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CARBON STOCKS IN LITTLE AND SILESIAN BESKIDS SOILS AGRICULTURAL USE**

Abstract. Organic carbon stocks (SOC_s) were determined in 14 pedons of the Little and Silesian Beskids (7 from each one: arable land and grassland) and compared with the C-stocks occurring in the soils of Ciężkowickie and Silesian Foothills. They were similar to SOC_s in the soils of the Silesian Foothills, but significantly higher than in the soils of the Ciężkowickie Foothills. The participation of SOC_s 0–30 cm layer at the stocks of this element in the whole pedon was higher than in the soils of the foothills. Different types of land used (arable land, grassland) did not affect the quantity of SOC_s in pedons and layers.

The quantity of the organic carbon stocks in soils is used, among others, to calculate its sequestration [1]. In the soil science literature there is scarce data on carbon stocks in pedons or certain layers in the Polish soils of the agricultural use. Estimated data can be found sin some sources calculated on the basis of the weight of organic C in soils and assumed soil density, without accounting for the content of the skeleton [2]. It is particularly difficult to estimate carbon stocks in mountain soils, highly diverse in thickness and content of the skeleton parts. The starting point there must be the carbon stocks defined for particular pedons or soil layers. Such data is rare for highland agriculturally used soils [3, 6, 7].

The aim of this research has been to determine organic C stocks (SOC_s) in different agriculturally used soils of the Little and Silesian Beskids and their comparison with the stocks of this component in soils from the Ciężkowickie and Silesian Foothills.

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MATERIAL AND METHODS

The study was conducted on 7 sites located in the Silesian Beskids (1–5) and the Little Beskids (6 and 7) (Table 1). These sites were in lower highlands at an altitude of 446–649 m above sea level in a moderately warm climate floor. At each site 2 soil pits were executed – one on arable land (R) and one on grassland - fresh meadows (Z).

At the arable land sites 1, 4, 6 and 7 corn and potatoes (once every 3 years) were cultivated. At site 3 instead of cereals grass was introduced with clover and at site 5 - oat with clover. Potatoes were always manured and cereals were fertilized with low doses of mineral fertilizers. At site 1 manure was used annually (including the cereals) and at site 5 every 2 years. At site 2 in crop rotation cereal mixture alternately with field pea and vetch were used, fertilized solely with phosphorus fertilizers. Grasslands were usually mowed once a year and then grazed, except for site 1 and 2, at which only sheep and goats were grazed. Grasslands were not fertilized (sites 2, 4, 6, 7) or fertilized with small doses of manure (sites 1 and 3) or mineral nitrogen fertilizers (site 5).

According to the Polish Soil Taxonomy [4], the studied soils belonged to two types: eutrophic brown soils (profiles 3 and 6) and dystrophic brown soils (profiles 1, 2, 4, 5 and 7), while according to the WRB [8] - to the main group of Cambisols (Table 1). These soils were developed on weathered flysch sediments of the Silesian unit and were characterized by the presence of skeletal parts. Compared soil profiles representing different ways of use were included in the same soil types (Table 1).

Carbon resources were determined in horizons in the soil layer ranging from the surface to 46–102 cm, in which soil forming processes were visible and roots of plants were present.

In soil samples taken out from all genetic horizons of studied soil profiles the following analyses were conducted: soil texture by Casagrande in Prószyński modification areometric method [10], pH in KCl by the potentiometric method [9], a sum of basic exchangeable cations (BS) through the estimation of individual cations after their extraction from the soil with CH_3COONH_4 (with Ca^{2+}, K^+, Na^+ determined by the flame photometer method, and Mg^{2+} by AAS method), potential acidity by Kappen's method and the content of organic carbon (TOC) by the method of high temperature combustion in the analyzer TOC-TN 1200. In soil samples with undisturbed structure, the percentage share of skeletal parts and density of fine earth parts were estimated.

