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Organic carbon concentrations and stocks in Romanian mineral forest soils

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Abstract. Estimating soils organic carbon stock and its change in time is an actual concern for scientists and climate change policy makers. The present article firstly focus on determination of C stocks in Romania on forest soil types, as well as development of the spatial distribution mapping using a Geographic Information System (GIS) and also the secondly on the quantification of uncertainty associated with currently available data on C concentration on forest soils geometrical layers. Determination of C stock was done based on forest management plans database created over 2000-2006. Unlike original database, the data for this study was harmonized on following depths: 0-10 cm, 10-20 cm, 20-40 cm, and > 40 cm. Then, the obtained values were grouped by soil types, resulting average values for the main forest soils from Romania. A soil area weighted average value of 137 t/ha is calculated for Romania, in the range of estimations for other European geographic and climatic areas. The soils that have the largest amount of organic carbon are andosols, vertisols, entic and haplic podzols, whereas the ones that have the smallest values of organic carbon are solonetz and solonchaks. Although current assessment relies on very large number of samples from the forest management planning database, the variability of C concentration remains very large, ~40-50% for coefficient the variation and ~100% of the average, when defining the range of 95% of entire soil population, rather showing the variability than uncertainty of the average estimated. Best fit for C concentration on geometric layers in any forest soil is asymmetric, associated with log-normal distributions.
Keywords forest, GIS mapping, soil carbon, soil types, variability, uncertainty.

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Introduction

Soil organic matter (SOM) is a mixture of dead plant residues in various stages of decomposition and microbial or chemically synthesized substances from the breakdown products (Ståhl et al. 2004). Soil organic matter is a key component of any terrestrial ecosystem, and any variation in its abundance and composition has important effects on many of the processes that occur within that system (Batjes 1996). Terrestrial ecosystems are a major sink for atmospheric carbon (C)(Schimel et al. 2001), although susceptible to erratic emissions by disturbances.

Soils contain twice as much carbon as the atmosphere and about 75% of the total terrestrial organic carbon pool (Prentice 2001). The global storage of C in soils is the largest C pools of terrestrial ecosystems, two to three times larger than the C pool of vegetation (Schlesinger 1991). Globally, forests store large amounts of carbon sequestered from the atmosphere and retained in living and dead biomass and soil (Whithead 2011). Over 40% of the soil carbon is found beneath forests. In Europe, forest soils store roughly 1.5 times more carbon than tree biomass (EC/UN-ECE, 2003). The carbon stored in forest soils can be directly managed to absorb or release atmospheric carbon to a degree that may have global implications (Johnson & Curtis 2001, Paul et al. 2002, Lal 2005).

However, forest soil carbon pools are not well studied compared to the aboveground carbon pools (Lal 2005, Peltoniemi et al. 2007). The large spatial variability in forest soil organic matter has also limited our ability to predict its spatial distribution (Johnson et al. 1991, Yanai et al. 2000, Fahey et al. 2005, Geambaşu et al., 2004). Inventory and analysis of soil organic carbon (SOC) are required for soil quality assessments (Sikora & Stott 1996) and carbon cycling predictions (Ellert et al. 2002), which are valuable tools for state and regional planning by policy makers (e.g. politicians, regulators, and agency employees)(Amichev & Galbraith 2004).

Estimates of forest soil organic carbon (SOC) have applications in to biogeochemical science, soil quality studies, develop CO_2 removal technologies, as well as for emissions reduction compliance or trading, with the purpose of either to determine long-term carbon fluxes or to manage natural resources and to design carbon sequestration strategies (Campbell et al. 2008). The UNFCCC's national GHG inventory and its emission reduction oriented Kyoto Protocol require the CO_2 emissions or removal from carbon stock changes on land use and activities at UNFCCC's (Annex I) countries to be reported as annual estimates along a specified period of time. It also calls for establishing carbon stock baselines in land project based activities, since for practical purpose, in order to estimate the change in the carbon stocks of the soils, it is first necessary to establish its baseline. However, problems arising from soil sampling, soil variability, and soil depth make it a difficult task (Swift 2007). Furthermore, reliable local or national estimates are needed for international acceptance (Watson et al. 2000).

