JCBPS; Section D; May 2015 – July 2015,Vol. 5, No. 3; 3114-3128. E- ISSN: 2249 –1929

Journal of Chemical, Biological and Physical Sciences

An International Peer Review E-3 Journal of Sciences

Available online at www.jcbsc.org

Section D: Environmental Sciences

CODEN (USA): JCBPAT Research Article

Role of different components of urban and peri-urban forests to store carbon – a case-study of the Sandanski region, Bulgaria

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Received: 04 June 2015; **Revised:** 03 July 2015; **Accepted:** 10 July 2015

Abstract: Urban areas currently make up about 4% of the world’s terrestrial surface and forest parks as elements of Green Infrastructure (GI) is currently of interest in their potential to store carbon. We studied carbon stocks in different components of urban and peri-urban forest parks: urban soils, forest floor and aboveground tree vegetation in Sandanski, Bulgaria. For all urban sites compared to controls, the value of carbon stocks in soils was much greater. In urban soils of Sandanski carbon stocks varied between 44 and 88 $tCha^{-1}$, compared to peri-urban 32 - 39 $tCha^{-1}$. The reverse was observed for carbon stocks in the forest floor and tree stands. Forest floor carbon stocks in Sandanski varied within 4.07 - 4.37 $tCha^{-1}$, while in peri-urban were higher (5.50 - 3.47 $tCha^{-1}$). Carbon stored in aboveground tree biomass in urban sites was calculated at 36.5 $tCha^{-1}$ for Sandanski and in peri-urban sites 37.0 and 67.8 $tCha^{-1}$, respectively. We concluded that carbon accumulation in urban forest parks is controlled by detailed management activities and confirmed their high potential to store carbon. It is clearly argued that there is a need to maintain and enhance the ecological functions of forest ecosystems as part of urban GI, which in turn will support the mitigation of sharp climatic changes at the local and regional levels.

Key words: urban and peri-urban forests, carbon stock, forest floor, tree stands, urban soils

INTRODUCTION

Changes in land use from agricultural and forest areas to urban land significantly disrupt carbon sequestration and carbon fluxes underlined by Pouyat *et al.*[1,2]. In this context urban areas play a key role in changes to the biogeochemical cycles of elements and particularly in carbon dynamics with implications for climate conditions[3-5]. In urban ecosystems, human disruption of the carbon balance is easy to identify and by studying this, we have the opportunity to better understand the detailed stages in carbon sequestration and accumulation in different components of the terrestrial ecosystems. The methodical approach is based on controlled comparison between sites with different levels of urbanization – urban and natural non-urban ecosystems. The native forest ecosystems represent one of the biggest "reservoirs" of carbon within the terrestrial ecosystems and forest parks as the main element of green infrastructure (GI) are the "green lungs" of cities. Despite the fact that urban forest parks, play a special role in improving environmental quality for human health and well-being, little is known about the functioning of this natural resource under increased urbanization. In this context, these large green systems could be significant components supporting the mitigation of climatic changes at the local level.

The process of urbanization creates urban ecosystems and urban soils with specific properties[6, 7]. At national level there are investigations which consider the specific characteristics of the components of urban environment focusing on specifics of urban soils, their classification features, pollution and chemical properties[8-10]. Meanwhile, at a broader level, there are limited studies on carbon accumulation and dynamics in urban soils[11-17], and a little on soils in city parks and allotments[18, 19]. The potential of forest systems to sequester and store carbon is acknowledged by many studies[20-23]. How urban afforestation affects urban soils, however, is largely unknown[24, 25]. Pouyat *et al.* [2] emphasized that the nature of management systems and lack of direct negative impacts on soils in urban forest parks and recreational areas are prerequisites to increase the potential to accumulate soil organic carbon.

Recent studies have shown that soil organic carbon "far exceeded" carbon stock in forest vegetation[26]. But it is assumed that in the terrestrial ecosystems from temperate climatic zone the organic carbon, is mainly stored in the aboveground biomass, while in those from colder climates the carbon stored in the soil is more significant. These differences are determined by the different decomposition rates of litter on the forest floor under different climatic conditions. Here the question arises as to how much carbon is accumulated and distributed in the urban ecosystems from different climatic zones.

Currently available data and information on urban forest parks are insufficient to assess the specific of carbon accumulation in these ecosystems and the influence of urbanization as an anthropogenic impact.

The aim of this study was to investigate the potential of different components of urban and peri-urban forests (soils, forest floor layer, and aboveground tree biomass) to store carbon. The case study region of Sandanski town in Bulgaria was chosen using urban and peri-urban forests.

