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### SOC STOCK IN DIFFERENT FOREST-RELATED LAND-USES IN CENTRAL STARA PLANINA MOUNTAIN, BULGARIA

**Abstract** Forest conversions may lead to an accumulation of carbon in vegetation, but little is known about changes in soil C storage with establishment of plantation forests. Understanding these effects is important to addressing issues relevant to ecosystem function and productivity, and to global balance of carbon.

The study investigated the effects of the created coniferous plantations on former beech and pasture sites on the soil organic carbon storage. The major forest-related land-uses in the high mountainous regions of central Stara Planina Mountain were investigated: mountainous pasture, coniferous plantations (planted on previous pasture and beech forests between four and five decades ago) and natural beech forests. The experimental data of soil properties, conducted in 2005, 2006 and 2007, were used in determining the variations in organic carbon storage in forest litter and in mineral soil under different land-use patterns. At each site five representative soil profiles were opened and described giving a total 75 soil samples from the soil layers respectively at 0-10, 10-30 and 30-50 cm depth. A total of 55 samples from forest floor layers (Aol, Aof, Aoh and greensward) were collected with 25:25 cm plastic frame. The main soil properties were determined in accordance with the standardized methods in the Laboratory of soil science at the Forest Research Institute - BAS. The IPCC Good Practice Guidance for Land Use, Land Use Change and Forestry was used to estimate the soil organic carbon stock in soil and litter. The results obtained showed that the SOC stock was quite similar among forest land-uses. The conversion of natural beech forests to coniferous plantations in studied region is related with slightly expressed decrease in soil carbon storage. The values of SOC stocks in 0-50 cm soil layer in these sites were 8.5 ( $\pm 2.1$ ) tones/ha for pine and 11.0 ( $\pm 1.4$ ) tones/ha for spruce, while under the natural beech forest it was 14.8 ( $\pm 1.0$ ) tones/ha. The SOC stock in mountainous pasture was 20.7 ( $\pm 6.5$ ) tones/ha, while in spruce plantation created on previous pasture it was 13.5 ( $\pm 2.7$ ) tones/ha. Our finding showed that forest conversions effect in central Stara Planina Mountain is expressed by decrease in SOC stock related with losses of carbon from the upper mineral soil decades after creation of coniferous plantations. Nevertheless the relatively large organic carbon storage in forest litter in the spruce plantations compensated C lost from mineral soil after the land-use change. The overall carbon stock both in forest litter and soil under plantations ranged from 56 tones/ha (pine) to 77 tones/ha (spruce), while under natural beech forest and pasture the values were 70 and 81 tones/ha respectively. But in terms of stability C sequestered in mineral soil is more desirable than C sequestered in forest floor which are more vulnerable to decomposition following disturbances. The application of silvicultural activities in coniferous plantations created by conversion of forest lands or grasslands in the region of central Balkan is desirable to improve the carbon sequestration in soils.

**Key words:** forest soils, organic carbon stock

**Извод:** Промена шума може довести до нагомилавања угљеника у вегетацији, ипак мало је познато о промени концентрација угљеника у земљишту приликом пошумљавања. Разумевање ових ефеката важно је у домену решавања питања која су релевантна за функције екосистема и продуктивност, као и глобални садржај угљеника. У овом раду истраживане су последице настале сађењем четинара на теренима који су некад били под буквом и пашњацима, на земљишту богатом угљеником. У централном делу Старе планине истраживани су планински пашњаци, зимзелене шуме (које су сађене на некадашњим пашњацима и буковим шумама), као и природне букове шуме. Подаци карактеристика земљишта, који су прикупљени током 2005, 2006 и 2007 коришћени су у циљу детерминације колебања садржаја угљеника у земљишту. На

