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Biotechnol. Agron. Soc. Environ. 2000 **4** (4), 285–289

Carbon stocks estimates for French forests

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This paper gives a short description of the data and methods used for inventorying the carbon stocks in the biomass and soil pools in metropolitan French forests. The data concerning the biomass pools are measured by the French National Forest Inventory (NFI) while data necessary to estimate the soil carbon pools are obtained from the 16 × 16 km soil inventory of the International Cooperative Programme on Assessment and Monitoring of Air Pollution Effects on Forests in the UN/ECE. Some of the problems raised by the implementation of the Kyoto protocol articles 3.3 and 3.4 in France are discussed and a preliminary estimate of the changes in relevant carbon storage is given.

Keywords. Carbon stock, forests, Kyoto Protocol, France.

1. INTRODUCTION

The "Centre Interprofessionnel Technique d'Études de la Pollution de l'Air (CITEPA, on line: <http://www.citepa.org>) is in charge of the National Communication (NC) on greenhouse gas emissions. The NC2 was submitted in November 1997.

The articles 3.3 and 3.4 of the Kyoto Protocol request that the amount of carbon stored in different pools of forest ecosystems of industrialised countries (Annex B countries) and its changes in time must be estimated with transparent and verifiable methods. The main carbon pools of a forest ecosystem are the biomass of living trees, including their dead parts, biomass of understorey plants, litter and woody debris and soil organic matter. The other pools represent a negligible part of the entire ecosystem carbon stock, e.g., the soluble soil carbon or higher-order producers and decomposers. Soil carbonates, such as calcium carbonate, may represent a large stock of carbon but its residence time is several order of magnitude longer than organic pools. The resulting carbon loss occurs mainly as leaching of soluble carbonates and does not generally result in CO_2 emissions. Conversely, under drier climates, carbonates may precipitate in the soil profile and produce CO_2 emission but this would be negligible as compared with organic carbon cycling. Only the carbon stored in the soil organic matter and biomass of French metropolitan forests is considered in this paper. This paper gives the main outlines of the national assessment of forest carbon stocks while related definitions and technical details are documented in the appendices.

2. SOIL CARBON ESTIMATE

Available data are as follows:

– soil analysis from the 540 plots of the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests of the United Nations – Economic Commission for Europe (<http://www.dainet.de/bfh/inst1/12/>). Soil cores have been taken in 1993–1994 on a systematic grid of 16 × 16 km covering the entire French forests. The network is further abbreviated as the "16 × 16 network". Therefore, owing to this systematic sampling design, this sample may be regarded as unbiased. Soil cores were taken in each plot for each 10 cm layers until a depth of 40 cm.

– soil analysis data from the RENECOFOR network which includes 102 forest plots. These plots correspond to the level III of the IPC network. Soil have been sampled in 1993 and 1995. However, this network was not designed for sampling forest soils but rather forest vegetation. Hence, the soil data collected may not be regarded as a representative sample of the French forests. For instance, acid soils are oversampled.

From the 16 × 16 network, the mean carbon stock in the forest litter, humus + soils between 0 and 0.4 m depth was estimated to 92 $t\ C{\cdot}ha^{-1}$, litter and humus layers accounting for 9%, the top 0–10 cm layer to 40%, and deeper layers to 24, 14 and 14%, respectively (recalculated from Dupouey *et al.*, 1999). For the 0–30 cm layers, a second evaluation based on the data collected in both the 16 × 16 and RENECOFOR networks weighted by the soil type / land use surface areas (Arrouays *et al.*, 1999) provided a value of 68 t C·ha^{-1} close to the 16 × 16 estimate of 70 t C·ha^{-1}.

The soil carbon amount is characterised by a high spatial variability, which cannot be directly related to environmental variables such as those measured by the French National Forest Inventory (NFI). At the moment, this impedes to use the data collected by the NFI in estimating the soil carbon stocks in forests at the national level or for coupling the national soil and forest databases.

The evolution of the soil carbon pool is not well documented in France: data from repeated measurements of soil carbon stock are not yet available in forests where only local and limited studies were achieved. However, such data will be available in the near future: the RENECOFOR network will be re-measured ten years after the first soil sampling campaign and the 16 × 16 network will also probably be measured a second time in a foreseeable future. These repeated measures will allow a first assessment of the evolution of forest carbon stocks in France.

3. BIOMASS CARBON POOL ESTIMATES

3.1 Local estimates

The estimate of the biomass carbon pool in French forests is derived from measurements of trunk volume achieved by the NFI, assuming that stem, crown and root biomasses can be apportioned to overbark trunk volume using simple coefficents. Conversion coefficients are successively:
– volume expansion factors for “crown” and “roots” which allow to calculate the volume of the entire tree;
– basic density values which allow to convert volume in dry mass;
– carbon content. A common value of 0.5 is applied for each compartment;
– additional data when necessary, such as expansion factors to include leaves or needles and understorey (herbaceous and woody species).