TABLE 1. LOCATION, BEDROCK, THE TYPE AND SUBTYPE OF THE INVESTIGATED SOILS

No	Location				Altitude a.s.l. (m), slope and exposure	Geological substrate	Soil type and subtype [4]	Soil unit [8]
	Sites		N	E				
1	Brenna Bukowa	R	49°43’16,5”	18°58’15,2”	560; flat	Godulskie sandstones	Dystrophic brown soils humic	Leptic Cambisols (Humic, Dystric, Skeletic)
		Z						
2	Wisła Tokarnia	R	49°40’21,9”	18°52’12,1”	557; 3°NNE	Schists and sandstones–Godulskie upper strata[1)]	Dystrophic brown soils – humic (R), typical (Z)	Haplic Cambisol (Dystric, Skeletic)
		Z	49°40’20,8”	18°52’12,8”	557; 3°NE			
3	Wisła Jawornik	R	49°39’16,6”	18°48’59,1”	564; 10⁰SSE	Sandstones and schists – Godulskie lower strata[1)]	Eutrophic brown soils humic	Leptic Cambisols (Humic, Eutric, Skeletic)
		Z	49°39’17,1”	18°48’00”	560; 10°ESE			
4	Mlaskawka	R	49°34’27,7”	18°55’50,0”	641; 3°S	Dark sandstones – Paleogen[1)]	Dystrophic brown soils typical	Haplic Cambisols (Humic, Dystric, Skeletic)
		Z						
5	Mikszówka	R	49°35’16,6”	18°53’58,1”	649; 2°S	Istebniańskie upper schists with siderites[1)]	Dystrophic brown soils humic	Haplic Cambisols (Humic, Dystric, Skeletic)
		Z						
6	Tarnawa Górna	R	49°46’49,8”N	19°29’56,3”	446; 6°SSE	Sandstones thick-layered conglomerates - Istebniańskie upper strata[2)]	Eutrophic brown soils - leached (R), typical (Z)	Haplic Cambisols (Ruptic, Epidystric)(R) Haplic Cambisols (Ruptic, Eutric)(Z)
		Z						
7	Okrajnik	R	49°44’41,1”	19°16’26,5”	611; 20°SSE	Schists and sandstones, Malinowskie conglomerates– Godulskie upper strata[2)]	Dystrophic brown soils – typical (R), humic (Z)	Haplic Cambisol (Humic, Dystric, Skeletic)
		Z	49°44’42,5”	19°16’34,4”				

* Dorda A., 2005. Ukształtowanie powierzchni. [W:] Ustroń 1305–2005. (Red.) I. Panic, 43–44;

[1–2)] Mapa Geologiczna Polski 1:50000: [1)]Arkusz Wisła, [2)]Arkusz Lachowice;

R – arable land, Z – grassland

SOC stocks in 1 m^2 of individual genetic horizons were calculated according to the equation formula:

$$SOCs= (100\text{-}\%V_{sk})\ 0{,}01\ V_h\ BD_{f.e.}\ TOC \qquad (1)$$

where: %Vsk – skeleton share in % volume, V_h – volume of 1 m^2 horizon (m^3), $BD_{f.e.}$ – fine earth parts density (Mg m^{-3}), TOC – organic carbon content (g kg^{-1}), and then SOC_s in 1 m^2 soil to the depth 30 and 60 cm and in the whole pedons.

For the statistical analysis of the results, the *STATISTICA 8* program was used.

RESULTS AND DISCUSSION

The examined soils, according to "Particle size distribution and textural classes of soils and mineral materials" [11], belonged to medium heavy soils (profiles 1, 3, 4, 6, 7 except lower part of 3Z profile) and heavy soils (profiles 2, 4, 5 and lower part of 3Z profile). Medium heavy soils were characterized by sandy loam, loam and silty loam texture, and heavy soils belonged to the following granulometric subgroups: loam, clay loam, silt loam. Tthe comparison of soil profiles of arable lands and grasslands shows indicates that the texture is generally very similar , with the exception of humus levels which in the case of arable land contained more clay (Table 2).