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свакој локацији одређено је пет профила из којих је узимано 75 узорка земљишта из слоја на 0-10, 10-30 и 30-50 цм, дубина. Укупно 55 узорка узето је из шумске подлоге (Аол, Аоф, Аох и бусен) у рам од пластике димензија 25:25 цм. Основни својства земљишта су утврђена у складу са стандардизованим методама у Лабораторији за науку земљишта - Шумарски институт - Бас. Водич Међувладиног панела за климатске промене коришћен је за процену залихе угљеника у земљишту. Добијени резултати су показали да је СОЦ залихе биле прилично сличне међу шумским земљиштем. Конверзија природних букових шума у шуме четинара у региону била је праћена смањењем угљеника у земљишту. Вредности СОЦ у слоју 0-50 цм земљишта на овим локацијама су 8,5 ( $\pm$  2,1) тона / ха, за бор и 11,0 ( $\pm$  1,4) тона / ха, за смреку, под природном буковом шумом је било 14,8 ( $\pm$  1,0) тона / хектару. СОЦ у планинским пашњацима износи 20,7 ( $\pm$  6,5) тона / ха, док под омориком, а на претходним пашњаку је 13,5 ( $\pm$  2,7) тона / хектару. Резултат је показао да је конверзија шума у централном делу Старе Планине утицала на пад СОЦ у вези са губицима од угљеника из горњег слоја минералниог тла након стварања засада четинара. Ипак релативно велика складишта органског угљеника у шуми оморике могла су надокнадити угљеник минералниог тла након промене употребе земљишта. Вредност угљеника у шуми и земљишту под засадима креће се у распону од 56 тона / ха, (бор) до 77 тона / ха, (смрека), док се под буковом шумом и природним пашњацима вредности крећу између 70 и 81 тона / ха. Угљеник присутан у шумском покривачу склонији је растварању од оног у земљишту. Примена узгојних активности у засадима четинара створио конверзије шумских земљишта и пашњака у региону централног Балкана требало би да побољша секвестрацију угљеника у земљишту.

**Кључне речи:** шумско земљиште, залихе органског угљеника

## Introduction

In view of climate change and carbon (C) trading programs, an increase in biofuel production and new demands on agriculture and forestry, the need for a better understanding of net terrestrial C sequestration has become essential to understand the cumulative effects of these developments (Negra et al., 2008). The carbon sequestered in forest ecosystems is a major part of the global terrestrial C stocks. It is estimated that the forest biomass contains more than 80% of all global C contained in the aboveground biomass and that forest soils contain more than 70% of the C contained in soils (Batjes, 1996; Six et al., 2002).

Moreover the forest conversions of grasslands into forest plantation have been cited as an effective method for reducing the atmospheric CO<sub>2</sub> concentration because of the ability to sequester C in vegetation and soil (IPCC, 2003; Jandl et al., 2007).

Despite the considerable SOC sequestration potential that afforestation offers, many studies have reported contradictory findings. Afforestation resulted in either a decrease (Parfitt et al., 1997; Farley et al., 2004) or an increase in soil organic carbon (SOC) stocks (Del Galdo et al., 2003; Grünzweig et al., 2007), or had a negligible effect (Davis, 2001; Davis et al., 2007; Smal & Olszewska, 2008). Laganière et al. (2009) have undertaken meta-analysis on the carbon accumulation in agricultural soil after afforestation and summarized that the positive impact of afforestation on SOC stocks was more pronounced in cropland soils than in pastures or natural grasslands and suggested that broadleaf tree species have a greater capacity to accumulate SOC than coniferous species. Moreover they established that afforestation using pine species does not result in a net loss of the whole soil-profile carbon stocks compared with initial values (agricultural soil) when the surface organic layer is included in the accounting (Laganière et al., 2009).

In a previous study in Central Balkan, based on ANOVA analysis, it is established that different land-use type influence the carbon and nitrogen contents in the upper soil layers (Zhiyanski et al., 2008). Consequently more information about organic carbon stocks in forest soils is needed with regard to the monitoring of trends in soil C pools and fluxes and the assessment of long-term C-sequestration potentials of soils under different land use.

In this paper, we study the organic-C stocks in soils and the effects of forest-related land-use changes on soil carbon stocks in representative ecosystems from the high-mountainous region of central Stara Planina Mountain in Bulgaria.

## Materials And Methods

Five representative experimental sites within the altitude range 1050 - 1500 m were chosen in the Beklemeto region, central Stara Planina Mountain. Some of their specific characteristics are presented here (Table 1). The main forest-related land-uses in the high mountainous regions of central Stara Planina Mountain were included. The experimental data of soil properties, conducted in 2005, 2006 and 2007, were used in determining the variations in organic carbon storage in forest litter and in mineral soil under different land-use patterns.

