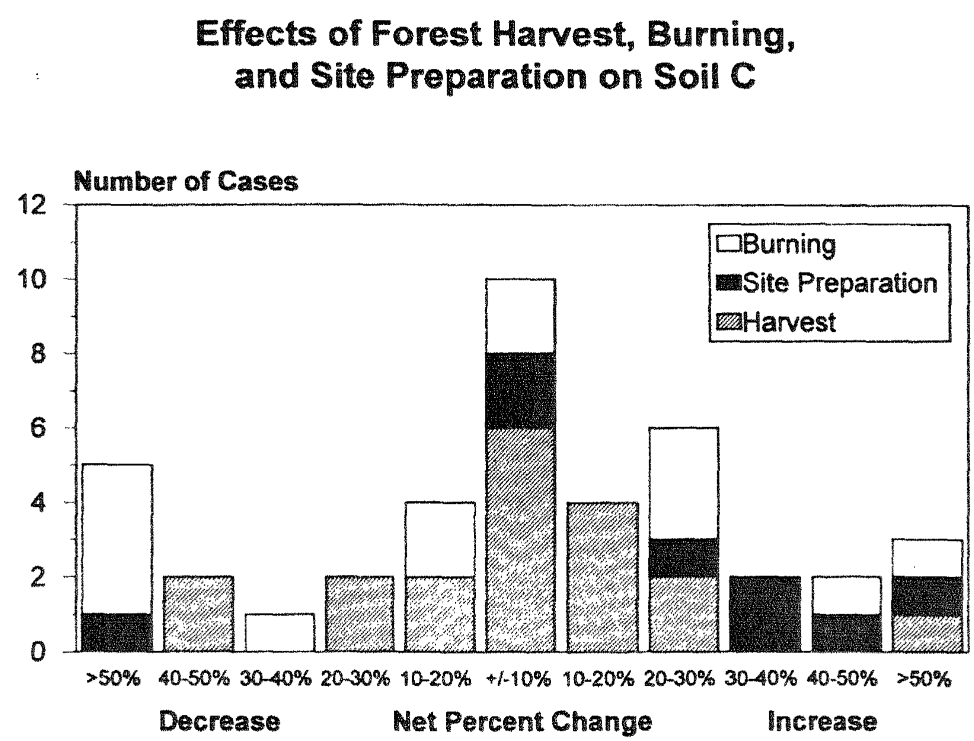


Figure 5.—Effects of forest harvest, burning, and site preparation on soil carbon (Johnson 1992).

Site preparation before forest re-establishment was found to have a significant impact on soil C — the trend was toward substantial C loss with extreme measures and fire. The one important exception to this occurred when logging residues were masticated and incorporated into the soil at the site. The impact of burning, either from prescribed burns or wildfires, was found to depend on fire intensity. High-intensity burning generally resulted in a significant loss in soil C, whereas low-intensity burning showed little or no effect. The establishment of nitrogen-fixing plant species following burning generally resulted in a significant increase in soil C over time.

Modeling Effects of Land Use Change on Soil Carbon

Bill Pulliam presented an overview of the Century model and discussed its application in modeling the effects of land use change on soil C. The Century model simulates carbon, nitrogen, phosphorus, and sulfur cycling in the plant-soil system. It was originally developed to simulate soil organic matter dynamics in native grasslands and agroecosystems but has since been modified for forest and savanna systems.

Century was used to simulate soil and whole ecosystem C associated with three different land-use histories in Harvard Forest. In 1750, part of Harvard Forest was clearcut and subsequently divided into three areas: one was reforested, the second converted to pasture, and the third cultivated and planted to wheat. These land-use scenarios remained constant for the next 100 years, at which time the pastured and cultivated land was abandoned and allowed to regenerate. The model simulation indicated that the initial soil C level was approximately 100 Mg C ha^{-1} and that a substantial decline in soil organic C occurred at all three sites after clearcutting. Approximately 20 and 50 percent of the original soil C was lost over a 50-year period for the regenerated forest and the land converted to agriculture, respectively. Only after the agricultural lands were abandoned did soil C levels at these sites begin to recover, and the simulation indicates that current rates of C accumulation are nearly the same for all three sites. The simulations also suggest that current rates of total ecosystem C accumulation are the same for the three land-use histories.

Effects of Land Use and Management Intensity on Soil Carbon in the Lake States

Terry Strong reviewed the results of several studies that focused on the effects of land use and management intensity on soil C in the Lake States Region. He focused specifically on species comparisons (red pine vs. hardwoods and hybrid poplar vs. crops), soil compaction, and forest floor removal after whole-tree harvesting of aspen, and harvest intensity in hardwood stands.