MATERIALS AND METHODS

General characteristics of the study areas: The urban forest park, experimental sites were located in Sandanski town. The town is situated in South-Bulgarian xerothermal zone and characterized with transitional Mediterranean climate. The town of Sandanski is a regional center and spa-center for respiratory diseases. The population is ~ 30,000 inhabitants, but in the spring and autumn it is doubled by health tourism. In the both cities, there are well-organized green infrastructures with a distinct urban gradient from the city center of the surrounding mountains.

Sampling sites: Forests in the urban and peri-urban regions were distinguished as either: urban (US) and peri-urban forests (NUS).

Two urban experimental sites were studied in City Park "St. Vrach" in the town of Sandanski, one of the largest urban parks in the country, founded 100 years ago. The park sites US1 and US2 differ according to the management activities performed in US1 (active management) and US2 (no management). The control sites were selected near peri-urban afforested areas: NUS1 road to Water Electrical Station (WES) Liljanovo and NUS2 – long-term experimental station of Forest Research Institute (FRI-BAS).

The characteristics of the experimental sites are presented in Table 1.

Table 1: Characteristics of study experimental sites in Sandanski regions

Site	Coordinates	Altitude m	Aspect	Slope °	Distance from the urban center Km	Built area %	Dominant tree species	Soil type (WRB, 2014)
				Sandanski				
US1	N 41°34’08.66’’ E 23°16’53.25’’	247	NW	2	4	35	*Quercus petraea* L. + *Platanus orientalis* L.	Anthrosols
US2	N 41°33’56.46’’ E 23°16’56.46’’	232	NW	3	1	55	*Quercus pubescens* L. + *Pinus nigra* L.	Anthrosols
NUS1	N 41°35’35.73’’ E 23°17’35.73’’	385	W	7	15	0.1	*Pinus nigra* L.	Chromic Luvisols
NUS2	N 41°34’17.67’’ E 23°17’11.65’’	272	W	12	6	1	*Quercus petraea* L. + *Q. pubescens* L.	Chromic Luvisols

Sampling: At each site square field test sampling plots were outlined with an area of 50 x 50 m and the following components of the ecosystem were examined: soil, forest floor, and aboveground tree vegetation.

In each site one representative soil profile was prepared for the depth of the parent materials and four additional soil profiles to the C horizon were excavated. The mineral soil was sampled at 0-10, 10-30 and 30-50 cm depth. A total of 18 soil samples was collected per site and used to estimate the carbon content. A total of 44 samples was collected and analyzed, including both the urban and peri-urban forests. Forest floor was divided into three sub-layers: L, F and H.

To estimate the aboveground biomass of trees (AB) across the full area of the sampling plot biometric measurements was undertaken in order to obtain the parameters needed to calculate carbon stock applying the Biomass Conversion and Expansion Factors (BCEF) method described by Fonseca, Marques[27].

Visits to the study areas and sampling procedures were carried out in vegetation growth periods (spring/summer) between 2010 and 2013.

Analytical methods: The soil samples were dried at 105^o C for 48 h and sieved through a 2 mm mesh to remove coarse sand then soil was desegregated. The following soil properties have been determined in accordance with the standardized methods applied in the laboratories of FRI-BAS: coarse fragments (ISO 11646), particle size distribution (ISO 11277), pH (H_2O) (ISO 10390), bulk density (volumetric method), nitrogen content (Kjeldahl method), carbon content (Tjurin method), described by Donov *et al.*[28] The carbon concentrations, combined with bulk density and coarse fraction content, were used to estimate the amount of carbon per unit area according the equation (1):

$$\text{SOCsite } (\text{tCha}^{-1}) = \text{SOC } (\text{gC100g}^{-1}) \times \text{depth of soil layer (cm)} \times \text{BD } (\text{gcm}^{-3}) \times K \quad (1)$$

Where: SOCsite – carbon stock in experimental site BD – bulk density - the real values corrected with the percentage of the coarse fraction (> 3 mm) – coefficient K.