Each experimental site had an area of 0.5 ha and characterized different type of forest-related land uses – extensive mountainous pasture (PSP1), spruce plantation (PSP2) created on part of adjacent pasture PSP1, natural beech forest (PSP3), spruce (PSP4) and pine (PSP5) plantations, created through conversions of natural beech forests. The first site (PSP1) is a high-mountain pasture, used intensively in the past but in the last decade the pasture was occasional. The site is located on the top of the mountain, but the north aspect predominates. PSP2 is forest plantation of *Picea abies* Karst., created to increase the forest zone in this region and characterizes with lack of any silvicultural activities after the creation. The conversion from pasture to plantation is realized in 1970 through planting of 3-years-old spruce trees. The stand density is very high and no underground vegetation was observed. The third site is natural forest of *Fagus sylvatica* L. with mean age of 45 years.

The coniferous plantations from Norway spruce (PSP4) and Scot's pine (PSP5) are created on the sites of previous natural beech forests after clear cutting. The experimental sites PSP3, PSP4 and PSP5 are managed in accordance with the local management plans.

At each site five representative soil profiles were opened and described giving a total 75 soil samples from the soil layers respectively at 0-10, 10-30 and 30-50 cm depth. The samples for bulk density determination have been taken with volumetric ring, from each soil layer in two repetitions, only in one soil profile per site. A total of 55 samples from forest floor layers (Aol, Aof, Aoh and greensward) were collected with 25:25 cm plastic frame. The samples were preserved in plastic bags and transported to the laboratories. The fresh weight of forest floor layers was measured, then these samples were dried in oven at 72°C for 48 hours and the dry mass was determined. The soil samples were air dried. The content of coarse fractions in soils was determined before the samples were sieved through 2 mm.

**Table 1. Characteristics of the experimental sites in central Stara Planina Mountain**

Site	Soil type	LU pattern and dominant tree species	Altitude [m a.s.l.]	Age [years]	Aspect and slope [°]	Forest floor [FF]	Thickness of FF [cm]
S1	<i>Cambisol modic</i>	High mountain pasture	1500	-	N, 4	greensward	13
S2	<i>Cambisol modic</i>	Pure plantation 1 <i>Picea abies</i> Karst.	1420	35	W, 12	<i>dysmull</i> AoL, AoF	4
S3	<i>Cambisol eutric</i>	Natural forest stand - <i>Fagus sylvatica</i> L.	1240	40 - 45	N, 15	<i>Hemimoder</i> AoL, AoF	2.5
S4	<i>Cambisol dystric</i>	Pure plantation 2 <i>Picea abies</i> Karst.	1300	45	NE, 15	<i>moder</i> AoL, AoF, AoH	4.5
S5	<i>Cambisol dystric</i>	Pure plantation <i>Pinus silvestris</i> L.	1050	55	W, 24	<i>moder</i> AoL, AoF, AoH	4.0

The following soil properties have been determined in accordance with the standardized methods in the Laboratory of Forest Soil Science at the Forest Research Institute – BAS (Donov et al., 1974): bulk density, coarse fractions, textural fractions, pH (H<sub>2</sub>O), nitrogen content (Kjeldahl method), and carbon content (Thurin method). The IPCC Good Practice Guidance for Land Use, Land Use Change and Forestry was used to estimate the soil organic carbon stock in soil and litter (IPCC, 2003).

### Results and discussions

The distribution of soil organic carbon under different studied land-uses is presented on figure 1-A. The carbon contents in the upper 0-30 cm of soils in the high-land pasture vary between 7 % ( $\pm 2$ ) – 10 % ( $\pm 4$ ) for 0-10 cm and 10-30 cm respectively and are significantly higher compared with other studied forest land-uses, where the SOC is fewer than 5 %. Only one exception in 10-30 cm on soil under the beech stand, where the carbon was higher (8 %  $\pm 1$ ), was detected. The overall SOC within the whole profile is 20 % under the pasture, while under the forests it ranges from 8 % (in S5) to 15 % in S3.

