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CARBON STORAGE IN SHELTERBELTS IN THE AGROFORESTRY SYSTEMS OF THE BAČKA PALANKA AREA (SERBIA)

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ABSTRACT

Field shelterbelts as agroforestry practice provides numerous ecosystem services. Carbon capture and storage potential in biomass and soil is among regulating services shelterbelts provide. Designing shelterbelts to address the various demands and provide services, requests special attention to choosing structural and spatial characteristics of shelterbelts, and species selection for shelterbelts. This paper presents the research results of C storage in 20-years old shelterbelts established on Gleyic Phaeozem in the area of Bačka Palanka (Serbia). Investigated shelterbelts were consisted of the most commonly used species for shelterbelt establishment in Serbia: Siberian elm (*Ulmus pumila* L.), poplar (*Populus x euramericana* (Dode) Guin. cv. „Serotina“) and black locust (*Robinia pseudoacacia* L.). The diameter at breast height (d) and the height (h) of all trees in studied shelterbelts were measured. Carbon stock in biomass was estimated according to IPCC (2003) methodology. Soil profiles were opened in studied shelterbelts with soil sampling carried out at fixed depths of 0-10 cm, 10-20 cm and 20-40 cm. Assessment of carbon storage in soil was performed according to IPCC (2003). According to the research results, living biomass C stock in 20-years old Siberian elm and poplar shelterbelts per tree is almost the same 0.333 t per tree and 0.300 t per tree, respectively. In black locust shelterbelt carbon stock is considerable less 0.111 t per tree. However, in species selection for shelterbelts some characteristics should take into account such as adaptability and suitability to the environmental conditions, longevity and their impact on crops that are grown in the sheltered fields, as well as the natural potential vegetation communities of the area. The results of this study indicate that the poplar is preferred species than the Siberian elm in given environmental conditions. The average carbon stock in the soil of studied shelterbelts in a layer 0-40 cm is 9.33 kg m^{-2} C.

Keywords: *agroforestry, field shelterbelts, carbon storage, species selection.*

INTRODUCTION

Field shelterbelts are among the most commonly used practices in temperate agroforestry systems. Field shelterbelts have the potential to provide numerous ecological and environmental services, starting from wind erosion control and protection of soil and crops, biodiversity maintenance and protection, the mitigation of greenhouse gases (GHGs) by carbon (C) sequestration (Possu *et al.*, 2016). The characteristics of shelterbelts (biological, structural and spatial) should be compatible with the other components of the agroforestry system, in order to meet various requirements. The selection of species for shelterbelts is an important task particularly in designing the field shelterbelt network in agricultural lands and in the absence of natural vegetation communities. There are different criteria in the selection of species for shelterbelts, ranging from the need for the provision of the protective function of shelterbelts as soon as possible by choosing fast-growing species, through the intention to provide some ecological services such as biodiversity conservation by providing habitats for birds and wildlife and unimpeded pollination, providing connectivity by creating corridors between habitat remnants etc. (Jose, 2009), by choosing tree species of natural vegetation communities. The tree species for shelterbelts could, also be chosen in accordance with the intentions to provide various socio-economic services such as the improvement of the touristic potential of the area by creating shelterbelt networks at local, national and regional levels for recreation and cultural heritage preservation by choosing autochthonous tree species of the area. Field shelterbelts provide an important ecosystem regulating service of atmospheric CO_2 capture through photosynthesis and its storage in biomass (Kirby and Potvin, 2007; Shoeneberger, 2009). Forest ecosystems can be C sources or sinks, depending on the dominant biological and physical factors. Considering that forests accumulate the highest amount of C among terrestrial ecosystems, the concept of planting trees, as a strategy for using trees to mitigate global climate change, is widely accepted (Marland and Marland, 1992). According to Oelbermann *et al.* (2004), agroforestry systems have the potential to sequester atmospheric C in trees and soil, while maintaining sustainable productivity.