At each plot the tree stand parameters were determined applying biomass conversion and expansion factors (BCEFs) to Convert Stem Volume Raw Data into Above Ground Dry Biomass – BCEF Method[27, 29, 30]. The number of trees, the density of the stand, the mean tree diameter at breast height (1.3 m), and the mean height for stand were measured and calculated per hectare. The wood stocks were calculated using the data from growth tables for specific tree species and their penetration index[30], corrected independence of tree density. The calculated data for carbon stocks in aboveground biomass was corrected by data from tables of weight and growth for the selected tree species[29,31]. It is assumed that the dry matter (DM) in 1 m^3 of wood is 500 kg according Matthews[32] and the conversion of biomass estimates to carbon uses a factor of 0.45 Mega grams Dry Matter/Mega grams C according IPCC[33]. The results presented are in tonnes, having taken into account that 1 Mg = 1,102 t. In this study the values for oak species wood, in an air-dried condition had the density as follows[34,35]: - *Quercus rubra* L. – mean 790 kg/m^3; *Quercus robur* L. – mean 810 kg/m^3; *Quercus frainetto* Ten. - mean 870 kg/m^3. The wood of *Pinus nigra* L. has density - mean 590 kg/m^3 and that in oak stands 1 t = m^3 / 1.203, and for black pine stands 1 t = m^3 / 1.416.

RESULTS AND DISCUSION

Soil organic carbon (SOC) in urban and peri-urban forests: Soil characteristics influencing SOC.

The presence of different soil types implies specific differences in carbon storage. Pouyat *et al.*[36] highlighted the importance of soil type for organic carbon stock in urban ecosystems. In the region of Sandanski Chromic Luvisols are widely distributed soils characterized with thinner organo-mineral horizon compared with these in other regions of the country. Soils of urban forest sites are more strongly modified and classified as Anthrosols WRB [37].

Soil texture protects soil organic matter from being decomposed through chemical stabilization of organic molecules via mineral – organic matter bonds Six *et al.*[38]. Soils with a higher percentage of clay have a higher content of SOM and the reverse for soils with high coarse fractions[39] and is relevant for the whole profile[40].

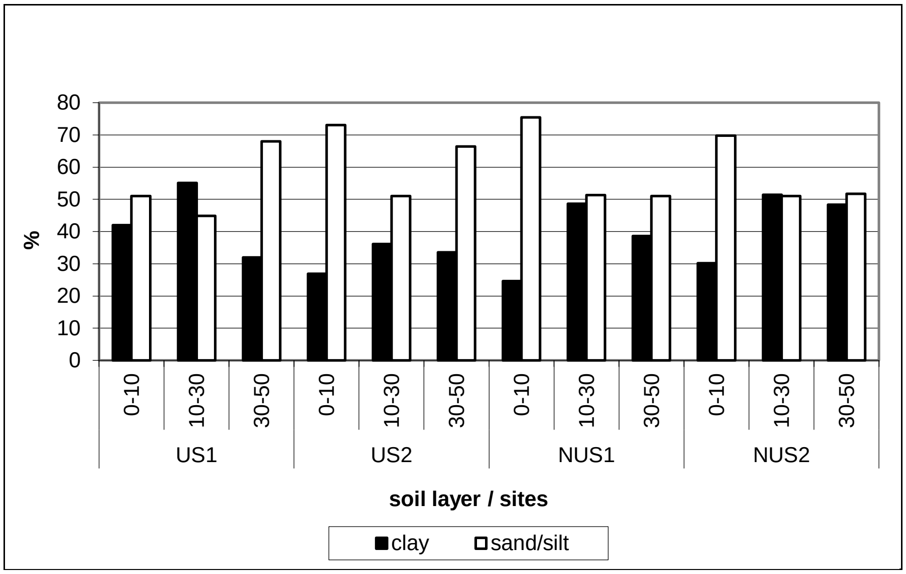

Figure 1: The distribution of clay and sand/silt fractions (%w/w) in soils from urban and peri-urban forest sites in Sandanski town, Bulgaria

The anthropogenic soils from forest parks in Sandanski differ in both experimental sites. US1 characterized with higher clay content in comparison with the other soil in US2. The soils from peri-urban sites have a typical textural structure for Chromic Luvisols – varying from low sandy–loam to sandy-clay, with clear clay differentiation through the soil profile and its accumulation in the middle part of the soil profile. The results obtained for the other soil properties from the experimental sites are presented in Table 2.

