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RESEARCH ARTICLE

Assessing the carbon stock changes in forest soils in Bulgaria

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Abstract

Forest soils are a key element of the forest ecosystems which could contribute to carbon storage and climate change mitigation. The carbon sequestration and storage potential of the forest soils, however, depends to a great extent on the forestry operations and forest management activities carried out in the forest. There is a widely accepted assumption that under a set of climate and management conditions the carbon content in the forest soils is at equilibrium. However, different factors like management activities, productivity, decay rates and/or natural disturbances could alter the carbon dynamics of forest soils. The aim of the current study was to assess the carbon stock and the carbon stock changes in mineral forest soils in Bulgaria based on the forest soil monitoring information gathered under the ICP Forest Programme. For that purpose, a dataset from the programme on mineral forest soils from 1998 was processed and analysed. The carbon stock for each sample plot was estimated for the 0-30 cm layer. The carbon stock change was calculated for all the sample plots with repeated measurements over the study period. The results were further analysed with parametric and non-parametric statistical tests to assess whether the carbon stock changes are significant. However, the lack of other relevant observations within the monitoring implementation such as litter decomposition, turnover rates, climatic conditions, etc., hinder the application of dynamic soil carbon models in assessing and predicting the current and the future rate of the soil carbon in forests in Bulgaria.

Keywords

carbon sequestration, soil organic carbon, soil organic carbon stock changes

Introduction

Forest ecosystems and their management play an essential role in mitigating climate change by contributing to the reduction of CO_2 emissions in the atmosphere. Forests in the temperate climate zone contain = approximately 70 tons per hectare (170 t/ha) on average. Nearly two-thirds of the carbon is stored in the soil, and more than one-third - in vegetation (Gorte, 2009). Many of these forests are managed to produce commercial wood products. The management practices used in forests can thus have a significant impact on carbon sequestration. However, the changing climate, as well as the unsustainable land management practices, could lead to a reduction in the amount of sequestrated carbon. Like this, the soil carbon pool might become a net source of GHG emissions. However, if forests are managed properly and with respect to preserving and maintaining the organic matter in the mineral soils, the soils have a great potential to sequester carbon and to contribute to climate change mitigation and adaptation (FAO, 2017).

The analysis and assessment of the dynamics in the carbon content in soils is of particular importance in relation to the compilation of the National GHG Inventory Reports under the United Nation Framework Convention on Climate Change (UNFCCC) and the international agreements such as the Kyoto Protocol and the Paris Agreement. As part of the national inventory reports, accurate calculations on the emissions due to soil organic carbon (SOC) stock changes should be reported based on the methodologies provided by The Intergovernmental Panel on Climate Change (IPCC) Guidelines. Temporal changes in SOC stocks can be assessed either by repeated soil inventories, through monitoring programs on representative sites before and after land use and/or management changes, or by repeated soil sampling over regular time intervals when no such changes occurred (Lorenz and Lal, 2016).

Taking into consideration some of the domestic studies on the mineral soils in forests in Bulgaria, the land-use change has been identified as a primary cause of changes in key soil characteristics, including the carbon stocks (Zhiyanski et al., 2016). In addition, it was established that the forest composition also influences the quantity of accumulated soil carbon (Zhiyanski et al., 2008; Zhiyanski and Glushkova, 2013). There are studies on soil fertility and the factors that affect it (Naumov and Grozeva, 1985), which show that intensive cuttings have a negative impact on both fertility and physical, and chemical soil properties (Zhelyazkov, 1986). However, specific information on the soil organic carbon stock changes in these studies is missing. The importance of the forest management practices, and its effect on the soil organic carbon stock is already considered in some local studies (Kirova, 2020; Kirova and Zhiyanski, 2021) but they encompass only beech forests.

Considering the lack of a large-scale assessment of the soil organic carbon stock dynamics in forest soil in Bulgaria, and the importance of the evaluation of the soil carbon stocks and its changes regarding the National GHG Inventory Reports under UNFCCC, and the international agreements such as the Kyoto Protocol and the Paris Agreement, with this study we aim to analyse and assess the forest soil carbon stocks and forest soil carbon stock changes, and to check whether there is a significant change in the soil carbon stocks, and if it is in positive or negative aspect.