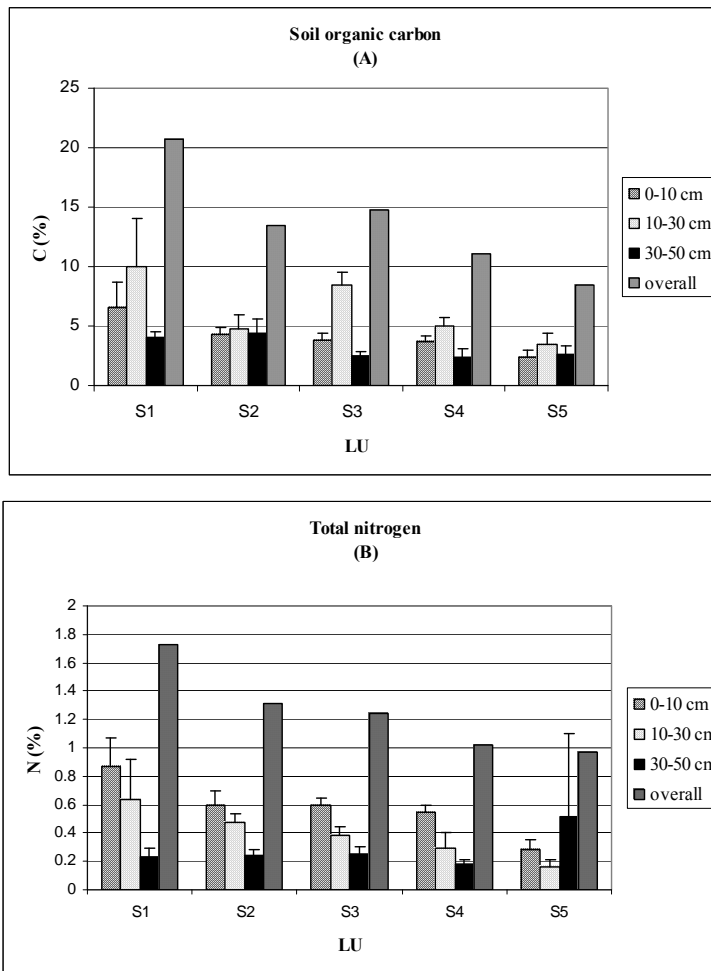


Fig.1. Soil organic carbon (A) and nitrogen contents (B) in studied land-uses

In most cases the total nitrogen content follows the tendency of soil organic carbon (fig.1-B). The highest nitrogen contents are located in the upper 0-10 cm of soils and decrease in depth. The soil from pasture characterizes with the highest nitrogen content (0.8 % in 0-10cm), while soils under different forest types have comparatively less N (0.4 - 0.6 % in 0-10 cm).

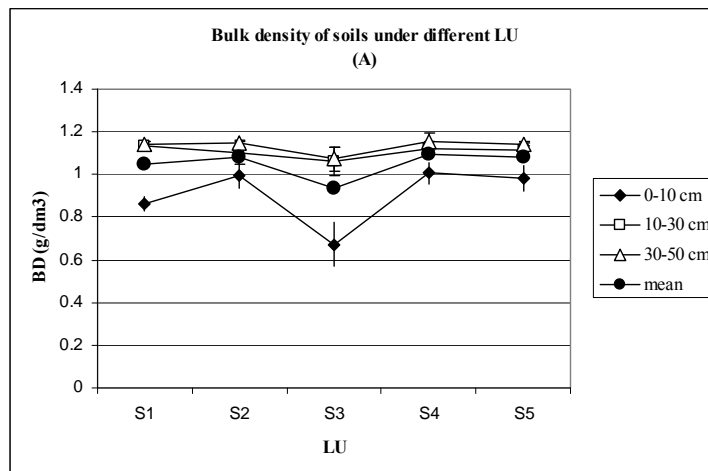
The soil bulk density is shown on fig.3. and the values are within the range for *Cambisols* (FAO, 1991). A decrease in bulk density of all soil layers was determined for the beech natural forest (S3), clearer expressed for the surface layer.