The examined soils were generally very acid or acid. Sorption properties of analyzed soils were very different (Table 2). Humus horizons of grassland soils were characterized by a higher cation exchange capacity (CEC_{pot}) than in the analogical horizons of arable land soils (with the exception of site 5). A degree of complex saturation with basic cations (BS) exceeded the value of 50% in soils from profiles 3R, 3Z and 6Z and in the till horizons of 7R profile, Ap horizon in 4R profile and in humus horizons in 4R and 5Z profiles (Table 2).

In soil fine earth fraction of the surface layers the content of organic carbon ranged from 14.1 to 58.7 g kg^{-1}. In each pair of profiles the organic carbon content was higher (1.1–1.9 fold) in fine earth fraction of the A1 horizon of grassland soils than in Ap horizon of arable land soils. In A2 horizons it was always a lower amount of organic carbon than in the A1 horizons and usually (with the exception of site 1) equal or lower than in Ap horizons. The content of soil organic carbon (SOC) in fine earth fraction in genetic horizons in each site generally decreased with increasing depth. This trend was not found in the case of organic carbon stocks (SOCs) in different genetic horizons because they depend not only on the content of SOC but also on the thickness and the content of the grain skeleton levels (Table 2).

TABLE 2. MAIN PROPERTIES OF INVESTIGATED SOILS

Profile	Horizon	Depth (cm)	Soil texture classes* [11]	Clay (%)	pH_{KCl}	CEC_{pot}**	BS***	$BD_{f.e.}$	V_{sk}	V_h	TOC	SOCs
						(mmol(+) kg^{-1})	(%)	(g cm^{-3})	(%)	(m^3)	(g kg^{-1})	(kg m^{-2})
1R	Ap	0–18	gp	5	4.4	146.1	49.2	1.16	15.0	0.18	33.97	6.01
	A	18–30	gp	3	3.8	137.3	20.5	1.34	10.0	0.12	23.73	3.42
	ABC	30–47	gp	4	3.9	110.6	14.5	1.37	75.0	0.17	15.67	0.91
	C	47–70	gp	7	4.1	86.5	17.3	1.37	90.0	0.23	7.43	0.23
1Z	A1	0–10	gp	2	3.9	192.3	16.7	1.12	20.0	0.10	58.67	5.27
	A2	10–22	gp	2	3.8	192.4	15.4	0.96	65.0	0.12	43.74	1.77
	ABC	22–53	gp	5	4.1	139.6	7.8	0.96	85.0	0.31	32.23	1.44
2R	Ap	0–20	pyg	6	4.5	207.7	49.9	0.96	20.0	0.20	46.37	7.13
	ABC1	20–33	pyi	23	4.3	147.1	48.3	0.70	20.0	0.20	13.11	5.20
	ABC2	33–60	gi	27	4.2	147.1	47.0	0.88	70.0	0.13	8.95	0.45
	C	60–73	gi	29	3.8	196.5	21.6	0.91	85.0	0.27	5.15	0.33
2Z	Ahg	0–12	gp	3	3.9	220.4	22.5	0.91	90.0	0.13	50.18	0.06
	AB1	12–30	pyi	14	3.9	203.6	15.2	1.12	4.9	0.12	19.54	6.43
	AB2	30–54	gi	27	4.0	159.8	10.6	0.62	60.0	0.18	9.03	0.87
	BC	54–85	gi	33	4.0	151.5	11.8	0.80	80.0	0.24	6.14	0.35
	C	85–94	gi	32	3.9	168.7	17.5	0.93	80.0	0.31	5.06	0.35
3R	Ap1	0–14	pyg	7	4.5	170.1	48.2	0.95	24.0	0.14	39.20	3.97
	Ap2	14–29	pyg	8	4.5	155.5	52.7	1.18	52.2	0.15	27.30	2.30
	A/B	29–57	pyg	10	4.5	124.1	49.6	1.56	43.7	0.28	12.65	3.11
	BC	57–77	pyi	15	4.4	118.7	59.7	1.56	85.0	0.20	5.25	0.25