In comparisons of red pine and hardwoods, C in the total standing crop was the same for both species (Don Perala and Jeanette Rollinger, unpublished data on file at Rhinelander, WI). The total amount of soil C was also the same under both species, though the distribution differed by depth. Red pine sequestered more C under cool, moist climates, whereas hardwoods sequestered more C in warm, dry climates.

In hybrid poplar plantations, soil C was correlated positively with stand age (Hansen 1993). Soil C gain was most significant in the 30 to 50 cm layer and was attributed to tree root growth. Soil C was significantly greater under hybrid poplar plantations than under adjacent cultivated crops after 15 years of plantation establishment.

Soil compaction and forest floor removal after harvest of aspen forests had little or no impact on soil C immediately after harvest (Alban et al. 1994). One year after harvesting, soil C in the 0 to 10 cm layer increased, presumably as a result of root death.

Harvest intensity in northern hardwoods did not significantly impact total aboveground C. However, the distribution of aboveground C did differ among cutting intensities and was related to the amount of light penetrating the canopy (Terry Strong, unpublished data on file at Rhinelander, WI). Soil C storage correlated weakly with cutting intensity; less soil C was associated with increasing cutting intensity.

Soil Carbon and the National Carbon Budget

Linda Heath closed with a discussion of forest C in the context of the national C budget. The U.S. Government and other signatory countries of the Framework Convention on Climate Change have agreed to address the issue of global climate change and are committed to adopting policies designed to stabilize atmospheric greenhouse gas concentrations. The U.S. Government has committed to reducing this country's greenhouse gas emissions to 1990 levels by 2000. Net greenhouse gas emissions in the United States were estimated at 1,442 million metric tons (MMT) of C equivalent for 1990 and are expected to increase by about 7 percent by 2000 without the implementation of the Government's Action Plan (U.S. Gov. 1994). Under the plan, net emissions are projected to be reduced by about 108 MMT by 2000. This will be accomplished by promoting the use of energy-efficient products and renewable-energy technologies. The plan calls for a reduction in the depletion of nonindustrial private forests, acceleration of tree planting in these forests, and shifts to alternative timber harvesting methods that reduce disturbance and promote C sequestration. These measures are projected to offset emissions by at least 10 MMT.

The Forest Service is using forest resource inventories such as "Forest resources of the United States, 1992" (Powell et al. 1993), estimates of timber production and utilization, and forest growth and C budget models to predict the impacts of disturbance (harvesting, wildfires, and land use changes) on forest C dynamics and on the potential for C sequestration in forest systems (Fig. 6). One source of uncertainty is the assumption regarding the impact of forest disturbance on soil C dynamics. Currently, the model assumes that 20 percent of the soil C is lost after clearcut harvest and that original levels are regained after some period of time unless the land is converted to agricultural use, in which case soil C could decline further depending on the degree of soil disturbance. The purpose of this workshop, as previously stated, was to re-evaluate these assumptions.

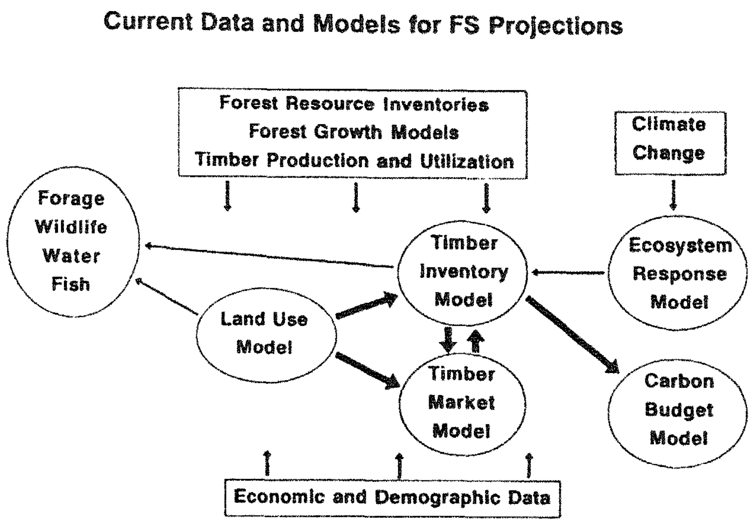


Figure 6.—Current data sources and models for Forest Service projections.