The aim of this research was set according to the multifunctional role of the field shelterbelts and primarily has ecological character. The research was aimed at determining the efficiency of tree species in C storage in the shelterbelts of agricultural areas, highlighting the importance of species selection for shelterbelts in terms of C accumulation and pointing out the role of shelterbelts as agroforestry practice in climate change mitigation.

MATERIAL AND METHODS

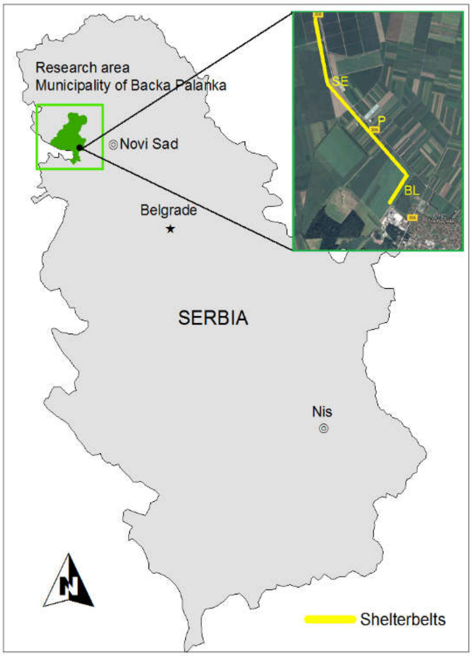
The investigated shelterbelts located in the area of Bačka Palanka were established by planting 2-year old seedlings in 1995 (Dožić et al., 1995) (Fig. 1). The Siberian elm shelterbelt (*Ulmus pumila* L.) (SE) with total length of 935 m and average width 4 m, was mowed every year since established, and in 3rd and 7th year, side branches were pruned and removed from the shelterbelt. The poplar shelterbelt

(*Populus x euramericana* (Dode) Guin. cv. „Serotina") (P) with total length 800 m and average width 3,5 m was mowed occasionally. Regular care and maintenance were not applied in the black locust (*Robinia pseudoacacia* L.) shelterbelt (BL) (total length 750 m, average width 2 m) so there were a number of forked trees of smaller dimensions. According to the General project of field shelterbelts network the proposed shares of species in total number of seedlings in the whole area of Bačka Palanka (Dožić et al., 2001) was as follows: Siberian elm 9.41%, poplar 11.49% and black locust 23.67%.

In order to estimate C stock in the biomass of shelterbelts the diameters at breast height (dbh) and heights (h) of all trees in the shelterbelts were measured. Soil investigations were performed to estimate the C stock in the soil of the shelterbelts. The assessment of C stock was obtained according to the recommendations of IPCC (2003) methodology.

The diameter at breast height (dbh) and height (h) of all trees in the shelterbelts were measured including those with a dbh less than 10 cm. On the basis of this data, the structural and production elements per ha of Siberian elm, poplar and black locust shelterbelts were obtained, using the following parameters: the number of trees (N) and their distribution by diameter classes, basal area (G), height curves and volume (V) (Banković and Pantić, 2006). A total of two soil profiles were opened in each shelterbelt with soil sampling carried out at fixed depths of 0-10 cm, 10-20 cm and 20-40 cm. Basic physical and chemical properties of air-dry soil were determined using the following methods: the pipette method was used for particle size analysis (ISO-11277:1998), bulk density was calculated according to Adams (1973), soil pH was determined in distilled water with solid-liquid, hydrolytic acidity (Y_1) and the sum of exchangeable basis (S) was determined using the Kappen's method (1929), the total capacity of cation adsorption (T) and the degree of base saturation (V%) were calculated (Hissink, 1925), CaCO3 was determined using the Scheibler's calcimeter. Humus content was measured using the Turin method (Nelson and Somers, 1996), total N using the Kjeldahl method (ISO 11261:1995) and C/N was calculated. The available P and K were determined by the Egner-Riehm method (Čakmak et

Figure 1. Study area with marked shelterbelts



al., 2010). In this paper are presented the results of C stock assessment in shelterbelts which are an integral part of the agroecosystems of the area of Bačka Palanka. Although shelterbelts are a part of agroforestry systems, C stock evaluation was carried out according to the methodology proposed for forests, because the Law on Forests (Official Gazette of RS 30/10) recognized shelterbelts as forests. General C pools for forest ecosystems are: living biomass, dead organic matter and soil.