The main objective of this article is to understand the variability and uncertainty associated to concentration of organic C in mineral forest soils and to determine the organic carbon stocks of the main forest soil types in Romania as well as to provide its spatial distribution on a country level GIS map.

Materials and methods

Analysis is made on pest 2000 soil records available with forest management plans database (FMP) archived by ICAS (Forest Research and Management Institute, Romania). FMP is organized as hard copies, consisting in complete information about stands and sites characteristics and wood the production and productivity. Inherited from centralized economy of communist era, a plan consists in that the forest districts are subject to renewal of their forest management plan every ten years, so in a decade entire country's forests are revisited, with each occasion all parameters are reassessed and updated.

Description of the forest management plans database on forest soils

Soil data has been collected on Romanian forestry for the purpose of supporting planning of forest management activities and harvesting, starting with 70s. An individual FMP is developed for a production unit (UP) of some of 5-10 kha. Here, the stand and site data is recorded at a very disaggregated scale of forest parcels of area an of 0.3 to 30 ha. Further, several such UPs are managed in a forest district.

Soils sampling and analysis is achieved according a standard procedure approved as an official technical norm [(Ministerul Apelor, Pădurilor şi Protecţiei Mediului, 2000 - currently in force)]. Sampling plots are located randomly, but strictly following a pre-defined density, according to sites characteristics, with only condition that selected location is "representative", as based on the field assessor expert guess.

Sampling methodology assumes only mineral soil sampling, meantime dead organic matter layer on the top soil (i.e. litter and dead wood pools, according to Table 3.1.2., pag 3.15 of the IPCC (2003) is only qualitatively assessed based on its thickness and spatial uniformity of the layer. The methodology requires that a sample of 1 kg is gathered from a genetic horizon, after digging a soil pit (depth to more than 1 m or to rock bed for shallow soils). Two samples from different depths were gathered for the horizons that are larger than 20 cm. Preparation of soil samples was based on the ISO 11464 method (ISO 1994b). Samples are either air dried or oven dried at a temperature of 40 °C and stored until chemically analyzed (Cools & De Vos 2010). Analysis consisted in on organic matter (i.e. humus) determination. Further on, organic C concentration (g/kg), resulted by its multiplication with a coefficient of 0.58 as suggested by many authors (IPCC 2003, Sakin et al. 2010, Nelson & Sommers 1982, Fang & Xu 1996, Post et al. 1998, Scolt et al. 1999, Li & Zhao 2001). Laboratory method relies on dichromate oxidation technique, such as the Walkley-Black method and loss-on-ignition, which are still used worldwide (David 1988, Nelson & Sommers 1996, Yanai et al. 2000), but requires a factor that converts organic matter content to carbon content. The traditional conversion factor is 1.724, which is based on the assumption that carbon accounts for 58% of organic matter in soil (Fakahashi 2005), obviously a source of additional errors (i.e. compared to direct organic C analyze).

Database was further structured on soil types (following Romanian nomenclature, adopted from FAO) and standard depths (i.e. 0-10 cm, 10-20 cm, 20-40 cm, > 40 cm), following European monitoring activity procedure (Cools & De Vos 2010). Overall, it resulted in a total number of 10.027 values of C concentration for different types of soils and depths from 148 forest districts (more than 3000 soil profiles). Some 1500 samples were sampled and analyzed over 2000-2002, 7000 samples over 2000-2004 and a total of 10.000 samples over 2000-2006, along with the sampling. Analysis were performed by ICAS Braşov, which implements its own quality assurance system (e.g. 10 % of samples is blindly processed) and quality control like regularly participating to the European inter-calibrations exercises in the FutMon Project, (Cools & De Vos 2009).