Summary of Working Group Discussion

Workshop participants presented and discussed available data and the current state of knowledge regarding the effects of disturbance on forest soil C. Participants agreed that insufficient data are currently available from which to estimate, with confidence, the impact of disturbance on soil C for all major forest types. Most available data were reviewed by Kristiina Vogt and Dale Johnson in their overview presentations. Participants generally agreed with the conclusion reached by Dale Johnson that current evidence indicates no general net change in soil C due to disturbance. His analysis of the literature revealed little or no change in the majority of situations, but in some situations disturbance had a negative effect on soil C and in others it had a positive effect.

Data supplied by workshop participants are given below by geographical region. This compilation is not comprehensive, but represents the data that, in conjunction with the data summarized in the overview presentations, were used by workshop participants to address the issue of management impacts on soil C dynamics.

Southeastern Region

Table 1.—Organic matter (OM) in vegetation and soil for a 25-year-old, even-aged, second-rotation slash pine (*Pinus elliottii*) plantation before and after clearcutting.

Vegetation/soil	Before harvest	After harvest	2 years after harvest
	Mg OM ha^{-1}		
Trees	160	0	5
Understory	5	0	5
Forest floor	35	70[a]	40[b]
Mineral soil	125	125	125

[a]Forest floor "debris" determined from mass balance.
[b]Measured as part of the mineral soil.
Source: Gholz and Fisher 1982.

Site preparation after harvest consisted of roller chopping, broadcast burning, machine bedding, and planting. Site preparation did not involve fertilizer application, herbicide use, or thinning. Although there is a change of 5 Mg OM ha^{-1} that is not accounted for, there is no indication that this reflects anything other than measurement and statistical (averaging) errors or effects. For this scenario, the assumption is that organic matter in the mineral soil is constant.

Table 2.—Carbon in vegetation and soil for adjacent watersheds at Coweeta.

Vegetation/soil	30-year white pine	Old hardwood
	..........................Mg C ha^{-1}	....
Vegetation	127	145
Forest floor	14	14
Soil to 90 cm	38	71

Source: Personal communication, Dan Binkley, Colorado State University.

One watershed has been undisturbed since the 1920's ("mature" hardwoods, mostly oak); the other was harvested in the 1950's and subsequently planted to white pine (hardwoods were suppressed with herbicides).

Table 3.—Carbon accumulation rates for vegetation and soil in a loblolly pine forest.

Vegetation/soil	Carbon accumulation rates
	kg C $ha^{-1}yr^{-1}$
Vegetation	4,130
Forest floor	513
Mineral soil to 60 cm	0.07

Source: Richter et al. 1993; personal communication, Dan Binkley, Colorado State University.
Note: The top 15 cm of a nearby hardwood forest that has not been cultivated for a long period had about 10 Mg ha^{-1} more C.

The site was cultivated and planted in cotton until 1954 at which time it was planted to loblolly pine. Eight plots established in 1962 have been resampled every 5 years and the soils archived. The soil is a clayey, kaolinitic, thermic Typic Kanhapludult. Richter et al. (1993) used ^{14}C bomb carbon to estimate turnover rates. "Subsoil" (60 to 110 cm) dated to about 2000 years BP. About 65 percent of the A horizon carbon was in an active pool that turned over in about 12 years.

Northeastern and North Central Region

Table 4.—Carbon in overstory, detritus, forest floor, and soil in managed and unmanaged second-growth hardwood forests.

Component	Unmanaged	Managed
	..................Mg C ha^{-1}	....
Trees cut (1951-1991)	0	74
Total aboveground standing (1991)	118	81
Detritus (total)	71	69
Logging slash (1951-1991)[a]	0	17
Roots, cut trees (1951-1991)	0	19
Roots, standing trees (1991)	29	18
Dead trees (1951-1991)	33	12
Roots, dead trees (1951-1991)	9	3
Forest floor	17	19
Soil	110	100

[a]Breakdown of C in detritus.
Source: Personal communication, Terry Strong, USDA Forest Service.

Data are from a replicated study on a good-quality site. The treatment applied in the managed plots is typical of management practices applied to hardwoods in the Lake States and Northeast.

Cutting began in 1951 and was repeated every 10 years with residual overstory basal area around 18 m^2 ha^{-1}. There is no initial data for C in detritus, forest floor, or soil. Therefore, comparisons can be made only between present managed and unmanaged stand conditions.

Western Region

Table 5.—Estimated organic matter (OM) associated with residues and soil components of three old-growth forests representative of the northern Rocky Mountains.