According to the IPCC (2003) a total annual change in C stock in forests is the sum of changes in C stock in living biomass (aboveground and belowground), dead organic matter (dead wood and litter) and forest soil, expressed in t C yr^{-1}.

In this research, C stock estimation included only the living biomass pool and soil pool. Dead organic matter (dead wood includes wood lying on the surface, dead roots or stumps) was excluded from the estimation, because dead wood was removed from the shelterbelts, and also litter (includes litter, fumic, humic layers and fine roots), because shelterbelts were regularly mowed.

Carbon stock in aboveground living biomass (*B*t) was obtained using the following equation (IPCC, 2003):

$$B_t = V_t \times D_w \times BEF_2 \times CF$$

where V_t is the total bole volume (m^3 ha^{-1}), Dw is the wood density (Mg dry mass m^{-3} green; 0.57 for Siberian elm (Martin et al., 2009), 0.42 for poplar and 0.74 for black locust (Šoškić and Popović, 2002), BEF_2 is the biomass expansion factor (dimensionless), which is the conversion factor to expand under-bark bole biomass to include non-merchantable biomass such as bark and branches (1.4 – IPCC, 2003) and *CF* is the conversion factor from dry biomass to carbon (Mg C [Mg dry mass]-1; 0.5 – IPCC, 2003).

Belowground biomass was calculated using an allometric equation which related aboveground biomass to root biomass (IPCC, 2003):

$$Y = [-1.0587 + 0.8836 \times ln(B_t) + 0.2840]$$

C stock in belowground biomass was obtained by multiplying root biomass (Y) and the C fraction of dry matter (0.5; IPCC, 2003).

Carbon stock in soil (*SCD*) was calculated using the following equation (Stolbovoy et al., 2003):

$$SOCD = \sum_{i=1}^{n} \left[SOC_i \times BD_i \times T_i \times \left(1 - \frac{C_i}{100}\right) \right]$$

where *SCD* is the soil carbon density for the *j*-th layers (*l*) of the sampling site (Mg C ha^{-2}), SOC_i is the soil organic carbon content for a single sampled depth (g kg^{-1}), BD_i is the soil mass of the undisturbed volume of a single sampled depth (g cm^{-3}), T_i is the thickness of the sampled layer (cm), C_i is the volume of the coarse fragments in the single sampled depth (%).

RESULTS AND DISCUSSION

In the Siberian elm shelterbelt there were 1304 trees per hectare, and timber volume was 865.6 m^3 ha^{-1}. The poplar shelterbelt had a lower planting density and 980 trees per hectare with a timber volume 785.9 m^3 ha^{-1}. The highest number of trees was found in the black locust shelterbelt and it amounted to 2115 trees per hectare, and timber volume was 355.3 m^3 ha^{-1}. The achieved timber volume in 20-years-old black locust shelterbelt was a consequence of the high number of trees in the shelterbelt, and indicates low productivity on the one hand and the absence of silvicultural measures on the other.

The average volume of a single tree in the Siberian elm, poplar and black locust shelterbelts were 0.664 m^3, 0.802 m^3 and 0.168 m^3, respectively. Since all three species in 20-years-old shelterbelts were far from their ecological optimum, poplar had the highest productivity in specific conditions. The absence of care and maintenance in the black locust shelterbelts was probably one of the causes of its low productivity. Siberian elm is between poplar and black locust in terms of productivity. However, the estimation of production characteristics is only one (and less significant) element in the assessment of the suitability of species for shelterbelts. Primarily, the selected species should be wind-tolerant and adapted to environmental conditions in terms of soil, vegetation, climate, etc.