TABLE 2. CONTINUATION

3Z	A1	0–7	pyg	5	5.1	193.7	69.6	1.13	16.8	0.07	50.40	3.32
	A2	7–26	pyg	4	5.0	181.5	67.6	1.18	24.5	0.19	35.20	5.96
	A/B	26–43	pyg	12	5.1	133.5	61.5	1.56	25.3	0.17	15.45	3.06
	Bw	43–57	pyi	19	5.0	109.8	59.9	0.95	25.3	0.14	10.35	1.03
	BC	57–78	pyi	19	5.0	111.1	57.0	0.85	70.0	0.21	9.94	0.53
	C	78–102	pyi	15	4.8	101.2	63.7	0.85	90.0	0.24	5.06	0.10
4R	Ap	0–15	pyi	24	4.4	228.9	68.0	1.07	6.0	0.15	34.60	5.21
	ABC	15–30	gi	28	4.2	203.5	66.7	1.34	26.6	0.15	11.85	1.75
	BC1	30–48	gi	35	3.8	173.1	21.2	1.26	65.0	0.18	5.08	0.40
	BC2	48–68	gi	30	3.8	163.7	14.4	1.26	90.0	0.20	4.77	0.12
	C	68–(100)	gi	27	3.6	195.2	17.3	1.26	90.0	0.32	2.68	0.11
4Z	A1	0–7	pyi	14	3.9	238.6	37.0	1.03	5.4	0.07	53.40	3.66
	A2	7–17	pyg	11	3.8	213.3	31.9	1.14	6.1	0.10	36.20	3.88
	AB	17–28	pyi	25	3.9	179.8	27.7	1.32	16.9	0.11	15.45	1.86
	BC	28–46	pyi	26	3.9	176.7	26.7	1.40	30.0	0.18	5.35	0.94
5R	Ap	0–22	gz	11	4.1	213.7	52.6	1.15	5.6	0.22	37.62	8.98
	AB1	22–30	gz	15	3.8	187.2	37.4	1.24	23.1	0.08	15.24	1.16
	AB2	30–46	gz	15	3.6	187.1	21.6	1.89	32.5	0.16	16.69	3.41
	BC	46–70	gz	18	4.0	160.0	22.8	1.89	75.0	0.24	10.65	1.21
	C	70–(91)	gz	17	3.9	179.7	16.8	1.89	90.0	0.21	5.38	0.21

TABLE 2. CONTINUATION

5Z	A1	0–7	gz	9	4.1	211.1	51.6	1.10	5.7	0.07	40.95	2.98
	A2	7–17	gz	11	4.1	190.5	50.3	1.31	6.9	0.10	27.17	3.32
	AB	17–29	gz	20	3.8	171.3	46.9	1.51	8.9	0.12	11.85	1.95
	BC	29–58	gz	20	3.7	150.0	30.7	1.51	75.0	0.29	7.97	0.87
	C	58–(73)	gz	21	4.1	194.2	16.9	1.51	95.0	0.15	5.75	0.07
6R	Ap	0–16	gp	5	4.1	106.4	17.1	1.02	4.5	0.16	29.95	4.67
	A/B	16–35	pyg	5	4.4	75.4	17.2	1.08	18.8	0.19	13.10	2.18
	BC1	35–49	gz	5	4.4	50.8	27.0	1.15	23.3	0.14	3.00	0.37
	BC2	49–100	gp	7	4.4	52.1	35.8	1.86	85.0	0.51	2.03	0.29
	C	100–(106)	gz	13	4.1	81.7	32.5	1.86	90.0	0.06	2.48	0.03
6Z	A1	0–6	gp	1	4.5	158.8	37.5	0.91	4.3	0.06	55.65	2.89
	A2	6–26	pyg	3	4.1	101.9	12.6	1.15	5.0	0.20	19.93	4.36
	A/B	26–45	pyg	4	4.3	79.6	20.8	1.09	35.0	0.19	11.55	1.56
	BC	45–82	pyg	11	4.3	63.6	13.3	1.26	60.0	0.37	4.26	0.80
	BC	82–102	pyg	10	4.0	67.7	18.6	1.35	75.0	0.20	2.39	0.16
	C	102–112	pyg	14	3.9	88.0	37.4	1.14	85.0	0.10	2.78	0.05
7R	Ap	0–25	gz	14	4.4	70.3	37.3	1.36	2.7	0.25	14.05	4.64
	Bw	25–40	gz	8	4.1	41.1	37.4	1.86	40.2	0.15	3.34	0.56
	BC	40–55	gp	8	4.3	36.3	39.2	1.68	70.0	0.15	1.72	0.13
	2C	55–61	gz	21	4.2	88.1	66.6	1.68	90.0	0.06	2.65	0.03