Component	Organic matter content
	... Mg OM ha^{-1} ...
Pseudotsuga menziesii/Physocarpus malvaceus[a]	
Residue	45.1
Soil wood	37.0
Forest floor	26.3
Mineral soil, 0-5 cm	29.1
Mineral soil, 5-30cm	73.4
Abies lasiocarpa/Clintonia unifloraa[a]	
Residue	145.7
Soil wood	35.9
Forest floor	36.0
Mineral soil, 0-5 cm	26.1
Mineral soil, 5-30 cm	85.8
Tsuga heterophylla/Clintonia uniflora[a]	
Residue	83.2
Soil wood	50.5
Forest floor	49.7
Mineral soil, 0-5 cm	29.3
Mineral soil, 5-30 cm	68.6

[a]Habitat type.
Source: Harvey et al. 1987.

Table 6.—Quantity of soil organic matter (OM) from old-growth and second-growth forests distributed throughout the Inland Northwest.

Site location	Dominant tree	Age	Treatment[a]	Total OM in soil core[b]
		Years		Liters
Old-growth:				
W. Montana	Western hemlock	250	Undisturbed	0.82
W. Montana	Subalpine fir	250	Undisturbed	0.77
N. Idaho	Western hemlock	250	Undisturbed	0.54
W. Montana	Douglas-fir	250	Undisturbed	0.50
N. Idaho	Western white pine	250	Undisturbed	0.43
E.Washington	Ponderosa pine	200	Undisturbed	0.38
N. Idaho	Western hemlock	250	Undisturbed	0.32
NW. Wyoming	Lodgepole pine	165	Undisturbed	0.15
Second-growth:				
W. Montana	Lodgepole pine	50	WF	0.42
W. Montana	Douglas-fir	80	WF	0.39
W. Montana	Western larch	15-25	CC-BB	0.32
W. Montana	Douglas-fir	60-120	I-SC	0.26
W. Montana	Ponderosa pine	80-100	PC-UB	0.12
W. Montana	Lodgepole pine	15	WF	0.12

[a]Undisturbed=no history of human disturbance, WF=wildfire, CC-BB=clearcut with broadcast burn, I-SC=intermittent selective cut, PC-UB=partial cut with underburn.
[b]Mean liters per core.
Source: Harvey et al. 1986.

In general, high-productivity, old-growth forests had high organic matter reserves, whereas low-productivity, old-growth and second-growth forests had lower organic matter reserves.

Table 7.—Soil organic matter content as affected by site preparation technique in two northern Idaho stands.

Site treatment	Organic matter	
	Low elevation[a]	High elevation[b]
	Percent	
Mounded	15	28
Scalped	9	15
Undisturbed	14	29

[a]*Abies grandis/Symphoricarpos albus*, elevation 715 m.
[b]*Tsuga heterophylla/Clintonia uniflora*, elevation 1,456 m.
Source: Page-Dumroese et al. 1991.

Pacific Northwestern Region

Table 8.—Soil C data for Washington state, by species.

Species	Site quality[a]	Years since clearcut	Woody debris[b]	Forest floor O horizon	Soil carbon
			$Mg\ C\ ha^{-1}$		
Alnus rubra	IV	36	10	23	93 (60)[c]
Pseudotsuga menziesii	IV	36	3	8	64 (60)
Pseudotsuga menziesii	IV	1	nd[d]	5	46 (15)
Pseudotsuga menziesii	IV	10	nd	8	46 (15)
Pseudotsuga menziesii	IV	40	nd	14	29 (15)
Pseudotsuga menziesii	IV	70	nd	14	41 (15)
Pseudotsuga menziesii	IV	150	nd	15	29 (15)
Pseudotsuga menziesii	II	1	nd	17	145 (15)
Pseudotsuga menziesii	II	10	nd	9	64 (15)
Pseudotsuga menziesii	II	40	nd	12	41 (15)
Pseudotsuga menziesii	II	70	nd	12	70 (15)
Pseudotsuga menziesii	II	150	nd	10	64 (15)

[a]IV=low site quality, II=high site quality.
[b]Includes woody debris less than 1 cm in diameter.
[c]Numbers in parentheses represent the depth of analysis in cm.
[d]nd=no data.
Source: Vogt 1987; personal communication Kristiina Vogt, Yale University.

Conclusions

*Data are insufficient to confidently estimate the impact of disturbance on soil C dynamics for all of the major forest types in each geographical region of the United States.

*Available evidence indicates no net change in soil C, on average, following disturbance.