The living biomass of the 20-years-old Siberian elm shelterbelt was 867.6 t ha^{-1}, where aboveground biomass was 690.8 t ha^{-1} (79.6%), and belowground biomass amounted to 176.8 t ha^{-1} (20.4%). The living biomass of the poplar shelterbelt amounted 588.4 t ha^{-1}, where aboveground biomass was 462.1 t ha^{-1} (78.5%), and belowground biomass accounted for 126.3 t ha^{-1} (21.5%). In the black locust shelterbelt, 471.2 t ha^{-1} of living biomass was distributed in the aboveground biomass 368.1 t ha^{-1} (78.1%) and belowground 103.1 t ha^{-1} (21.9%). The ratio of aboveground and belowground biomass was not significantly different among the investigated species and it was about 0.8:0.2 for each species.

According to the results (Table 1) the largest portion of C stock per hectare was accumulated in the living biomass of the Siberian elm shelterbelt (433.8 t ha^{-1}), where the aboveground C stock was 345.4 t ha^{-1}, and the belowground C stock 88.4 t ha^{-1}. The total C stock in the poplar shelterbelt was 294.2 t ha^{-1} of which the aboveground C stock was 231.1 t ha^{-1}, and 63.1 t ha^{-1} was the belowground C stock. In the black locust shelterbelt total C stock was 235.6 t ha^{-1}, while C stock in the aboveground biomass was 184.1 t ha^{-1}, and belowground C stock was 51.5 t ha^{-1}. Average C stock per tree in the Siberian elm shelterbelt was 0.333 t ha^{-1}, in the poplar shelterbelt it amounted to 0.300 t ha^{-1} and 0.111 t ha^{-1} in the black locust shelterbelt.

Table 1. Carbon stock in 20-years-old shelterbelts in the area of Bačka Palanka

Diameter class	Carbon stock n living biomass								
	Aboveground biomass			Belowground biomass			Total		
	SE	P	BL	SE	P	BL	SL	P	BL
	t ha^{-1}	t ha^{-1}	t ha^{-1}	t ha^{-1}	t ha^{-1}	t ha^{-1}	t ha^{-1}	t ha^{-1}	t ha^{-1}
2.5									
7.5			0.56			0.25			0.81
12.5	0.16		18.37	0.09		5.56	0.25		23.93
17.5	2.04	1.49	41.77	0.80	0.61	11.50	2.84	2.10	53.27
22.5	17.05	5.88	69.72	5.21	2.03	18.08	22.27	7.91	87.81
27.5	65.27	17.55	29.01	17.06	5.34	8.33	82.33	22.89	37.35
32.5	132.91	62.19	10.43	31.98	16.35	3.37	164.89	78.54	13.80
37.5	100.64	50.74	14.17	25.01	13.66	4.43	125.66	64.39	18.60
42.5	24.03	62.22		7.06	16.35		31.09	78.58	
47.5	3.27	30.98		1.21	8.83		4.48	39.81	
Total	345.39	231.05	184.04	88.42	63.17	51.54	433.80	294.22	235.57