Two sets of values are available. The first consists in bulk values published by FAO (**Table 1**) (United Nations, 1986). Mean values of the conversion coefficients for temperate forests were calculated from available data published. These values are used in subsequent calculations and resulting estimates of carbons stocks in biomass have been published in France (Direction de l’Espace Rural et de la Forêt, 1995) and by the United Nations Economic Commission for Europe, Food and Agriculture Organization of the United Nations (2000).

Table 1. Conversion coefficient used by FAO – UN – EEC (1986) for estimating carbon stocks in the biomass pools (first assessment).

	Volume biomass/ volume measured (m^3·m^{-3})	**Dry weight/ volume** (t·m^{-3})
wood		
coniferous	0.86	0.40
broadleaved	0.87	0.55
bark		
coniferous	0.14	0.35
broadleaved	0.13	0.35
other biomass above ground		
coniferous	0.30	0.40
broadleaved	0.40	0.55
stump and roots		
coniferous	0.20	0.40
broadleaved	0.20	0.50

The second set of conversion coefficient values is only available for research use. It aims at improving the accuracy and precision of the first assessment by using more detailed results recently obtained by forest research. The main improvements under examination are listed in **table 2**. They consist in:
– integrating an individual stem volume effect for estimating the branch expansion factor in Quercus (oak) and Fagus (beech) species (Bouchon *et al.*, 1981);
– estimating basic wood density per species;
– for coppices, direct estimate of the biomass through specific allometric relationship (Auclair, Bige, 1984).

These recent data include also a large uncertainty due to the low sample size of allometric studies, and high variability of the expansion factors and conversion coefficients, within a tree, between trees and between species.

3.2. Upscaling at the country level

The estimate of the global carbon stock in biomass pools of French forests depends on the timing of NFIs. The NFI is continuous with a period of 10–12 years. Every year, 8 to 10 “départements” among 94 in metropolitan France are measured, using only temporary plots. The country estimate results from a simple aggregation of the most recent results obtained in each “département”, without actualisation. In other words, the national estimate at a given date is a sum of the data measured over the last 10–12 years,

Table 2. Data and results used for estimating carbon stocks (2nd assessment).

Variable	Source of data, values used
Volume (stem + branches)/ Volume stem	highforest : – oak and beech: detailed ratios according to the stem volume (Bouchon *et al.*, 1981) – other broadleaved: the same as oak
	standards (Bouchon *et al.*, 1981) – beech: 1.7 – oak and other broadleved: 1.6
	coniferous : 1.125
Volume (stem+ branches + roots) /Volume (stem + branches)	broadleaved: 1.19
	coniferous: 1.235
Dry mass/ Volume	wood density by species
coppices	a specific equation gives the dry weight of the stand according to the volume and the number of stem per ha (Auclair, Bige, 1984)
Complementary components	ground vegetation and deadwood (t C·ha^{-1}) – maritime pine: 4 – other: 1
	needles and leaves (t C·ha^{-1}) – coppices: 1.4 – highforests: beech: 1.7; oak and other broadleaved: 2; coniferous: 6

average date being 6–8 years before the reference date. For instance, the value calculated in 1999 was corresponding at an average year of 1991. The bias introduced through this shift in time may be significantly higher than the error on the estimates, which is 1% of the total for commercial wood.

4. MAIN RESULTS

4.1. mean stock per hectare

Table 3 gives the values obtained from 1979 to 1991. It is worthnoting more than half of the mean forest stock is accounted by the soil, litter and organic layers pool. For the period covered by inventories, the biomass pool has been increasing at a rate of 0.5 – 0.6 t C·ha^{-1}·y^{-1} according to either the first or the second assessment.

Table 3. Mean carbon stocks per ha calculated for French forests.

	Date	Carbon stock t C·ha^{-1}	
soils	1993–94	79	
		1st assessment	2nd assessment
biomass	1979		53
	1981	48.3	
	1986	51.4	
	1991	54.6	59

4.2. Estimate of the carbon stock at the national level

From 1979 to 1991, the forest area in France increased from 13.82 to 14,53 Mha at an average rate of 59,000 ha·y^{-1} and the biomass carbon stock increased from 732 to 857 Mt C (+ 11.2 Mt C·y^{-1}). The net increase is the balance over the period 1979–1991 between a net production –including the recruitment of new forests– of 30 Mt C·y^{-1} equivalent to 83 Mm^3·y^{-1} and losses (natural mortality and harvests) of 19 Mt C·y^{-1} equivalent to a net uptake (mortality + harvest) in commercial wood reaching 52.6 Mm^3·y^{-1}. When compared to the annual carbon emissions in France, excluding forests and forest management), which reached an average of 110 Mt C·y^{-1} over the period 1987–1997 (CITEPA, personal communication) the forests have compensated for 10% of these emissions.

