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ACCUMULATION OF ORGANIC CARBON IN RECLAIMED SOILS. DUMPING GROUNDS: BEŁCHATÓW, MACHÓW, TURÓW

Stanisław Gruszczyński
AGH – University of Science and Technology in Krakow

Summary

The paper presents the diversity of soil organic carbon (SOC) contents in soils of three reclaimed objects: external dumping grounds of mines Bełchatów, Machów and Turów. Sites vary in soil texture, age of tree stands and their species composition. The largest carbon pool in the organic level (litter) is in a dumping ground for the Turów mine, – the oldest of the objects. Similarly, the total SOC pool in the organic layer and the mineral to 30 cm deep in the soil is the largest dumping ground, Turów. The average annual increase in SOC stocks varied from about 0.5 t/ha/year in Bełchatów, after more than 1.2 t/ha/year in Machów. The annual deposition of organic carbon can be estimated at 1.7-2.5 t / ha / year.

Keywords: soil organic carbon (SOC), reclamation

INTRODUCTION

Organic carbon capture and storage by ecosystems is considered to be the primary form of limiting carbon dioxide concentration in the atmosphere (Commission.. 2010, Lal 2007). Therefore, the issue of protection and increase of the soil organic carbon (SOC) content becomes even more significant. The method of estimating the organic carbon content in ecosystems is decided upon by the European Union (Commission... 2010). The rehabilitation of wastelands is one of the means of restoring the carbon capture and storage potential of soils

(Lal 2004). At the same time, the observation of rehabilitated lands provides the opportunity to assess the rate of restoring this potential.

Soil Organic Carbon on reclaimed land

The problem of the level and change in SOC stocks remains difficult by a large number of unknowns, however there are models intended for the estimation of this stock under external influences. The most popular of them is the RothC model (Coleman *et al*., 1996), which also indirectly explains the mechanisms of achieving balance of this element in the environment

The RothC lists five compartments of soils with organic carbon content: Decomposable Plant Material (DPM), Resistant Plant Material (RPM), Microbial Biomass (BIO), Humified Organic Matter (HUM) and Inert Organic Matter (IOM). BIO, HUM and IOM compartments are the products of the transformation of DPM and RPM. All compartments are subject to decomposition: DPM and RPM into BIO, HUM and CO2, while BIO, HUM and IOM decompose into CO2. The SOC mass balance requires taking into account both of its sides: C input in the form of dead plant material and the loss of stocks as effect of transformation into BIO, HUM, IOM and CO_2. The loss of C mass of the individual compartments has a common prototype expressed by the formula (Coleman *et al*l., 1996; Yaron *et al*l., 1996):

$$C(1) = C(0) \times e^{-kt}, \tag{1}$$

where:

$C(0)$ and $C(t)$ – respectively: initial and final C mass in the compartment (DPM, RPM, BIO, HUM, IOM) per unit of surface area in a specific layer of soil, k – decomposition rate factor [1/t]), t – time between observations. The loss $\Delta C(t)$, of C from the compartment in time t equals:

$$\Delta C(t) = C(0) \times \left(1 - e^{-kt}\right). \tag{2}$$

The condition of the system reaching a balanced state (*equilibrium*) is the compensation of the $\Delta C(t)$ value by the input of C to the compartment, resulting from the transformation of its precursors. The consequence of these assumptions is the C stocks half-life in a compartment, equal to (Yaron *et al*. 1996):

$$t_{1/2} = \frac{\ln 0.5}{k}, \tag{3}$$

therefore:

$$t_{1/2} = \frac{0.693}{k}. \tag{4}$$

The RothC assumed the following k values for the conditions at the research facility in Rothamsted: k_{DPM} = 10 year^{-1}; gives the half-life $t_{1/2}$ = 0.069 year, i.e. approximately 25 days, after one year 0.004% of the C mass unit remains in this form, k_{RPM} = 0.3 year^{-1}; gives the half-life of $t_{1/2}$ = 2.31 years, i.e. approximately 845 days, after one year 74% of the C mass unit remains in this form, k_{BIO} = 0.66 year^{-1}; gives the half-life of $t_{1/2}$ = 1.05 year, i.e. approximately 382 days, after one year 51% of the C mass unit remains in this form, k_{HUM} = 0.02 year^{-1}; gives the half-life of $t_{1/2}$ = 34 years, after one year 98% of the C mass unit remains in this form, k_{IOM} = 10^{-5} year^{-1}; gives the half-life of $t_{1/2}$ = 50,000 years. RothC takes into account appropriate corrections, modifying the value of the *k* ratio, the variability of climate and soil conditions and the method of use. In this form, it is expressed as follows:

$$C(1) = C(0) \times e^{-abckt}, \tag{5}$$

where: *a* – correction for the mean monthly temperatures distribution, *b* – correction for the soil moisture deficit, *c* – correction for the soil surface cover by plants (all dimensionless).

The measurement of the mass of C supplied into soil in the form of plant litter is technically difficult and may be replaced by estimation based on the assumptions of the model. It can be assumed that the "annual compartment decomposition residue" factor $q = \exp(-abck)$ is generally constant in the long term. Similarly, the long-term constancy may be assumed for the annual mass of plant litter components deposition *z*. Therefore, the process of accumulation of C with the mass of *m* may be described as a power series with the limit of $z\,[q/(1-q)]$

The reclamation of soils without of C stocks initiates a series of processes which make the estimation of the rate of SOC increase difficult. Afforestation is preceded by a longer or shorter period of development of spontaneous succession, providing some C mass where DPM and RPM proportions are close to undeveloped grasslands, the surface of the land is uncovered for the most part of the year; it can be assumed that the decomposition of the plant residues is quicker than in a grown forest stand and the BIO and HUM production process – appropriately more intensive. The rate of HUM decomposition is generally slow ($k \approx 0.03$ year^{-1}), therefore the loss of C related to this process is relatively small.

Afforestation, in its initial stage, probably does not cause significant changes in this situation: still, the surface remains uncovered for a large part of the year, plant litter is mostly composed of herbaceous plants. The presence of a cover results in a reduced rate of decomposition, which fosters the accumulation of plant litter, BIO and HUM. Similarly to the Covington's model (Wójcik, 2013), it can be assumed that only forest stands older than medium age class represent the "model" form of organic input: a larger proportion of slow-decomposition compartments and surface cover contribute to the accumulation of plant litter and slow down the SOC decomposition. It is, however, difficult to assess the impact and role of groundcover plants on the creation of DPM and RPM mass. In summary, after reclamation, there is a changing plant litter deposition volume, possibly connected with changes in the DPM/RPM proportions and changes in the *k* value for the individual SOC compartments.

A significant problem, hindering the use of the RothC model is the indiscernibility of the carbon pool, at least without the use of advanced laboratory technologies. The analytical possibilities are limited to discerning ectohumus, which is a mixture of DPM, RPM and BIO and the organic substances of the mineral layer, joining the underground part of DPM and RPM with BIO, HUM and IOM. Therefore, the comparison of observations with the model may only apply to the total balance of organic substance found in soils.

In order to provide answers to questions regarding the effect of the diversification of reclamation conditions on the rate of SOC accumulation, samples collected from areas reclaimed in different periods, with different properties of the mineral material and the species composition of forest stands were studied.

The purpose of the research was the analysis of factors impacting the accumulation of carbon contained in ectohumus and in the mineral layer in the initial phases of SOC accumulation in reclaimed areas. The research was carried out at two reclaimed lignite mining facilities (Bełchatów and Turów lignite mines) and at the area of the spoil heap of the former Machów sulphur mine. These objects are very different (Gruszczyński *et al*. 2014).