TABLE 2. CONTINUATION

7Z	A1	0–6	pyg	5	4.9	97.9	54.9	1.23	0.9	0.06	19.35	1.42
	A2	6–19	pyg	5	4.7	80.9	54.6	1.41	6.2	0.13	12.35	2.12
	Bwc	19–42	gz	9	4.6	57.2	48.1	1.64	12.3	0.23	4.28	1.41
	BC	42–62	pyi	21	4.1	101.2	67.0	1.57	50.0	0.20	1.93	0.30
	C	62–(83)	gz	17	4.3	88.1	75.0	1.57	90.0	0.21	2.18	0.07

* Soil texture classes: gp - sandy loam, pyg - loamy silt, pyi - clayey silt, gi - clayey loam, gz - boulder loam.
** CEC_{pot} – potential cation exchange capacity; *** BS – base saturation ratio.

TABLE 3 SOIL ORGANIC CARBON STOCKS IN SPECIFIED LAYERS OF STUDIED SOILS (kg m^{-2})

Profiles	Arable lands (R)				Grasslands (Z)			
	0–30 cm	30–60 cm	>60 cm	pedon	0–30 cm	30–60 cm	>60 cm	pedon
1	9.43	1.04	0.1	10.57	7.41	1.07	–	8.48
2	7.47	0.44	0.06	7.97	7.30	0.41	0.33	8.04
3	6.38	3.04	0.21	9.63	9.52	3.44	0.56	13.52
4	6.96	0.48	0.05	7.49	9.50	0.84	-	10.34
5	10.14	4.11	0.72	14.97	8.29	0.85	0.06	9.20
6	4.83	0.52	–	5.35	4.22	1.01	0.10	5.33
7	6.28	1.01	0.32	7.61	7.58	1.48	0.68	9.74

Organic carbon stocks in pedons in differently used soils ranged within the similar limits - in arable soils from 5.35 to 14.97 kg, in grassland soils from 5.33 to 13.52 kg, and their mean values were similar and respectively amounted to 9.09 and 8.99 kg · m^{-2} (Table 3). At sites 3, 4 and 7 soil organic carbon stocks were higher in grassland soils than in the corresponding arable soils. Such a relationship is usually described in the literature and it may be interpreted by higher input of organic matter to the grassland soil [1, 3, 6, 7, 12, 13]. At other sites carbon stocks in differently used agricultural soils were similar (sites 2 and 6) or significantly higher in arable soils (sites 1 and 5) than in grassland soils. At these sites of the arable soils high doses of manure and mineral fertilizers were additionally used. Grasslands were not fertilized (sites 1, 2 and 6) or fertilized with a small dose of mineral fertilizers (sites 5), however intensively grazed (at sites 1 and 2 sheep and goats and at sites 5 and 6 cattle). This type of administration is widely practiced in higher-lying farms in the Carpathians. That is why, the calculation of carbon stocks in soils in mountain areas should take account of the possibility of higher carbon stocks in arable soils than in grassland. Leifeld *et al.* [3] also proves that in the Swiss grassland located in unfavourable conditions (high altitude, shallow soil) organic carbon stocks are lower than in arable soils. According to Vleeshouwers and Verhagen [14], the range of the annual carbon balance of grassland soils in Europe for the period 2008–2012 indicates that we have to deal with a negative annual carbon balance in grassland soils (of course not as much as on arable land).