Methods and materials

Information from the ICP Forest Programme at Level I has been used for this analysis. In Bulgaria, the Programme started in 1986 with focus on the coniferous plantations as these forests have been considered more vulnerable to air pollution. The observation network was first established at a 16x16 km grid. For these sample plots where pollution had been found, additional sampling plots were set at a 8x8 km or a 4x4 km grid. Throughout the first years of the programme the number of the sample plots was reduced to 256 based on expert judgement and circumstances related to the terrain. This introduced a shift in the grid, so the grid became randomly distributed among the forest territories in the country. Since 2009, the sample plots have been revised in connection to the implementation of the EU project FUTMON after which the observation network numbers 159 permanent plots. Forest monitoring in Bulgaria is conducted by the Executive Environment Agency under the Ministry of Environment and Water.

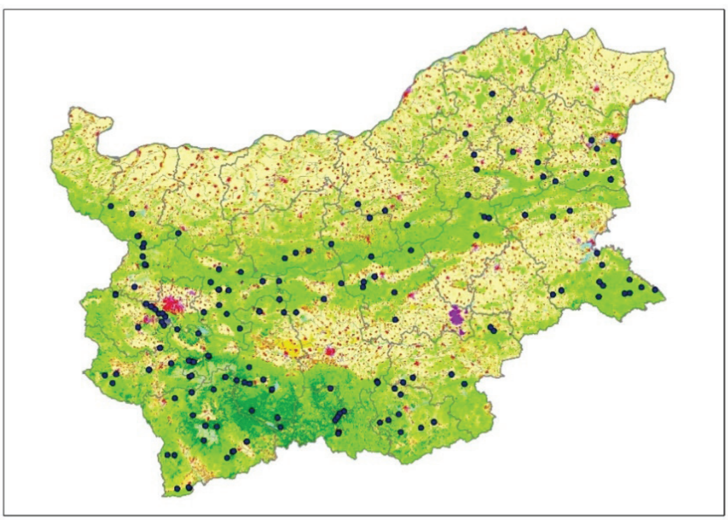

Figure 1. Distribution of the permanent sample plots under ICP Forest Programme, Level I.

Soil data from 1998 on 171 sample plots have been provided by the Executive Environment Agency. The data contain information on the carbon content per layers of 0-10 cm, 10-20 cm, and 20-40 cm, information on bulk density, coarse fraction, etc.

The SOC contents in the 0-30 cm depth is obtained by summing the SOC contents of the constituent soil layers. The SOC content of each layer is calculated by multiplying the concentration of soil organic carbon in a sample (g C (kg soil)$^{-1}$) with the corresponding depth and bulk density (Mg m^{-3}) and adjusting for the soil volume occupied by coarse fragments (IPCC GPG, 2003).

$$SOC = \sum_{\text{layer}=1}^{\text{layer}=n} SOC_{layer} = \sum_{\text{layer}=1}^{\text{layer}=n} ([SOC] \cdot BulkDensity \cdot Depth \cdot (1 - frag) \cdot 10)_{\text{layer}}$$

Where:

SOC – *representative soil organic carbon content for the forest type and soil of interest*, tonnes C ha^{-1}; **SOC** $_{\text{layer}}$ – *soil organic carbon content for a constituent soil layer*, tonnes C ha^{-1}; [**SOC**] – *concentration of soil organic carbon in a given soil mass obtained from lab analyses*, g C $(kg\ soil)^{-1}$; **Bulk Density** – *soil mass per sample volume*, tonnes soil m^{-3} (equivalent to Mg m^{-3}); **Depth** – *layer depth or thickness of soil layer*, m; **frag** – *% volume of coarse fragments/100*, dimensionless

The information on bulk density for all layers is available for the sample plots, which have been analysed since 2011. For the soils analysed before 2011, the bulk density is available in most cases only for the 0-10 layer. Thus, the bulk density for the deeper layers of these records has been estimated using the Alexander B (1980) PTF function (De Vos et al., 2005).

The data on coarse fraction is also available for all layers since 2011. For the years before that, the data is not available for all samples, thus a gap-filling approach has been implemented – for the paired plots, the data from later observations have been used, whereas for other plots – an average value.