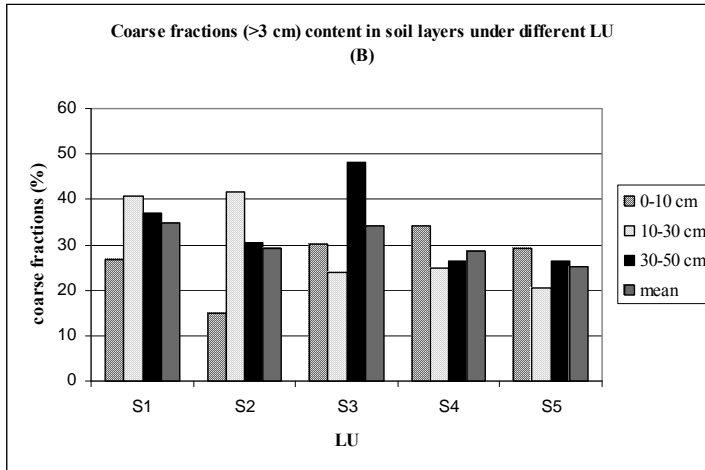
According to the percent of coarse fractions in studied land-uses two groups could be divided (fig.4). The first group is formed from S1 and S2 sites, where the coarse fractions content is less in the surface 0-10 cm and increase in depth. The other group includes the sites located on the lower altitude - S3, S4 and S5, where the percent of coarse fractions in the upper soil layer is higher due to the fluxes and movement of materials down the slopes. Both the characteristics of soil sub-types and the topography influence the variations of this parameter, which is closely related to the soil organic carbon stock.

**Table 2. Mineral soil C:N ratio in studied sites**

C:N	S1	S2	S3	S4	S5
0-10 cm	7.6	7.1	6.4	6.7	8.4
10-30 cm	15.9	10.2	22.0	16.9	20.7
30-50 cm	17.3	17.9	9.7	13.3	5.1

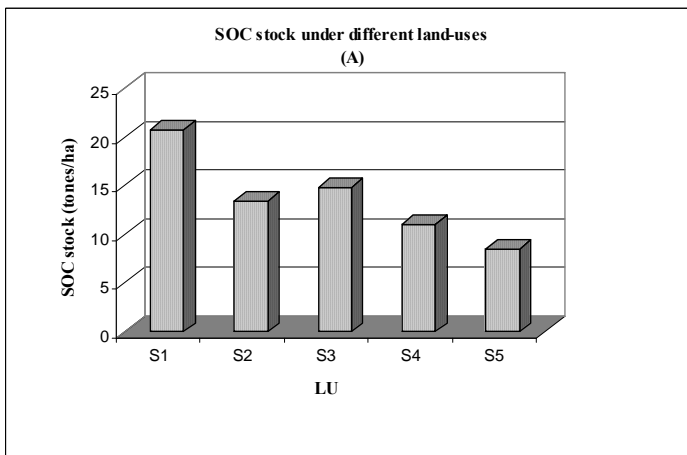
The C:N ratios in different soil layers from forest-related land-uses strongly vary from 6 to 22 (Table 2). Nevertheless the values in the upper 0-10 cm are similar (<8), which indicates that the enrichment of organic substances with nitrogen in this layer is medium. The values are higher for the deeper soil layers. The C:N ratio higher than 20 in 10-30 cm soil layer under the beech and pine is an indication of high levels of organic materials incorporated into the soil system (Saikh et al., 1998), or change in type of organic material present in the soil, which is related with the specifics of the aboveground vegetation.





**Fig.2. Bulk density (A) and coarse fractions distribution (B)  
in soil profiles in studied land-uses**

The organic carbon stock in 0-50 cm of soils under different forest-related land-uses in central Stara Planina Mountain shows well expressed variations (fig.3) especially between pasture and forests. The results obtained for the SOC stock are quite similar among forest land-uses. The highest SOC-stock (20 tones/ha) is determined in the high-land pasture. The SOC stock under the natural beech forest is also high – 14 tones/ha, while under the coniferous plantations it is lower and varies from 7 tones/ha under the pine to 10-13 tones/ha under the spruce. The percentile expression of soil carbon stock in 0-50 cm profile of *Cambisols* under different forest-related land-uses shows that the high-land pastures have high importance in formation of carbon stocks in mountainous soils, followed by the natural beech forests and spruce plantations.