Organic carbon stocks in the studied soils were similar to those found in the soils of the Silesian Foothills but significantly higher than in the Ciężkowickie Foothills soils (Table 4).

TABLE 4. COMPARISON OF SOCs VALUES IN SELECTED MESOREGIONS (IN kg m^{-2} IN SPECIFIED LAYERS OF SOILS)

Mesoregions	0–30 cm	0–60 cm	Pedon
Ciężkowickie Foothills n=8 [7]	2.2–6.7 (4.4)^{a*}	3.1–8.3 (5.7)^{a}	3.5–11.2 (6.7)
Silesian Foothills n=14**	4.7–8.4 (6.3)^{ab}	5.2–12.5 (8.2)^{ab}	6.4–14.1 (9.2)
Silesian and Little Beskids n=14	4.2–10.1 (7.5)^{b}	5.2–14.2 (8.9)^{b}	5.3–15.0 (9.2)

* in parentheses are the arithmetic mean; means marked in column with the different letters are significant at $p<0.05$ according to Tukey test for unequal sample sizes. ** Miechówka *et al.* [6] and unpublished data.

The soils of the Silesian and Little Beskids were characterized by a different distribution of carbon stocks in the profile than the soils of both foothills

(Table 5). The surface 0–30 cm layers contained 66.7–93.7% out of the total carbon stocks in the pedon, because soils are shallow and strongly skeletal in the lower part of profiles. The percentage share of organic carbon stocks in 0–30 cm layer in the stocks of the whole pedon was greater than in the foothills soils - usually deeper and less skeletal (Table 5).

The range of organic carbon stocks value in the 0–60 cm layer in the the Silesian and Little Beskids grassland soils under consideration, which reached 5.3–13.5 kg m^{-2}, was very close to the range given by Mestdagh *et al.* [5] for the loamy soils in Flanders (4.9–15.1 kg m^{-2}).

TABLE 5. THE SHARE OF SOCs IN 0–30 CM AND 0–60 CM LAYERS IN SOCs OF WHOLE PEDONS (RANGES AND ARITHMETIC MEANS) IN SOILS OF RESPECTIVE MESOREGIONS (IN %)

Mesoregions	0–30 cm	0–60 cm
Ciężkowickie Foothills (n=8) [7]	43.3–79.7 (68.0)[a]	66.6–98.5 (87.1)[a]
Silesian Foothills (n=14)**	58.8–77.1 (69.5)[a]	80.9–99.2 (88.3)[a]
Silesian and Little Beskids (n=14)	66.3–93.7 (83.6)[b]	93.0–100 (97.8)[b]

* as in Table 4; ** as in Table 4.

CONCLUSIONS

1. Organic carbon stocks in the studied arable and grassland soils varied to a similar extent.

2. Mountain soils used as arable land may contain higher carbon stocks than the soil of fresh meadows, if they have similar properties.

3. Organic carbon stocks in the Silesian and Little Beskids soils were similar to those found in the Silesian Foothills soils, but significantly higher than in the soils of the Ciężkowickie Foothills.

4. The percentage share of organic carbon stocks in the 0–30 cm layer in the stocks of the whole pedon was in the studied soils higher than in the soils of the Silesian and Ciężkowickie Foothills.

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ZASOBY WĘGLA W GLEBACH BESKIDU ŚLĄSKIEGO I MAŁEGO UŻYTKOWANYCH ROLNICZO

Zasoby węgla organicznego (SOC_s) określono w 14 pedonach z Beskidu Śląskiego i Małego (po 7 z gruntów ornych i użytków zielonych) i porównano je z zasobami występującymi w glebach Pogórza Śląskiego i Ciężkowickiego. Były one zbliżone do SOC_s w glebach Pogórza Śląskiego, ale wyraźnie wyższe niż w glebach Pogórza Ciężkowickiego. Udział SOC_s warstwy 0–30 cm w zasobach tego składnika w całym pedonie był większy niż w glebach pogórzy. Na wielkość SOC_s w pedonach i warstwach nie miał wpływu sposób użytkowania (grunty orne, łąki).