5. ESTIMATES RELATED TO THE ARTICLES 3.3 AND 3.4 OF THE KYOTO PROTOCOL

The Kyoto protocol includes the possibility of accounting for the sink of greenhouse gases due to activities such as land use, land use change and forestry. Preliminary estimates of this carbon sink have been calculated for France in July 2000. These calculations, based on the NFI data, are available on line at <www.unfccc.int/resource/docs/2000/sbsta/misc06.pdf>.

The article 3.3 defines the accounting rules related to afforestation, reforestation and deforestation (ARD). It specifies that the net carbon stored or released between 2008 and 2012 in stands concerned by one of these three activities since 1990 must be accounted for. This raises several difficulties. First is the estimate of the area of afforested lands. At the moment, the land area concerned by ARD activities is small; 15,000 $ha \cdot y^{-1}$ are deforested while 8,500 $ha \cdot y^{-1}$ are afforested artificially by plantation and error associated with these values are relatively high. Second, the NFI's data are not measured simultaneously which makes difficult to provide a precise estimate for the whole national territory at a given date. For instance, the current inventory covers the period 1981–1990 but extreme dates for two consecutive measurements in a given "départment" are 1975–1986 and 1988–1999. On this particular point, the use of data from annual inventories of land use (TERUTI) must be considered (Agreste, 1993; Agreste, 1999).
Carbon stock change in the biomass pool has been calculated using the parameters described in **table 1** with the following adjustments:

– deforestation is considered to induce an immediate loss of the entire biomass pool;
– the change in stand volume for the afforested and reforested stands younger than 20-years is calculated using specific age-volume relationships for the following types: broadleaf, coniferous plantations and other coniferous.

The carbon stock change of the soil pool was estimated only for the land-use changes according to the following model (Balesdent, Arrouays, 1999):

$$C_i(t+dt) = E_i + (C_i(t) - E_i) \exp^{(-k_i \cdot dt)} \qquad \mathbf{(1)}$$

where
$C(t)$ is the carbon stock at time t in $t\ C \cdot ha^{-1}$,
E is the steady state carbon stock for a given land use type in $t\ C \cdot ha^{-1}$,
k is a kinetic parameter in year,
i denotes the soil organic matter type, according to its turn-over rate.

For each land use type, equation (**1**) is applied to two organic matter types, first with a fast turn over rate, second with a slow turn over rate, the parameters E, and k differing between those two types. The initial situation of the soil in a given land use type is assumed to be a steady state. This assumption leads to maximise the changes in time of the soil carbon stocks and to overestimate the carbon fluxes. The fate of deforested lands and initial land use type of reforested and afforested lands have been mainly obtained from the TERUTI inventory.

The article 3.4 will allow to integrate additional activities for accounting for carbon exchange from forests. Three activities have been considered in the French national report:
– forest management of forest stands submitted to a management plan before 1990. The net increase in the carbon stock in the biomass has been considered as a result of management: it was estimated according to the method described in §2;
– conversion from coppice with standards to high forests. The forest inventory data were used to estimate the area of stands converted at 18,400 $ha \cdot y^{-1}$ from 1981 to 1992. Two additional parameters were estimated from the forest inventory data: the duration of conversion which was estimated to 40 years and the increase in standing stock due to conversion, + 3 $m^3 \cdot ha^{-1} \cdot y^{-1}$.
– the increase of the carbon stored in the wood product pool. This calculation was achieved by a private expert, Serge Lochu. The amount of carbon stored in wood products in France was assessed from data about the consumption of wood each categories of wood products during the 20th century and the life duration of each type. Two predictions have been calculated according to two different values of economy growth rate: 1 and 3% respectively.

6. CONCLUSION

Most of the data estimated until now fit under working group I related activities (inventory of C sinks and sources). They give preliminary estimates of carbon stocks and carbon stock changes in time. An understanding of the errors and uncertainties associated with those values and standardization of methods and definitions between countries are still necessary as far as those values must be used in commercial or political negotiations. It was beyond the scope of this paper to discuss the main factor of uncertainty and errors associated with the data presented here, but there is evidently a need to refine expansion and conversion coefficients, to set up methods for actualising inventory data at a reference date, coupling soil and biomass inventories.

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Manuscript received 23 October 2000