Procedure of estimation of C stock on soil types

Currently, C stock for a given soil strata is estimated by extrapolating a SOC content per soil mass to SOC per soil volume, obtained by multiplying SOC by soil bulk density and soil layer depth. However, this approach does not

Table 1 Concentration of organic C (g/kg) on soil types and standard depths

Soil type	0-10 cm depth			10-20 cm depth			20-40 cm depth			> 40 cm depth		
	No. of samples	Average	Uncertainty (% to average)	No. of samples	Average	Uncertainty (% to average)	No. of samples	Average	Uncertainty (% to average)	No. of samples	Average	Uncertainty (% to average)
Chernozem	109	24.80	96	72	13.60	67	82	9.30	65	103	4.60	96
Phaeozem	177	30.20	79	97	16.50	73	129	10.10	60	150	5.50	96
Rendzic leptosol	143	36.00	81	73	21.00	75	88	10.50	81	50	4.60	92
Eutric cambosol	881	32.30	87	405	19.90	103	533	11.40	95	660	4.80	80
Dystric cambosol	673	32.60	85	279	21.60	92	365	12.20	119	449	4.90	72
Haplic luvisol1	328	27.50	85	168	15.60	68	234	9.20	60	294	4.80	70
Haplic luvisol2	578	31.50	77	345	15.80	72	416	9.50	69	542	4.80	72
Entic podzol	252	47.90	59	141	29.30	77	151	13.90	106	112	5.60	67
Haplic podzol	31	41.30	87	22	23.00	82	18	12.00	89	8	7.10	94
Vertisol	19	33.60	76	13	20.10	121	12	11.90	81	11	5.60	95
Andosol	14	45.80	87	14	31.40	90	13	19.90	144	6	13.00	147
Gleysol	65	28.10	88	25	15.20	89	50	10.60	59	48	5.50	68
Stagnic luvisol	37	29.10	131	22	13.60	69	28	9.40	57	33	4.80	84
Solonchak	29	18.90	85	20	11.90	79	20	7.60	61	32	4.50	57
Solonetz	23	20.70	88	15	13.20	69	13	8.60	29	23	3.80	56
Average	3345	33.19		1677	19.23		2139	11.45		2515	5.36	

Note: There are 2 kind of luvisols according to the Romanian soil classification: "preluvosol" (haplic luvisol 1:Ao-Bt-C) and "luvosol" (haplic luvisol 2: Ao-El-Bt-C) Lower and upper bound of the lognormal distribution Total number of samples is 3345 for 0-10 cm, 1677 for 10-20 cm, 2139 for 20-40 and 2515 for > 40 cm. Uncertainty is estimated as percent of half of difference between upper and lower bound (97.5% - 2.5% of the lognormal dis tribution) interval to average value

take into account that soil bulk density is variable between soils (Balesdent 1996). This may be the source of some error when soils with very different bulk densities are compared. In order to eliminate this inconvenience, different soil density values were used based on soil type and the standard depth. Thus, in order to calculate the quantities of organic carbon accumulated in different types of soils, according to the method described by Batjes (Batjes 1996), the values for each soil type were multiplied with the bulk density and with the standard's depths, however the values corresponding to a soil depth above 40 cm were considered by the soil type (e.g. chernozem 60 cm, rendzic leptosol 10 cm, etc.). The soils proportion of

coarse fragments was also taken into consideration.
Thus, we used the following formula:

$$C\text{-}stockmin = C\text{-}conc \cdot BD \cdot d \cdot CFst \quad (1)$$

where: *C-stockmin* is the C stock in the mineral soil (t/ha), *d* is the depth class/horizon thickness (m), *C-conc* is the concentration of organic carbon (g/kg), *BD* is the bulk density (kg/dm^3) and *CFst* is the correction factor for stoniness, with *CFst* = 100 − (% stones) / 100.

Country average values of soil apparent density and stoniness for each type of soil and depth were used as reported in the Romanian literature (Spârchez et al. 2011); thus apparent density was assumed either uniform (e.g. chernozem) or increasing with depth (ex: luvosol).

Further on, a country-wide, the average C stock in forest soils was derived by weighting the average C stocks and areas on soil types (estimated based on data from own GIS mapping/database).

GIS mapping

In order to provide a GIS map, the forest ecosystems geodatabase and its associated map (Doniță et al. 2008) was overlapped on Romania's soils map (National Institute of Research and Development in Soil Science, Agro-chemistry and Environment, INCDPAPM-ICPA, 2010) - resulting thus the forest soils spatial distribution. For each soil category (463 categories encompassing soil types, forms or varieties), an organic carbon value for the depth of 1 meter was assigned.