According to Bura (1962), plantations of Euramerican poplar hybrids established in agricultural systems have always had a higher productivity than plantations of the same hybrids outside agricultural production. A significant amount of C stock and nutrients were accumulated in biomass of hybrid poplars in systems of riparian buffer strips (Fortier et al., 2010/b). Fast growth of poplar clones and cultivars defines the production cycle (rotation) of poplar plantations. If the production targets were set as secondary, as in shelterbelts, then the life cycle of poplar plantations could be significantly longer. In addition, poplar (*Populus x euramericana* (Dode) Guin. cv. „Serotina") reaches its peak productivity later in life cycle compared to Siberian elm, and unlike Siberian elm still has high productivity in the investigated shelterbelts. Siberian elm is a fast growing species and at the age of 10 years in favourable environmental conditions it could reach the height of 13 m and a diameter of 9.3 cm (Jovanović, 1982). In its ecological optimum Siberian elm can reach the age of 100-150 years. However in the conditions of continental climate prevailing in the study area, Siberian elm is a short-lived species that hardly reaches more than 60 years of age (Grbić, 2014). It was widely applied in shelterbelts' establishment in steppe conditions (Jovanović, 1982), but also in Serbia (Grbić, 2014). Siberian elm tolerates a variety of conditions such as poor soil and low soil and air moisture and it is fairly wind-tolerant, which makes it suitable for shelterbelts, but shows the tendency to be invasive (Grbić, 2014). The extract from the leaf litter of Siberian elm inhibits the radical growth of herbaceous plant native species, such as *Dactylis glomerata* L., *Trifolium repens* L. and germination of *Chenopodium album* L. which reduces the growth of understory species (Perez-Corona et al. 2013). The allelopathic effect of Siberian elm that may limit the establishment of the most abundant species of natural vegetation communities may lead to clear effects on understory vegetation structure and function. Although every monoculture has adverse effects on soil properties and function and could cause soil sickness (Pavlović et al., 2011).

Considering previously mentioned facts, poplar is a preferred species for shelterbelts establishment in the area studied. Poplar is well adapted to environmental conditions and has beneficial effects on crops in protected fields

(Bura, 1962). It also does not have the allelopathic potential to suppress native species. In multifunctional agroforestry systems, poplar shelterbelts represent an appropriate way for the production of high amounts of biomass and wood in short rotation, and at the same time contributing to the mitigation of ecological problems (such as agricultural non-point source pollution) which had occurred as a consequence of intensive agricultural production (Fortier et al., 2010/a). Carbon stock in the biomass of black locust of the same age expressed per tree is significantly lower and amounts to 30% of the C stock accumulated in the Siberian elm and poplar. Black locust in shelterbelts in the area of Bačka Palanka is the least efficient species, not only in C accumulation but in its adaptation potential to the environmental conditions. In the given site conditions, black locust has a low increment and low trunk quality which partly is a consequence of the complete absence of care and maintenance, but also its unconformity with the environmental conditions.

The observed soil type was Gleyic Phaeozem (WRB, 2006). It belongs to the textural class of clay and contains no particles sized 2.00 mm. Soil reaction (pH in water) ranged from 7.82 to 8.14. Concerning nutrient content in the studied soil, the following values were recorded: the humus content ranged from 2.04 to 6.16%, indicating moderate to high humus level, the total N ranged from 0.26 to 0.40%, indicating a soil well supplied with N, while the average content of available P was 4.8 mg/100g soil, and the average content of available K was 24.13 mg/100g soil. C:N ratio ranked from 4.08 to 9.67. Narrow C:N ratio indicating the formation of a better quality humus (mull humus) (Knežević and Košanin, 2007).

The average C stock in the studied soil in the 0-20 cm layer was 9.33 kg m^{-2}. The largest amount of C stock was accumulated in the soil layer up to 10 cm and amounts to 3.24 kg m^{-2} on average, while decreasing with depth, consequently amounting to 1.84 kg m^{-2} and 1.42 kg m^{-2} in the 10-20 cm and 20-40 cm layers, respectively.

Compared to the C stock in the 0-20 cm layer in soil of the same type in Srem, which ranged from 2.72 to 5.05 kg m^{-2}, and averagely 3.56±0.94 kg m^{-2}, there was a larger amount of C stock accumulated in the studied soil in these shelterbelts, that amounted 5.07±0.16 kg m^{-2} on average in the 0-20 cm layer. The soil organic matter content in arable land on Chernozems of Vojvodina is constantly decreasing, and in the period 1990-2004 by up to 0.05-0.2% (Ličina et al., 2011). According to Vidojević et al. (2013), C stock was decreased in agricultural lands due to the increase in agricultural production and land use changes. By the implementation of agroforestry systems and reintroduction of trees in agricultural lands by shelterbelt networks establishment, rapid decrease in soil organic matter could be mitigated in agricultural soils.