Table 2: Parameters studied for soils from urban and peri-urban forests

Soil depth (cm)	Bulk density (BD) g/cm^3	pH	C (%)	N (%)	C/N
US 1					
0-10	0.93 ± 0.13	6.60 ± 0.00	3.03 ± 0.17	0.23 ± 0.04	12.98 ± 1.25
10-30	1.02 ± 0.02	6.25 ± 0.78	2.46 ± 0.08	0.14 ± 0.00	16.97 ± 0.23
30-50	1.11 ± 0.01	6.50 ± 0.07	1.49 ± 0.62	0.13 ± 0.01	11.33 ± 5.10
US 2					
0-10	1.36 ± 0.06	6.95 ±÷ 0.07	1.35 ±0.35	0.12 ± 0.01	10.97 ± 1.63
10-30	1.55 ± 0.49	6.85 ± 0.07	0.63 ±0.05	0.04 ± 0.01	17.04 ± 7.25
30-50	1.52 ± 0.54	6.85 ± 0.07	0.45 ±0.12	0.03 ± 0.01	17.52 ± 0.20
NUS 1					
0-10	0.95 ± 0.01	6.20 ± 0.42	2.36 ±÷0.21	0.11 ± 0.02	22.31 ± 5.51
10-30	1.18 ± 0.04	5.95 ± 0.21	0.46 ± 0.28	0.04 ± 0.02	15.64 ± 14.77
30-50	1.20 ± 0.07	6.03 ± 0.18	0.33 ± 0.28	0.02 ± 0.01	22.84 ± 24.49
NUS 2					
0-10	1.08 ± 0.04	6.10 ± 0.14	1.38 ± 0.08	0.08 ± 0.01	16.53 ± 0.65
10-30	1.13 ± 0.04	6.20 ± 0.00	0.85 ± 0.08	0.05± 0.02	16.46 ± 3.51
30-50	1.23 ± 0.04	6.30 ± 0.14	0.39 ± 0.17	0.02 ± 0.02	17.52 ± 4.17

The bulk density in top 0-10 cm layers of soils from urban forests differ in both studied sites. The soil profile from US2 was strongly compacted compared with other plots. The bulk density in US2 was higher than in US1 and peri-urban sites, which confirms an anthropogenic influence, which most often occurs in the compacting of soil surface due to more human intervention. However, the differences are only small as the sampling profiles were not located close to walkways and paths. Nevertheless, all management activities as well as number of visitors influence top soil compaction[41,42], and is related with decreased soil porosity[43] and increased bulk density[44].

Soil pH determines the performance of a number of processes associated with the accumulation of carbon. Some of carbon can be dissolved in the soil solution and may be lost through leaching processes[45]. The microbiological activity also depends on soil pH, which is also included in the carbon cycle[46]. Moreover, the accumulation of carbon in soils appears to be a buffer against rapid changes in the soil pH. The soil pH in sites US1 and US2 from Park "St. Vrach" in Sandanski varied from low acid to neutral (pH = 6.25 – 6.95) and have a comparatively higher pH than soils from the peri-urban sites (5.95 – 6.30). Some studies reported that increased visitor numbers are related to an increase in pH of soils[43, 44], but also higher pH is a feature of anthropogenic impacts on soil[10].There is a minor relationship between N and C in the soil system. Fu *et al.*[47] established that the nitrogen content is increased by the accumulation of SOC[47]. For Sandanski sites the values for N content were between 0.02 % and 0.12 %, with the exception of US1 (0.13 % - 0.23 %). The highest N content is established on the surface 0-10 cm layers, following the carbon content trend. In general, the soils are poorly supplied with nitrogen. Overall, soils of Sandanski region showed lower C: N ratio (11 - 17) due to warmer climatic condition. Only soils for NUS1 (coniferous plantation) showed a slower mineralization rate, determined by the nature of litter from coniferous trees compared with broadleaved compounds by Albrechtova *et al.*[48].

Carbon stocks in soils of forest parks: The SOC stocks in soil layers and summed total (0-50 cm soil depth) are presented in Figure 2.