In total, a dataset of 418 measurements for the 0-30 cm depth from 171 sample plots has been obtained and processed further. First, the dataset has been split into two periods 1998-2008 (P1) and 2009-2019 (P2) taking into consideration the maximum number of sample plots with at least one observation per period. Further analysis has been done to extract only the paired sample plots, which have been observed at least once for both periods. At the end, data for 90 paired sample plots have been sorted and processed to analyse the carbon stock changes. The carbon stock change in each plot has been obtained as a difference in the mean value on carbon stock for each plot, divided by the number of years from the beginning of the observed period until the end of it – 23 years. The resulted carbon stock changes (CSCs) have been checked for outliers via double standard deviation ($x \pm 2\sigma$) and removed (6 outliers in total). Thus, the sample size of the paired plots has been reduced to 84. The remaining data have been further analysed per soil type. To assess whether their population means differ we applied a paired t-test. All the statistical analysis has been performed in R (v.3.6.0).

Results

The analysis of the ICP Forest data on soil organic carbon stock in forest soils shows that the carbon stock (0-30 cm) varies in wide ranges for the two analysed periods (Table 1), from 3.244 tC/ha in the first period and 4.185 tC/ha in the second, till 115.683 t/ha for P1 and 154.856 t/ha for P2. The mean values for the two periods are

50.753 t/ha for P1 and 46.176 t/ha for P2. The information on the carbon stock for both periods does not follow the normal distribution (Fig. 2), which is expected, taking into consideration that SOC values are commonly found with positively skewed distribution.

Table 1. Summary statistics of the soil organic carbon (SOC) stock and the carbon stock changes (CSC) between the two periods, tC/ha.

Variables	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
SOC stock, P1	3.244	38.757	49.765	50.753	62.855	115.683
SOC stock, P2	4.185	29.057	41.233	46.176	63.104	154.856
CSC	-2.245	-0.716	-0.269	-0.199	0.389	1.871

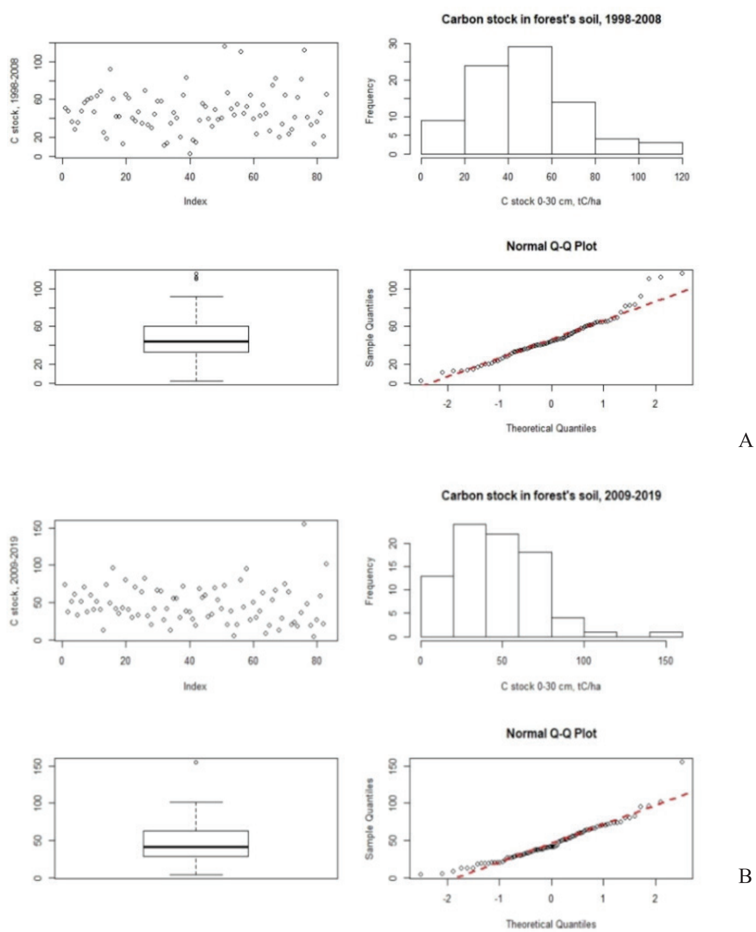

Figure 2. Distribution of the soil organic carbon stock for 0-30 cm for the period 1998-2008 (A) and for the period 2008-2019 (B), n=84

However, the carbon stock change between the two period is normally distributed (Fig. 2), which has been proved by Shapiro-Wilk test (*p-value – 0.233*). Therefore, we performed a paired t-test to check whether the population means for the two periods differ (Fig. 3). The outcome of the paired t-test (*p-value = 0.064, df = 83*) confirms the null hypothesis – that the difference in means is not statistically significant.