Statistical analysis

The database was developed in Microsoft EXCEL, while the statistical processing was achieved with STATISTICA 8.0 (Stat Soft Inc., 1984-2007) and @RISK (Palisade Inc, 2012). First purpose was to provide estimates of C stocks (tC/ha) on forest soils types. Missings of the collected values of C concentration for some soil horizons were gap filled by a procedure that consisted in pooling together all available data on each depth layer, thus determining the „average" C content on layers for each type of soil. Across processing, the values beyond two - standard deviations of original datasets were considered as outliers and removed from the pools used for estimation (although complete pools were maintained when testing the best fit). A theoretical assumption we do in this study is that the entire variability is naturally determined, and not linked to sampling, processing and analyzing errors; othernise it needs further consideration by bivariate analysis of uncertainty and variability, in a future work. Furthermore, current paper only assess the range of C stock based on input values, without considering the entire uncertainty and variability of inputs parameters, i.e. bulk density or coarse fragments presence (also subject to future assessment).

The processing focused on assessing the FMP database ability to allow assessing and estimating the likely variability of C concentration (g/kg) on soil geometric horizons and across the soil types. Because of this, the best fit was performed by Anderson-Darling test, which is sensitive to distribution's tails changes. The best fit was then compared to normal (as the simplest possible approach in uncertainty estimation) and lognormal distributions (as expected for a parameter which naturally ranges from 0 to +infinite, according Vose 2008).

Results

Organic C concentration variation based on soil type and depth

Although the C concentration decreases strongly with soil depth, its variation slightly decreases. The coefficient of variation (std/average; std approximated as the 95% interval divided to 4 for any type of distribution) of C concentration on layers is actually large, in average 50% for upper (0-10 cm) layer and around 40 % for all subsequent layers, for any type of soil. The distribution of almost all the values were right-skewed. Both skewness and kurtosis have shown highest values by Rendzic leptosols and Chernozems (Table 2). Noteworthy, assuming that soil C concentration is normally distributed would lead to an underestimation of true variability between -29% to 4% according to the soil type (Fig. 1). Additionally, such assumption would also induce a systematic underestimation of both lower bound values in average by -16 % (range -3 to -63%, on soil type) and upper bound by -7 % (i.e. range -0 to -35 %, on soil type).

For the upper 0-10 cm horizon, the largest variability was recorded for Andosol and Haplic Podzol, whereas the lowest variability can be claimed for Solonchak and Solonetz, soils that have, beside some specific characteristics (i.e. high amount of soluble salts and natrium cations), the lowest values of organic carbon. Higher variability is shown by above soils for deeper layers, under >40 cm depth. Noticeable, for each soil the best fit of C concentration data on depth was given by non-normal type of distributions, respectively asymmetrically positively skewed (i.e. log-logistic, Weibull, beta, inverscausian, log-normal, etc), with indeed negligible differences compared to the lognormal one.

Spatial distribution of organic carbon in Romania's forest soils

From the overview of the GIS map (Fig. 2), it can be seen that a representative area for the low quantities of organic C in the forest soils was Bărăgan Plain, the areas with larger quantities of organic C were the high mountains from the Meridionali Carpathian Mountains (i.e. Făgăraş and Lotru Mountains) and the areas with very large quantities of organic C were the volcanic mountains (i.e. Gutâi,