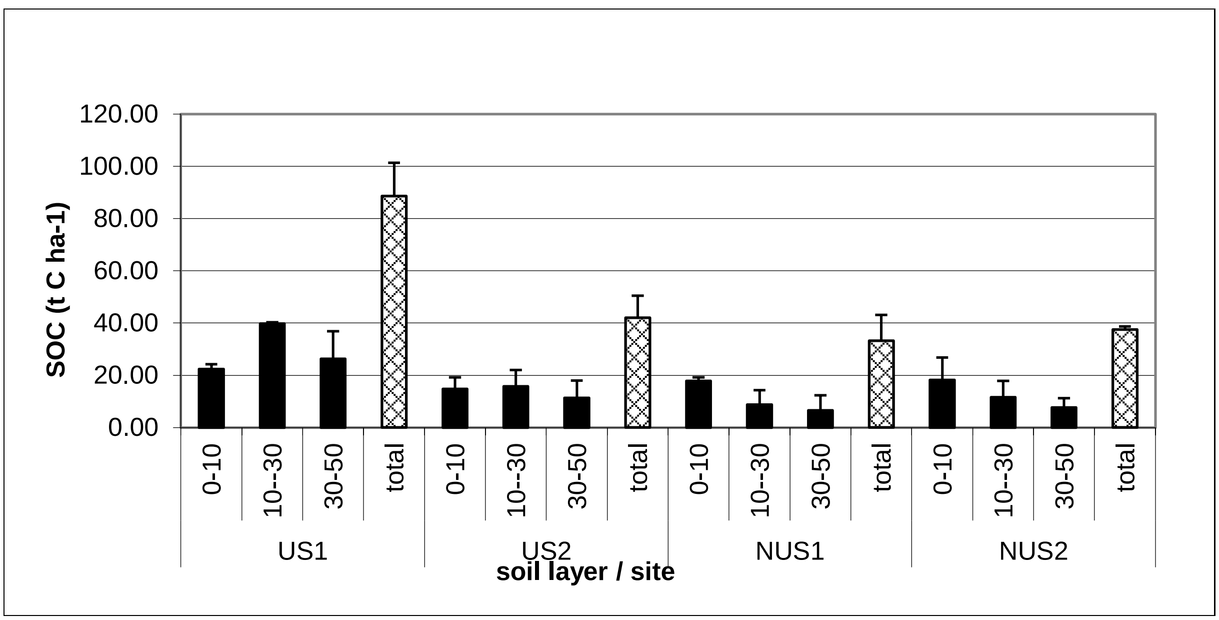

Figure 2: Distribution of carbon stocks in soils from urban and peri-urban forests in the Sandanski region

The carbon stock in the soil profiles in the urban park zone and controls in Sandanski is substantially different, with an extremely high value US1 (88 t Cha^{-1}) in comparison to other locations. The values in the other sites varied from 33 (NUS1) to 44 (US2) $tCha^{-1}$. This variability could be explained by the active management undertaken in US1, including regular irrigation and grass cutting. Urban soils accumulate organic carbon mainly in 10 -30 cm, where the bulk density is higher (especially in US2). In control sites, lower SOC values were estimated, varying from 32 to 39 $tCha^{-1}$, as the accumulation is mainly in top 0 - 10 cm layers.

The results suggest that the management activities may have a significant impact on SOC contents in the urban forest park soils. According Lorenz, Lal[4] urban regions with warmer and/or drier climate could support higher soil carbon stocks, depending on climate and eco-regional factors. In this study whilst two contrasting climatic regions were evaluated the data obtained could not clearly confirm the role of climate factors on carbon accumulation in urban soils from park zones. Based on comparisons between the summed carbon stocks in 0-50 cm soil profile the urban forest parks in Sandanski showed strong local variations and management activity and degree of urbanization appear to be important factors influencing the carbon accumulation.

Carbon stocks in forest floor layer from urban and peri-urban forests: In terms of carbon accumulation and stocks, forest floor appears to be the most valuable intermediate unit that affects the dynamics of the carbon cycle in the soil - plant system[49]. How the forest floor retains carbon in stable form determines the soil as a “sink" or a "source" of carbon emissions.

The warmer climate and low degree of urbanization in Sandanski region reflect on the characteristics and processes of forest floor layer in comparison with discussed for Sofia region (*unpublished data in report, 2014*). The altitude of the study sites is also lower (200 - 400 m). Under oak plantation the processes of decomposition and mineralization of organic substances are faster due to higher mean temperature and the type of forest floor referred to as mull. Under a pine plantation (particularly for US2 and entirely for NUS1) the type of forest floor layer is referred to mull-moder and moder. For NUS1 the H (humification) layer of forest floor could easily be separated.

The data obtained for the main characteristics of the forest floor from urban and peri-urban forests in Sandanski region are presented in table 3. The carbon stocks in forest floor of the study sites are presented in $tCha^{-1}$.

Table 3: Main characteristics of forest floor in urban forest parks and controls in the Sandanski region

Site	Thickness (cm)	Total mass ($t\ ha^{-1}$)	Carbon stocks ($t\ C\ ha^{-1}$)
US 1	2.3	10.39 ± 0.66	4.37 ± 0.53
US 2	2.0	10.41 ± 0.95	4.07 ± 0.34
Average	**2.15**	**10.40**	**4.22**
NUS 1	3.2	14.77 ± 0.17	5.50 ± 0.25
NUS 2	1.8	8.76 ± 0.72	3.47 ± 0.36
Average	**2.5**	**11.80**	**4.50**

Data obtained showed similar values for thickness of forest floor in urban forest parks in Sandanski (~ 10 tha^{-1} per site). The lowest mass is measured in non-urban plot under oak plantation NUS2 (8.76 tha^{-1}). The highest total mass of forest floor layer is estimated under coniferous plantation of *Pinus nigra* L. in NUS1. The characteristics of forest floor influence the carbon stocks: the highest stock of carbon is determined on the forest floor of NUS1 (5.50 to^{-1}). This implies a higher density of forest floor in this site. In comparison with US1 the site NUS1 accumulated 1.2 times higher carbon (tha^{-1}). For NUS2 however, was measured the lowest carbon content (37 %) referred to the total mass of forest floor.