The interactions between trees and soil are very complex. In the same soil condition investigated tree species shown different average timber volume as a result of different species requirements and allelopathic effects. The soil properties such as pH and availability of nutritive macro and microelements, organic matter quality, structure, texture and soil moisture are some of the most important factors

for biomass production and timber volume increment. Also, the backward effect of trees on soil should not be neglected. Leaf litter and dead wood influences the organic matter quality and turnover which is beneficial in treeless agricultural land. These beneficial interactions between trees and soil are utilized in agroforestry systems (Jose, 2009).
The total C stock in biomass and soil (0-40 cm) of the studied shelterbelts was presented in Table 2. The largest amount of C stock was accumulated in the Siberian elm shelterbelt 527.1 t ha^{-1}, and the lowest one was accumulated in the black locust shelterbelt 328.9 t ha^{-1}. The share of accumulated C by C pools in the total C stock differed among the studied tree species. According to the results, aboveground C stock was the largest in the Siberian elm shelterbelt (65.5%), and the smallest one was in the black locust shelterbelt (56.0%). The share of belowground C stock was slightly different in the Siberian elm, poplar and black locust shelterbelts (16.8%, 16.3% and 15.6%, respectively), while the share of C stock in soil was the largest in the black locust shelterbelt (28.4%), and in the Siberian elm shelterbelt it amounted to the lowest value of 17.7%.

Table 2. Carbon stock in biomass and soil in the studied shelterbelts

	Siberian elm		Poplar		Black locust	
	t ha^{-1}	%	t ha^{-1}	%	t ha^{-1}	%
Total C stock	527.09	100.0	387.51	100.0	328.86	100.0
Aboveground C stock	345.39	65.5	231.05	59.6	184.04	56.0
Belowground C stock	88.42	16.8	63.17	16.3	51.54	15.6
Soil C stock	93.29	17.7	93.29	24.1	93.29	28.4

The C stock per tree was slightly different in the 20-years-old Siberian elm and poplar shelterbelts in the given site conditions, with that being the total C stock differently distributed in the aboveground, belowground and soil C pools. Siberian elm accumulated more C in the aboveground biomass at the expense of C accumulation in the soil, unlike poplar which accumulated less C in the aboveground biomass in favour of the C accumulation in soil. These ratios indicate the beneficial effects of poplar on the content and quality of soil organic matter. When selecting species to establish field shelterbelts in the area studied, a number of relevant ecological and economic factors, and above all, interactions of the tree species and specific site conditions should be considered.

CONCLUSION

Designing shelterbelts to address the various demands and provide services, requests special attention paid to the choice of structural and spatial characteristics of shelterbelts and the selection of species for shelterbelts. An appropriate selection of species provides the multifunctionality of these shelterbelts. The C stock in 20-year old shelterbelts in the area of Bačka Palanka consisted of Siberian elm and poplar, expressed per tree, is almost the same 0.333 t and 0.300 t, respectively, and in the black locust shelterbelt it is considerably lower amounting to 0.111 t per tree.

Although it has a lower C stock in biomass (20-years old shelterbelts), poplar is a preferred species in comparison to Siberian elm in the given environmental conditions, due to its adaptability and suitability to the environmental conditions, longevity and the impact on crops that are grown in the sheltered fields. Namely, in contrast to Siberian elm, poplar still reaches high productivity in the examined shelterbelt. The distribution of C stock in living biomass and soil indicates that poplar litter gives a better quality organic matter and affects more C accumulation in soil than Siberian elm. Siberian elm, also expresses a tendency to be invasive, especially in monocultures, thus having a negative impact on crops in sheltered fields.

Poor conditions of the black locust shelterbelt, its volume and C stock indicate the importance of regular care and maintenance, which were not applied in the examined shelterbelt.

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