Table 2 The quantity of organic C (t/ha) accumulated in Romania's forest soils

Soil type	Organic carbon stock (t/ha)						Stdev on soil type	Stock assessment
	0-10 cm	10-20 cm	20-40 cm	>40 cm	0-100 cm	0-30 m		
Chernozem	30	17	22	35	104	58	8,9	Low
Phaeozem	35	21	25	45	126	69	7,9	Low
Rendzic leptosol	46	29	29	6	110	90	11,6	Low
Eutric cambosol	42	26	33	40	141	85	7,7	Moderate
Dystric cambosol	42	28	33	43	146	87	7,3	Moderate
Haplic luvisol1	38	23	31	44	136	77	5,8	Moderate
Haplic luvisol2	43	20	32	40	135	79	6,7	Moderate
Entic podzol	63	41	41	31	176	125	9,4	High
Haplic podzol	57	32	40	38	167	109	12,8	High
Vertisol	52	29	42	64	187	102	10,0	Hugh
Andosol	65	41	46	65	217	129	14,2	Very high
Gleysol	41	23	31	26	121	80	8,9	Low
Stagnic luvisol	42	22	30	36	130	79	8,8	Low
Solonchak	24	15	22	26	87	50	4,6	Low
Solonetz	23	16	15	15	69	57	5,3	Low
Total	43	26	31	37	137	84	8,3	Moderate

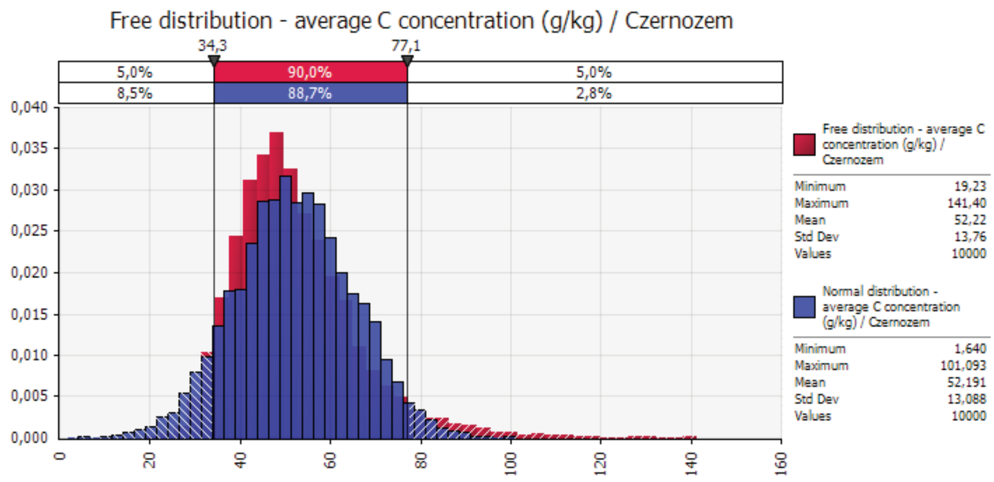

Figure 1 Normal vs. best fit for C concentration (g C/kg) in chernozem soil under forest (1 m depth) Monte Carlo simulated interval of 90% statistical coverage, showing left shifted free fit distribution, which also corresponding to a narrower interval of normal fit

Ţibleş, Giurgeu, Gurghiu).

Discussion

Variability and uncertainty in soil C stock estimation

When C concentration (g C/kg) on soil profile is concerned, there is an overall shift of the normal fit toward higher values, overestimating the true variability and uncertainty. Thus, *a priori* assuming a normal fit would lead to shift of entire distribution toward smaller values, underestimating the associated uncertainty.

Log-normal distribution of C concentration on soil horizons fits well for all soil types and horizons. Just to mention that under non-stratified determinations, our estimates and distribution shape reflect soil type „population" at country level (i.e. equivalent to „standard deviation" and not to „standard error of the mean"). Runs under best „free" and log-normal fits did not shown differences among themselves, while both were significantly different by the normal fit, for all type of soils. As an example, Fig. 1 shows the 'free' and normal fit for chernozem soils.

Knowing the uncertainty in the soil organic matter quantitative dynamics, there is a concern especially regarding C stock changes on short period of time (i.e. required in the framework of national greenhouse gas inventories under UNFCCC and supplementary reporting under Kyoto protocol). Nevertheless, both scientific community and policy makers make more and more difference between variability on one side, as an intrinsic particularity of sampled population, and uncertainty on the other side, which regards our inability to correctly measure and estimate the relevant parameter or proxies for estimating it. While variability is negligibly affected by the measurement methodology (assuming no systematic bias), the uncertainty associated to estimates needs much more attention starting with the representative sampling. This paper only discuss the uncertainty related issue (i.e. plots representatively, analytic method), but do not quantifies it.