Overall, the carbon stocks are lower in the forest floor layer in urban forest ecosystems (between 4.07 ÷ 4.37 $tCha^{-1}$). The highest was carbon stock calculated for forest floor in a black pine plantation NUS1 (5.50 $tCha^{-1}$), while under a pure oak plantation in NUS2 the stock was low (3.47 $tCha^{-1}$).

Differences in total mass (tha^{-1}) and total carbon contents (%) in forest floor and separately for L sub-layers and F+H layers are presented in Figure 3 and Figure 4.

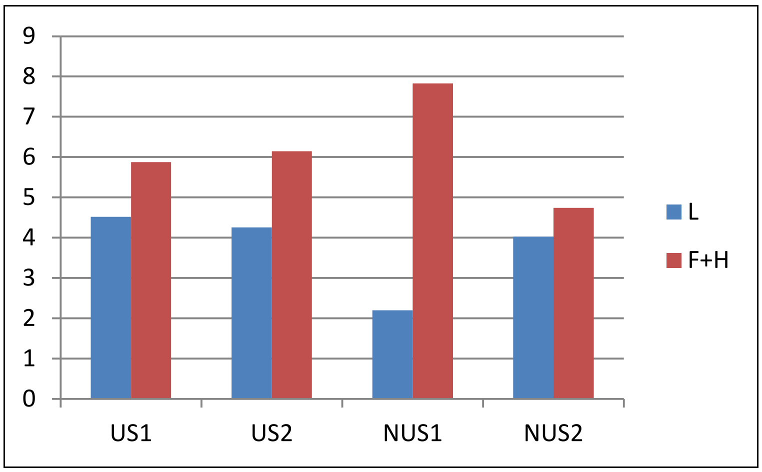

Figure 3: Total mass (t ha-1) of L and F+H layers of forest floor from urban (US) and peri-urban (NUS) forests in the Sandanski region

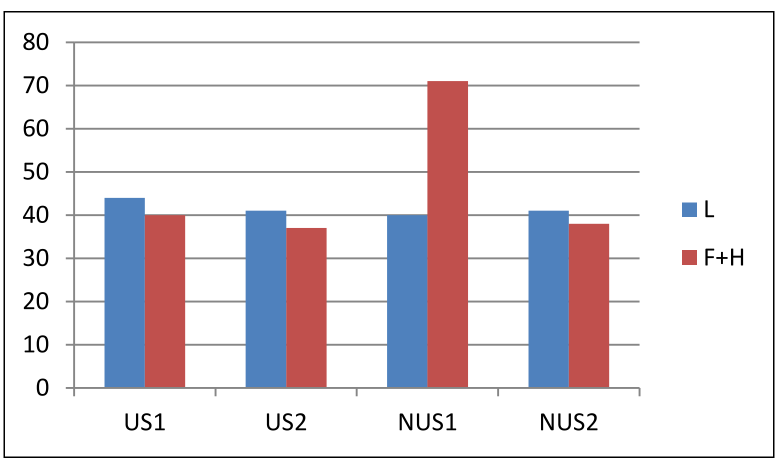

Figure 4: Carbon content (%) of L and F+H layers of forest floor from urban (US) and peri-urban (NUS) forests in the Sandanski region

There is a clear expressed tendency of concentration of total mass in both F+H layers of the forest floor in NUS1 and slight expressed in oak studied sites. The total mass of the forest floor from studying forests in Sandanski region supposed favorable conditions for microbiological activity and sequent faster decomposition of forest floor due to higher temperatures of region[50].

Carbon stocks in aboveground tree biomass from urban forest parks: The growth of tree species presents a net accumulation of carbon so the assessment of forest productivity supports the carbon stocks. Tree characteristics in studying sites were measured and presented in Table 4.