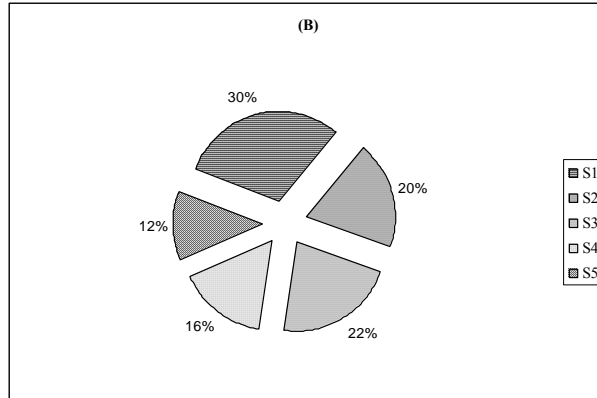


Fig.3. SOC stocks in tones/ha (A) and in % from total (B) in studied land-uses

The organic carbon stock in forest floor (and in greensward in S1) is notably higher than the SOC stock for all studied land-uses (fig.4). The carbon stock in forest floors is over 42 tones/ha and in some land-uses it arrives 60 tones/ha (S2). The spruce plantations have higher carbon stock in forest floor than all other land-uses, which is an indication for high potential of carbon accumulation in these forest land-uses. In terms of ecosystems stability the carbon accumulated in soils is more desirable and consider this fact it could be assumed that in the soils of high-land pasture the main carbon content is accumulated. But in soil system the forest floor remains the main reservoir of carbon.

The land-use change of native pasture and beech forests to coniferous plantation was pronounced in decrease the SOC-stock in mineral soil decades after planting. The results obtained confirm the conclusions from previous investigation where the decrease in soil carbon content after conversions from pasture to spruce plantation was determined (Zhiyanski et al., 2008). Here we could assume that the carbon losses in mineral soils are compensated through the carbon sequestration in the forest floor formed in coniferous plantations.

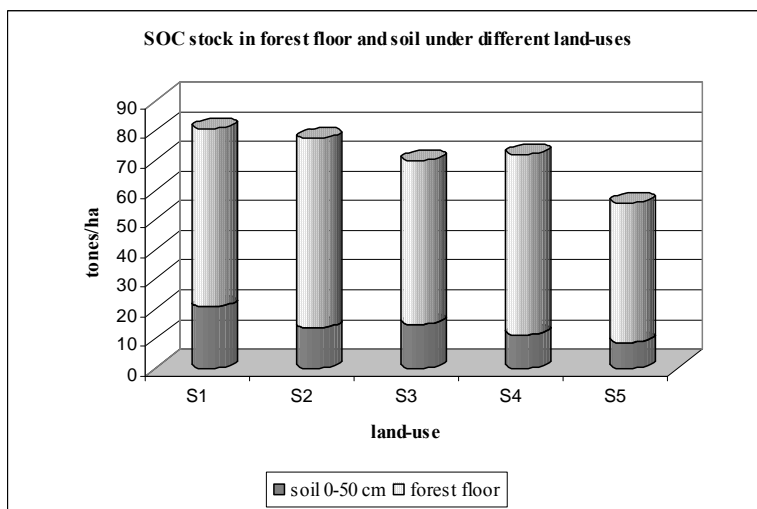


Fig.4. Organic carbon stocks in forest floor and in 0-50 cm soil profiles under different forest-related land-uses

## Conclusion

Our finding showed that the overall carbon stock both in forest floor and in soils was highest for high-land pasture (81 tones/ha), followed by spruce plantations (77 tones/ha), while the beech forest and pine plantation characterised with comparatively lower carbon stock.

The effect of conversion from natural pastures and beech forests into coniferous plantations in central Stara Planina Mountain is expressed by decrease of SOC stock. It is related with losses of carbon from the upper mineral soil decades after the creation of the coniferous plantations. Nevertheless the large organic carbon storage in forest floors in the spruce plantations compensates C lost from mineral soil after the land-use change. In terms of stability the carbon sequestered in mineral soil is more desirable than carbon sequestered in forest floor which is more vulnerable to decomposition following disturbances.

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Резиме

**САДРЖАЈ УГЉЕНИКА У РАЗЛИЧИТИМ ШУМСКИМ ТИПОВИМА  
ЗЕМЉИШТА У ЦЕНТРАЛНОМ ДЕЛУ СТАРЕ ПЛАНИНЕ, БУГАРСКА**

Наш резултат је показао да је укупан садржај угљеника, како на површини шумског тла, тако и у земљишту највиши на пашњаку (81 тона / ха), под омориком (77 тона / ха), док је под буковом шумом и боровима релативно низак садржај.

Утицај промене од природних пашњака и букових шума у шуме четинара у централном делу Старе планине је утицао на смањење СО<sub>2</sub> садржаја. Ипак релативно велика складишта органског угљеника у шуми оморике могла су надокнадити угљеник минералниог тла након промене употребе земљишта. Угљеник присутан у шумском покривачу склонији је растварању од оног у земљишту.