Methodological consideration of data sampling and analysis

Simple approach of data analysis may not be appropriate for analysis of soil C concentration and stock, because of the asymmetry of distributions in current database. Any further development could be in direction of (i) more disaggregated stratification of country's forestlands and (ii) metadata analysis with all available parameters (including site, stand and productivity). For the first issue, currently implemented statistic inventory (the Romanian National Forest Inventory) responds by implementing a systematic grid at country level and repeated sampling of soil in the same plots. Second issue may not lead to better estimation of C stocks, but it would certainly help to provide better understanding and highlight the subtle links among the ecosystem C pools, depending on the intensively of statistic procedure for the trend of C stock on stand structure. Such results can be successfully used to prove or reject assumptions of a C pool being or not a net source of CO_2 on short/medium term, without measuring the actual fluxes, which is indeed relevant for political commitment of reducing emissions by the countries (paragraph 21 of Annex to Decision 16/CMP 1; UNFCCC, 2005). For the estimation of the soil organic C stock change it is also methodologically relevant that the fine roots pool (namely living and freshly dead fine roots under 2 mm diameter) are certainly neither included in the fine root biomass pool (with exception of models), nor in soil organic matter pool as excluded in the laboratory processing for organic matter pool estimation.

While database may not capture the effect of climatic change, it can be argued that it encompass average climatic conditions around 2000-2006, and on long run this can serve as reference level for C concentration in the forest soils.

A weakness arises form sampling under the framework of the technical norms requirements behind the database: non-specialized personnel poorly trained (technical norms were considered sufficient); quality assurance/control based on expert opinion; non-systematic but random spatial sampling. On the other hand, the benefit could come from high sampling intensity at local and country level in a cyclic approach, which can be valuable for determination of C stocks in the soil.

Despite showing clear benefit from rejecting normal distribution for C stocks in the soils, a weakness of the study may come from taken into consideration of different distributions of C concentrations on each soil type and horizon, according the best fit tested (thus lognormal assumed as common type). This is simply explained by paper's focus on lower and upper bound of the C stocks, as parameters for determination of the C stock variability. First hand lesson in fitting soil data show that distributions are positively skewed in all cases and long tails (especially positive) distributions fit better to continuous type of data. Despite triangular fit was suggested as best fit in few cases, it is likely not advisable in uncertainty analysis when lower/upper bounds are important. Also, normal fit led to unrealistic values by expanding to negative range (indeed by very low occurrence frequency).

Magnitude of the maximum C concentration in any soil type reaches 3-4 compared to the minimum value, also shown by the variation coefficient. This may raise the question either on the soil type, as the most appropriate proxy for soil stratification criteria, or on quality of data, for which it should be moreover understood from the perspective of the quality assurance/quality control procedures implemented by FMP system. Nevertheless, soil classification in FMP system actually relies on a combination of expert guess based criteria and analytic data, which may involve classification errors leading to non-homogenous "classes". Further analysis of better proxies can be made based on database if additional site information coupling soil with stand data becomes available.

Accumulation of organic C in forest soils in Romania

The largest variation of the quantity of organic carbon in the soil is recorded at the depths of 0-10 cm and 10-20 cm, whereas on the soil types, the decreasing hierarchy of the soils based on the variation of the recorded values is the following: (i) between 0 and 10 cm: Haplic podzol, Stagnic luvisol, Chernozem, (ii) between 10 and 20 cm: Rendzic leptosol, Andosol, Haplic podzol, (iii) between 20 and 40 cm: Haplic podzol, Andosol, (iv) over 40 cm: Andosol, Haplic podzol.

If the content of organic carbon is analyzed on standard depths, the richest soils are: Andosol, Entic podzol, Haplic podzol and Rendzic leptosol.

However, based on the quantity of organic carbon (t C/ha) across the soil profile, the decreasing hierarchy is the following: andosol (217 t/ha), vertisol (187 t/ha), entic podzol (176 t/ha) and haplic podzol (167 t/ha).