Table 4: Characteristics of tree stands of study sites

Site	Origin	Stand age (Years)	Tree density (%)	Mean stand height (m)	Number of trees per 1 ha	Mean stands, diameter (cm)	Grass Coverag e (%)
US 1	Plantation	80	0.6	23	680	24.3	9
US 2	Plantation	80	0.6	22	620	23.8	9
NUS 1	Plantation	70	0.7	20	1360	24.3	3
NUS 2	Coppice	80	0.5	10	340	12.4	5

Subsequently the wood stocks calculated for the aboveground biomass in the study sites are presented in Figure 5. It is clear that the value of timber stocks in peri-urban forest areas in the Sandanski region is comparatively higher than in urban sites. This is determined by the higher mean number of trees per hectare and the higher bonitation index of stands in these sites. For the Sandanski sites the location comprising predominantly black pine NUS1, has a higher wood stock per hectare due to the higher standard density, compensating for the lower tree age, and is replicated in the other peri-urban site – NUS2 with values comparable to those in urban parks.

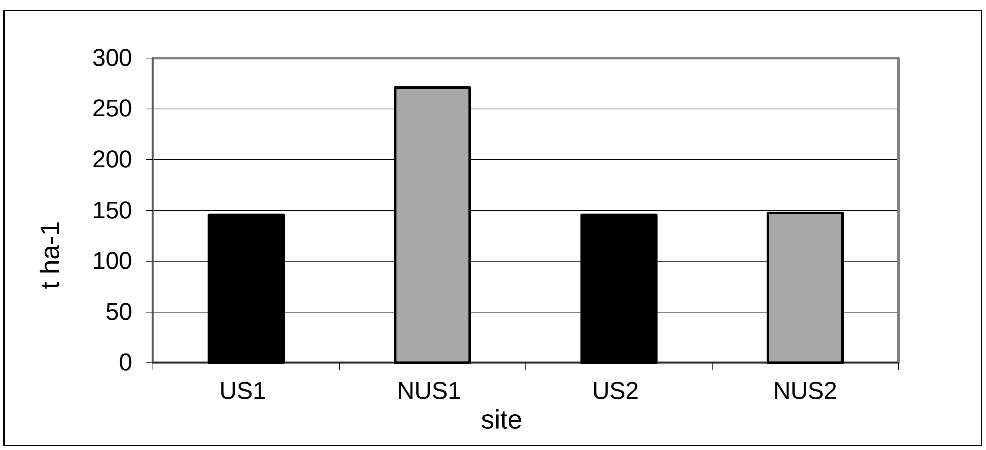

Figure 5: Distribution of wood stocks in studied forest parks and control sites in the Sandanski region

Carbon stock in aboveground tree biomass: The calculation of carbon stocks in aboveground tree biomass, including branches and leaves is presented in Table 5. It follows the trend seen for wood stocks. The differences are explained forest stand density.

Table 5: Carbon stock of aboveground tree biomass from urban and peri-urban forests in the Sandanski region

Carbon stocks in aboveground tree biomass ($tCha^{-1}$)			
Urban forests		**Peri-urban forests**	
US 1	36.5	NUS 1	**67.8**
US 2	36.5	NUS 2	**37.0**

In the forests studied in Sandanski town the carbon stock in coniferous plantation from peri-urban NUS1 was relatively high. The carbon stock in the oak stand of NUS2 was similar to those in urban forests. This suggests the low influence of urbanization on carbon accumulation in tree biomass in the Sandanski region. The carbon stock in aboveground biomass is particularly dependent on tree species and overall characteristics of the stands, ultimately influenced by forest management and planning.

Analyses of factors influencing carbon stock in soils from urban and peri-urban forests:

According Pouyat *et al.*[2], the data explaining the effect of urbanization on carbon accumulation is not detailed enough in order to make more than very general conclusions. Consequently, all prognoses at regional and global levels are difficult and characterized by high uncertainty. It is necessary to refine information on those factors, which strongly influence carbon accumulation and storage in urban ecosystems.

The statistical correlation results showed linear correlations between data. The accumulated carbon in soils (C) correlates linearly with the total nitrogen (N) and phosphorus (P) with high statistical significance (0.751, p=0,001). The positive correlation established with CEC (0.578, p=0,001) supposed that organic substances form proportional part of the total CEC in urban soils together with clay soil colloids.

We systematically applied Principle Component Analyses (PCA) [51,52] to composite data on soil quality and forest parameters including urban and peri-urban forest sites. The data in general revealed moderate to weak associations and typically 4 factors were found with Eigenvalues greater than 1 and accounting for a total of ~70% of the variance in the data. The strongest factors contributed less than 20% of the variance with the majority in the range 20%. Combining soil parameters and plant data produced insufficient data set for full analysis. Most relevant information came from the soil quality data in Table 6.