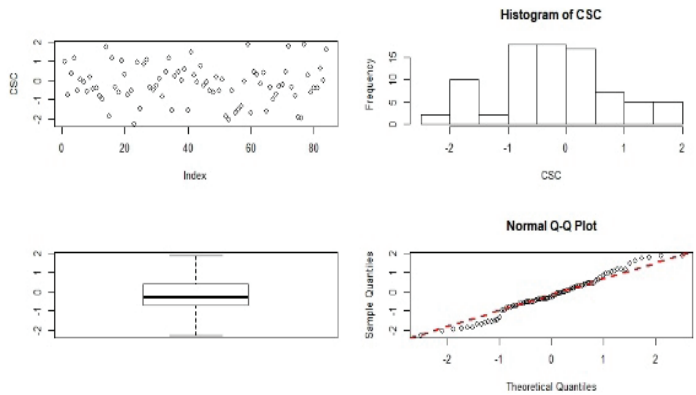

Figure 3. Distribution of the soil organic carbon stock changes for 0-30 cm, n=84

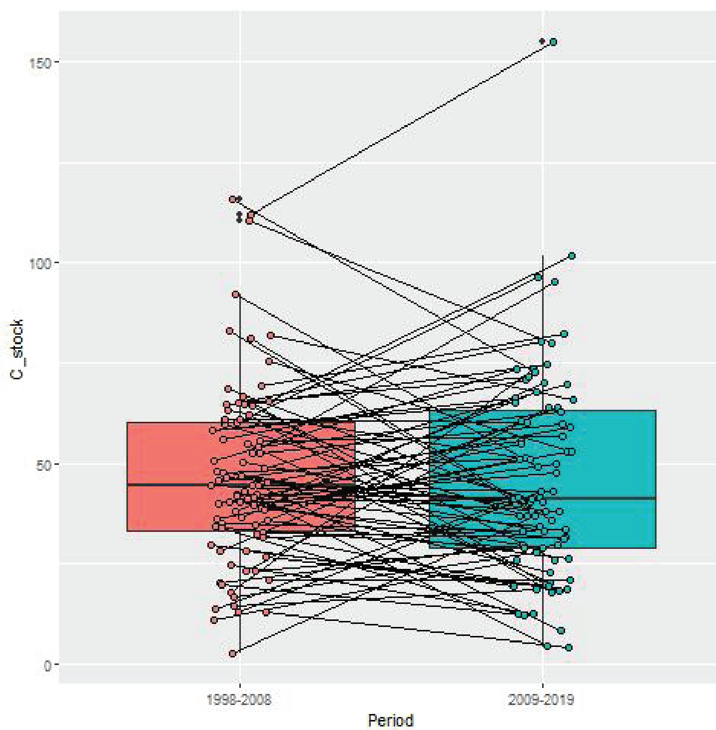

Figure 4. Graphical representation of the paired carbon stock changes, n=84

Discussion

There is a widely accepted assumption that under a given set of climate and management conditions the carbon content in soils reaches stable value specific to the soil, climate, land-use and management practices (IPCC, 2006). Some silviculture practices or disturbances could affect the soil organic carbon stock if the balance between the carbon inputs (for example from biomass residues or organic amendments) and the carbon losses (due to respiration, mineralization or leaching) is altered. Thus, any change in land use and/or in the system of management practices or disturbance regime brings about a SOC change that is assumed to occur linearly across a period, established by default over 20 years (FAO, 2017). Our results tend to confirm these assumptions although we could suggest that the study lacks full representativeness of the diversity of the soil types and forest ecosystems in Bulgaria, especially in respect to the highlands forests. However, the ICP Forest data in Bulgaria represent the only large-scale quantitative source of information about the carbon content in forest soil, which is obtained from systematically measured and monitored sample plots for a period long enough to assess the temporal changes in the soil organic carbon stock in the country. The representation of the soil types within the subsample of the paired plots (n=84), however, is very similar to those of the forests in the country. Most forests in Bulgaria are growing on *Cambisols* and *Luvisols* with a share of around 30% for each of these soil groups. That share is well represented in the analysed subsample (Table 2). In that respect we noticed that the *Planosols* are a bit underrepresented but taking into consideration that their share in forest ecosystems in Bulgaria is between 10-15%, we suppose that this would not affect the general results of the study. The more detailed look into the SOC and the SOC changes disaggregated by soil type (Table 2) shows that both the SOC changes in *Cambisols* and *Luvisols* have a negative aspect. However, the parametric test performed (paired t-test) showed that only the change in *Luvisols* could be considered as significant. At a country level this has not affected the SOC changes as the difference in means has no statistical significance (Table 1). In addition, we could provide some rationale about the relatively stable soil organic carbon content in the forest soils in Bulgaria. This is mostly related to the sustainable forest management implemented in our country since the adoption of the so called "Forest Principles" at the Earth Summit in Rio de Janeiro in 1992. The forest management in Bulgaria in the past few decades has resulted in a steady increase in the standing biomass stock by >50% since 1990 (EFA, 2021). This means that there is an increasing C flux to the litter and soil pool accordingly from dead leaves and branches and dead fine and coarse roots. In addition, the harvesting in Bulgaria has also increased in recent years, which means that the C flux from harvest residues (leaves, branches, roots, stumps, non-extracted stemwood) to the litter and soil pool has increased accordingly. This, together with the increase in the forests due to natural expansions of the vegetation could even suggest that in the future the SOC changes could have a positive increase if the restoration with native vegetation on abandonment pastures and croplands continues. This assumption is confirmed by a recently