*Assessing the impact of disturbance and alternative management practices on soil C using available data is difficult due to the lack of standardization of sampling depth and intensity, sampling protocols, and methods of chemical and physical analysis. Also, many studies lack accurate measurements of bulk density, adequate control plots, or sufficient replication.

Recommendations

*Access and collate existing data into a comprehensive database to be used for evaluation of the impact of disturbance and alternate management practices on forest soil C dynamics.

*Use existing databases (e.g., the Soil Conservation Service database, which contains detailed characterization of forest soils distributed globally).

*Reanalyze archival soils and resample existing plots to assess long-term trends in C storage.

*Initiate long-term, standardized field experiments designed specifically to address the issue of disturbance and management effects on soil C dynamics.

*In addition to determination of total organic C and N, analyze samples for functionally meaningful fractions including microbial biomass C and N, mineralizable C and N, and particulate organic matter C and N.

*Employ process-level ecosystem models (e.g., Century) to integrate field data and to make predictions at the regional or global scale.

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Workshop Participants

Dan Binkley, U.S. Forest Service, A116 NESB, Colorado State University, Fort Collins, CO 80523 Phone: (970)491-6519 Email: dan@cnr.colostate.edu

Richard Birdsey, U.S. Forest Service, 100 Matsonford Road, Radnor, PA 19087 Phone: (610)975-4092 FAX: (610)975-4095 Email: rbirdsey@lunar.nena.org

Mac Callaway, RLG/Hagler Bailly, PO Drawer O, Boulder, CO 80306-1906, Phone: (970)449-5515, FAX: (970)443-5684 Email: jcallawa@habaco.com

Vern Cole, Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, CO 80523-1499, Phone: (970)491-1990 FAX: (970)491-1965 Email: vern@nrel.colostate.edu

Ted Elliott, Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, CO 80523-1499, Phone: (970)491-5645 FAX: (970)491-1965 Email: tede@nrel.colostate.edu

Doug Fox, Terrestrial Ecosystems Regional Research and Analysis Laboratory, 1201 Oak Ridge Dr., Ste. 100, Fort Collins, CO 80525-5562, Phone: (970)282-5475, FAX: (970)282-5499, Email: dfox@terra.colostate.edu

Henry Gholz, U.S. Agency for International Development, 413B, SA18, G/ENV/ENR Washington, D.C.

20523-1812, Phone (703)812-2269 FAX: (703)875-4639 Email: hgholz@usaid.gov

Linda Heath, U.S. Forest Service, Pacific Northwest Research Station, PO Box 3890, Portland, OR 97208, Phone: (503)321-5850 FAX: (503)321-5901

Dale Johnson, Desert Research Institute, PO Box 60220, Reno, NV 89506, and Environmental and Resource Science, University of Nevada, Reno, NV 89512, Phone: (702)673-7379 FAX: (702)673-7485 Email: dwj@maxey.unr.edu

Carole Klopatek, U.S. Forest Service, Department of Microbiology, Arizona State University, Tempe, AZ 85287-2701, Phone: (602)965-9757 FAX: (602)965-2012

Keith Paustian, Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, CO 80523-1499, Phone: (970)491-1547 FAX: (970)491-1965 Email: keithp@nrel.colostate.edu

Bill Pulliam, Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, CO 80523-1499, Phone: (970)491-1919 FAX: (970)491-1965 Email: pulliam@nrel.colostate.edu

Kurt Pregitzer, Michigan Technological University, Rt. 1, Box 356B, Houghton, MI 49931, Phone: (906)487-2396 Email: kspregit@mtu.edu

Dave Schimel, National Center for Atmospheric Research, PO Box 3000, Boulder, CO 80307-3000 and Natural Resource Ecology Laboratory, Colorado State University, Ft. Collins, CO 80523-1499 Email: davesc@nrel.colostate.edu

Terry Strong, NCFES, 5985 Hwy K, Rhinelander, WI 54501, Phone: (715)362-1124

David Turner, MERSC, U.S. Environmental Protection Agency, 200 SW 35th, Corvallis, OR 97333 Phone: (503)754-4769 FAX: (503)754-4228 Email: dave@heart.cvr.epa.gov

Kristiina Vogt, Yale University, 370 Prospect Street, New Haven, CT 06511, Phone: (203)432-5076 FAX: (203)432-3929

Steven Winnett, U.S. Environmental Protection Agency, 2122, 401 M Street SW, Washington, D.C. 20460, Phone: (202)260-6923 FAX: (202)260-6405 Email: winnett.steven@epamail.epa.gov