The differences between the two is caused by the small depth of the profile for Rendzic leptosol (which, even though is very rich in organic carbon, in the total profile appears as averagely rich with this element) as well as to the high values for the bulk density of Vertisol (1.56 g cm^{-3}).

For the soil types with moder or raw humus, the quantity of organic carbon in the first 20 cm (Andosol = 106t/ha, Entic podzol = 104 t/ha, Haplic podzol = 89t/ha-data from tab.2.) is suggestively bigger, because the organic matter is disintegrated incompletely and also richer in organic C.

Comparisons between the quantity of organic C stock from Romania and other countries

The information concerning the quantity of organic C for soils belonging to different types of ecosystems is rendered in Table 3, showing that the value that we have obtained for Romania's forest soils (13.7 kg m^{-2}) is situated very well within the known limits, being almost identical with the one specific to the cool temperate wet forest.

With regards to levels of accumulated C at the first 30 cm of soil profile (84 t/ha, the value for the first 30 cm from Table 2), in France, Arrouays et al. (2002) have calculated a stock of organic carbon of approximately 70t/ha in the 0–30 cm soil layer. The biggest quantity of organic C from Romania's forest soils in comparison with those from France can be explained by the superior productivity of our forests, especially those from hill and mountain areas whereas in France low values are registered in the Mediterranean forests.

In Italy, carbon stock was highly correlated with the type of land use (i.e. forest, meadow, arable land), soil moisture and temperature regimes, lithology, as well as morphological classes, and decreased notably in the second decade but slightly increased in the third one, passing form 3.32 Pg, to 2.74 Pg and 2.93 Pg respectively (Fantappie et al. 2010).

Quantitative estimates were obtained for the biogeocenotic variation of the carbon pool in autonomous soils of the European territory of the former USSR, which indicated a high spatial variability of this parameter. The variation coefficient for carbon pool to 1 m depth soil layer can reach 60% even in similar biogeocenoses within the same bioclimatic region (Rhyzova et al. 2008).

The SOC stock in the Republic of Ireland, to 1 m depth, has increased from 1,391 Tg in 1851 to 1,469 Tg in 2000 despite soil loss due to urbanization. This increase is largely due to the increase of afforested land which has higher SOC stocks compared to agricultural lands (Eaton et al. 2008).

In the forest soils of Swiss Alps, at stand level, the mean SOC stocks of 98 t C ha^{-1} (N = 168, coefficient of variation: 70%) were obtained for the entire mineral soil profile, 76 t C ha^{-1} (N =137, CV: 50%) in 0–30 cm topsoil,

Table 3 The quantity of organic C stock accumulated in soils from different areas of the planet

Area	C org. (t ha^{-1})	Source
The global average	113	Sombroek et al. 1993
Cool temperate moist forest	121	Post et al. 1982
Cool temperate wet forest	139	Post et al. 1982
Forest area of Finland	42	Liski 1997
New Zealand	165	Tate et al. 1997
The state of Maine, USA	154	Davidson & Lefebvre 1993
Western Oregon, USA	136	Homann et al. 1998
Forest area of Japan	188	Morisada et al. 2004
Brazilian Legal Amazon	103	Moraes et al. 1995

and 62 t Cha^{-1} (N = 156, CV: 46%) in 0–20 cm topsoil. Extrapolating to national scale, it was calculated a contemporary SOC stock of 110 TgC (entire mineral soil, standard error: 6 Tg C), 87 Tg C (0–30 cm topsoil, standard error: 3.5 Tg C) and 70 Tg C (0–20 cm topsoil, standard error: 2.5 Tg C) for mineral soils of accessible Swiss forests (1.1399 Mha) (Perruchoud et al. 2010).