The used soil parameters sensitive to the urban level, such as: clay and sand fractions content, pH, bulk density and C:N ratio, carbon and nitrogen contents, contents of total Mg and Ca, exchangeable Al etc. from soil properties. The data suggest that dominant controls on soil variability relate strongly to textural factors and CEC drives the Ca availability in the sites. The clay colloids (Clay %) are mainly related to cation-exchange capacity (CEC), while the antagonistic relation between total Mg and total Ca confirmed the exchangeable form (ion - pH- independent) on the unspecific positions of clay minerals. The dominance of soil processes is more strongly associated with PC1.

Table 6: Varimax rotated principal components identified in soil quality data from urban and peri-urban forest soils along an urban rural gradient.

Parameter	PC1	PC2	PC3	PC4
CLAY	0.134	0.020	**-0.971**	0.004
SAND	-0.070	-0.115	**0.936**	0.126
BD	**-0.770**	0.602	0.074	-0.128
PH	**-0.858**	-0.211	0.274	-0.219
C	0.217	**-0.882**	0.125	-0.089
N	0.071	**-0.956**	0.089	-0.208
C:N ratio	0.449	**0.609**	0.069	0.188
CEC	0.123	0.387	0.257	**0.773**
P	**0.946**	-0.103	-0.060	0.133
K	**-0.721**	0.024	-0.283	**0.578**
CA	**0.659**	-0.226	-0.384	**0.463**
MG	0.170	0.092	0.019	**0.640**
% var explained	29.163	22.530	18.542	14.497
Cumulative %	29.1	43.7	62.2	76.7

CONCLUSION

This study focused on carbon accumulation in different components of urban and peri-urban forests (the main elements of green infrastructure): urban soils, forest floor and above ground vegetation. Our study confirmed the potential of urban soils in urban and peri-urban forests to be “reservoir” of carbon in the cities. An essential feature is comparable and inflated values of carbon stocks in soils of urban forest parks. The carbon accumulation in soils from urban forest parks is determined by soil type and type of aboveground vegetation and depends on management activities. The performance of various activities in the park territories (for example: periodic mowing the grass floor and leaving organic residues in place, irrigation, etc.) is demonstrated by an increase in carbon accumulation in the surface soil layers. This positive effect is seen more clearly for the site from the park in Sandanski (US1), where the location is regularly maintained. It is likely that the carbon content in the urban soils of forest parks is a good indicator of the impact of management activities on the carbon accumulation urbanized forest ecosystems.

The result obtained show that accumulation of carbon in soils under forest plantation is influenced by anthropogenic factors. Soils from urban forests may accumulate soil organic carbon in comparable amounts with naturally distributed peri-urban forest soils in the region. The values of carbon stocks are inflated where the management activities were applied in city parks.

The comparative analysis on characteristics of forest floor layer in urban and peri-urban forests in the Sandanski region showed considerably lower accumulation of biomass in forest floor of urban forests in comparison with peri-urban sites. For all sites (urban and peri-urban) from the studied region an accumulation of mass in F + H sub-layers of the forest floor are observed. Forest floor formed in urban and peri-urban forests is comparable and the forest floor carbon content seems to be strongly dependent on the characteristics of aboveground vegetation.

The results for carbon stocks in aboveground tree biomass in urban and peri-urban forests depend on tree density and tree biometrical parameters. Based on the comparative analysis of carbon stocks in aboveground trees it is concluded that the degree of anthropogenic impact is not the main factor affecting this parameter. In the assessment of carbon stocks in forests in urban parks the age of plantation should be taken into account.

Urban forest soils are good reservoirs of carbon. However, the assessment of carbon stocks needs to include the complex role of belowground tree biomass. It is clearly argued the need to maintain and enhance the natural function of forest ecosystems composing green infrastructure, which in turn will support the mitigation of sharp climatic changes especially in strongly urbanized and industrial areas.

ACKNOWLEDGMENTS

The paper was related to activities performed under COST Action FP1204 GreenInUrbs "Green Infrastructure approach: linking environmental with social aspects of studying and managing urban forests" and realized with the financial support of project DMU 02/15-18.12.2009 "Carbon pools and fluxes in soil-to-plant systems in urban forest parks", funded by NSF, Ministry of education, youth and science, R Bulgaria. We thank to Prof. M. Sokolovska and Dr. V. Doichinova for their valuable contributions for the other studied region of Sofia. We thank to eng. A. Zhiyanski, S. Daskalova, N. Starshova and Y. Vassileva for their contributions in field and laboratory works.

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