developed tool – SoilsRevealed by Sanderman et al. (2020), which suggests a gain of 1.15 Ct/ha annually in Bulgarian soils in case of the restoration scenario.

However, it is worth to further analyse the SOC changes in the most dominant soil types under forest vegetation considering their spatial representation and forest type vegetation cover or any other variables which correlate with soil organic carbon content in soils. For this it would be needed to expand the observations beyond the ICP forest data in order to increase the sample size and representation for further analysis. Possible data sources for this could be the LUCAS data, information from the Soil Monitoring system in Bulgaria, implemented by Executive Environment Agency at a 16x16 km grid since 2004, and local or regional scientific studies.

Table 2. Summary statistics of the soil organic carbon (SOC) stock per soil type and the carbon stock changes (CSC) between the two periods, tC/ha.

Soil groups, WRB		Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
Cambisols (n=26)	P1	3.244	41.953	52.378	55.207	66.471	111.816
	P2	4.185	31.320	51.033	51.609	69.167	154.856
	CSC	-1.924	-0.759	-0.369	-0.157	0.655	1.871
Luvisols (n=29)	P1	15.980	41.450	50.640	52.260	62.440	89.500
	P2	8.407	29.644	40.016	43.144	51.357	95.009
	CSC	2.245	0.769	-0.381	-0.396*	0.099	1.846
Regosols (n=12)	P1	15.600	21.510	31.840	32.330	37.300	64.640
	P2	4.779	17.008	23.659	31.872	45.868	74.635
	CSC	-1.673	-0.533	-0.162	-0.020	0.474	1.760
Planosols (n=7)	P1	19.970	38.700	45.730	41.910	49.790	51.170
	P2	34.470	42.290	51.060	48.720	55.220	60.490
	CSC	-0.647	-0.090	0.358	0.296	0.708	1.127
Others (n=10)	P1	26.720	51.700	58.750	63.080	71.220	115.680
	P2	18.550	38.710	51.670	56.230	72.340	101.520
	CSC	-1.978	-0.741	-0.211	-0.298	0.281	1.570

Conclusions and recommendations

The analysis shows that there is no statistically significant difference in the means of the soil organic carbon stock of mineral forest soils in Bulgaria based on the data from ICP Forest Programme at Level I. However, many challenges remain in conducting such analysis, related mainly to lack of common database maintenance which in general increases the uncertainty associated with data processing of the information. Another issue is the lack of historical data on bulk density and coarse fraction as these elements are key when considering the carbon stock evaluation. Many challenges remain also in connection to the representativeness of the data as the monitoring design

of the ICP Forest Programme at Level I has targeted mostly the coniferous plantations outside their natural habitat. However, these data are of particular importance for conducting SOC change analysis based on repeated soil measurements. The lack of other relevant observations within the monitoring implementation at a large scale, such as litter decomposition, turnover rates and climatic conditions hinder the application of dynamic soil carbon models in assessing and predicting the current and the future rate of the soil carbon in forests in Bulgaria.

The importance of the monitoring and evaluation of the soil organic carbon in mineral forest soils in relation to the climate change mitigation policy and its implementation is well recognized and will gain more attention in the future. Thus, specific actions, aiming at 1) increasing the monitoring activities in the forests and 2) implementing innovative tools and techniques such as application of dynamic models and/or geostatistical techniques in assessing and predicting the SOC changes, would be required.

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