Concerning the organic C stock at the depth of 100 cm, the information in the literature is similar with the ones we have obtained (Table 2). For example: Chernozem (Table 2: -104 t/ha and (Batjes 1996): -96 t/ha); Luvosols (Table 2: -136 t/ha and (Batjes 1996): -139 t/ha). Concerning the GIS map, the quantities of organic C from Europe has been mapped (Baritz et al. 2010) in order to develop a carbon concentration map, each Level I plot being assigned to the respective soil map unit (SMU) of the European Soil Database (SGDBE) using point-polygon analysis. The mean carbon concentration was then calculated and mapped for each SMU. Before that, the soil map was stratified according to climatic zones. In order to assess the reliability of the soil carbon concentrations map, the frequencies of plot occurrences per climate-SMU were separately mapped. The map that we have realized has an advantage: it is based on measurements of the carbon stocks in the soil, thus the obtained values which were assigned to the soil types present in different areas. Thus, it resulted in an extremely detailed map of the repartition of the organic carbon in Romania's forest soils as can be seen in Figure 2.

Conclusions

The average total amount of organic carbon (i.e. 137 t/ha) accumulated in Romania's forest soils is comparable with the values obtained in other European areas similar from geographic and climatic point of view. The smallest quantities of organic carbon were accumulated in the following forest soil types: Solonetz, Solonchak and Chernozem, while the largest ones were retained for Andosoil, Vertisoil and Podzol. Moreover, with regard to geographic distribution, the biggest quantities of organic carbon seem to be accumulated in the forest soils from the volcanic mountains, and the smallest ones in the forest soils from plains. Although current assessment relies on very large number of samples the variability of C concentration and C stock (assuming simple correspondence), remains very large, ~ 40-50% variation coefficient and ~ 100% of the average defining the 95% range of the C stock, which demonstrate the high variability associated to C stock in forest mineral soils, although post-processing by post-stratification of data could have led to derivation of some kind of uncertainty estimates for the average C stock in soils.

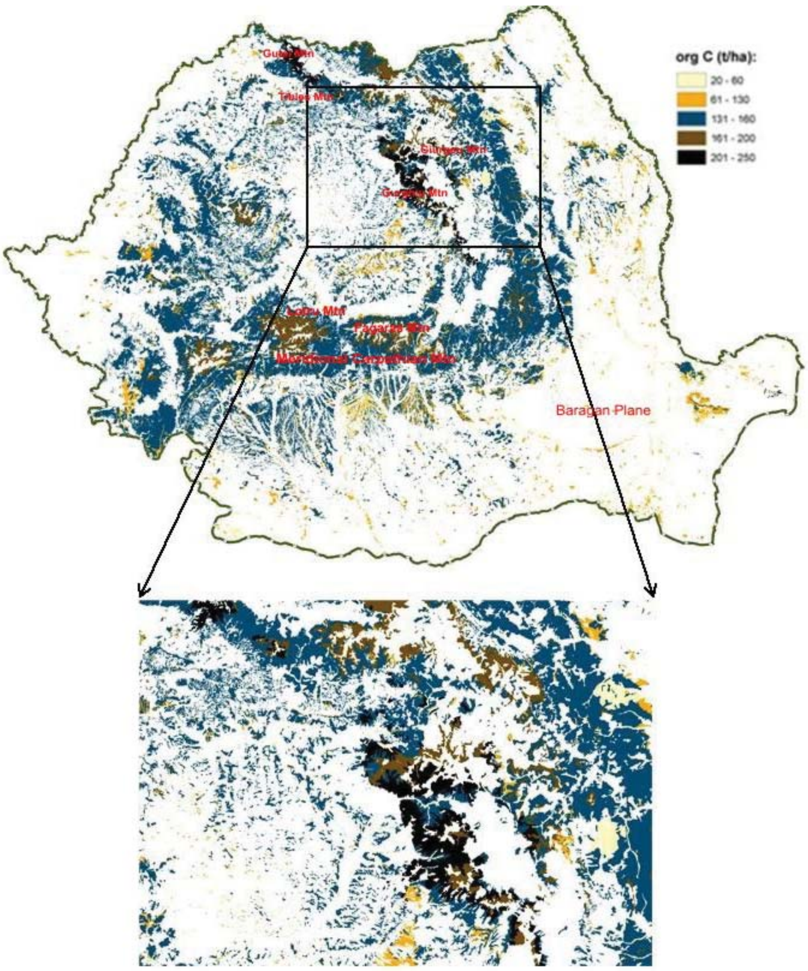

Figure 2 Accumulation of organic carbon in Romania's forest soils (GIS based analysis)

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