SITES

The spoil heap of the Bełchatów lignite mine is the youngest object of the group. It was created as an external spoil heap from 1977 to 1993, occupies the area of 1483 ha, with 1165 ha of the slopes and 318 ha of the top part. The relative height of the heap is 120 – 180 m, reaching 395 m above sea level – making it the tallest hill in central Poland. The spoil heap is composed mainly of the Quaternary and Tertiary sands, most common in the overburden (~65%), Quaternary loams and silts (~20%) and Tertiary clays (~15%). Quaternary sands are usually similar in composition to loose sands or, sometimes, loose silty sands. They are low in plant nutrients, with neutral or slightly alkaline reaction. Tertiary sands are often interbedded with silts and clays with different thicknesses; some of them, as carbonated or colliery formations are potentially toxic. Clays and silts are rich in carbonates and assimilable forms of potassium and magnesium, without assimilable phosphorus. On dumping ground Bełchatów examined 45 profiles 0-30 cm

The external spoil heap of the Machów sulphur mine (Gruszczyński *et al*. 2014) is in the middle of the three objects as for the time of creation and reclamation. The beginning of mining operations and heap creation is 1969, continued until 1992. The spoil heap takes up the area of approximately 880 ha and is up to 60 m high. The predominance of Tertiary formations in the overburden made it possible to locate the Quaternary formations with properties less advantageous for future reclamation (sands, gravels) in the deeper layers of the heap and the creation of an outer layer of formations representing the geological series named the "Krakowiec Miocene clays". The series, characterised by a relative uniformity is composed of cohesive or highly cohesive formations categorised as heavy loams or clays with a high content of colloidal clay – from 25% to 51%. The particular feature of the Krakowiec clays is the content of carbonates – from 4% to 17% and their slightly alkaline reaction, around 7.6 pH in KCl. In the mineralogical composition of the clay fraction, the Ca-montmorillonite is the most common. It is to be noted that the relatively high homogeneity of these formations is a specific feature, distinguishing this spoil heap from all the other ones in the Polish open pit mining industry. In most objects, the surface layer is composed of a mosaic of different overburden formations – pure or mixed in various degrees. On the Machów dumping ground 30 profiles 0-30 cm were examined.

The spoil heap of the Turów lignite mine (Gruszczyński *et al*. 2014) is the oldest of the group, its construction was started during World War II (early 1940's). After the war and the takeover of the mine by Polish staff in 1947, its construction was continued. The external spoil heap of the Turów mine is one of the largest in the world, taking up the area of 2200 (2175) ha, consisting of almost 1.5 10^9 m^3 of material and raising to 245 m of relative height (+465 m amsl). The heap was built using a non-selective method, from the mixture of Tertiary formations present in the overburden, mostly (approx. 80%) Kaolinite clays, sandy clays, carbonated clays and heavy loams. The remaining 20% of the heap mass are Quaternary formations – sands, gravels, post – glacial loams and Oligocene granitoid and basalt eluvia of the Palaeozoic bedrock. On the Turów dumping ground 34 soil outcrops 0 – 30 cm were examined.

Observation stands were established on dumping grounds, where the species composition and age of the forest stands were determined. In four points of the stands, in the corners of a 10 m by 10 m square, samples were taken of the soil with unbroken structure at the depths of 0 – 5 and 5 – 10 cm as well as 10 – 20 and 20 – 30 cm. Plant litter was also collected for laboratory weighing, after drying and carbon content determination. The physical and chemical properties of the soils were determined (graining, density, reaction, N, S and C contents). C stocks in the litter (mor, O – organic layer) and the mineral layer to the depth of 30 cm were calculated, after deducting the carbon stock in samples below the depth of 30 cm.

Figure 1 shows the distribution of the colloidal clay content (< 0.002 mm) in soil profiles. The soils of the Bełchatów spoil heap are characterised by a mechanical composition with the groups from loamy sand to light loams, sometimes medium loams. The soils of the Machów spoil heap represent the so-called Krakowieckie clays, with the colloidal clay content from 25% to 55%. The soils of the Turów spoil heap are located in the middle and can be categorised as loamy formations.

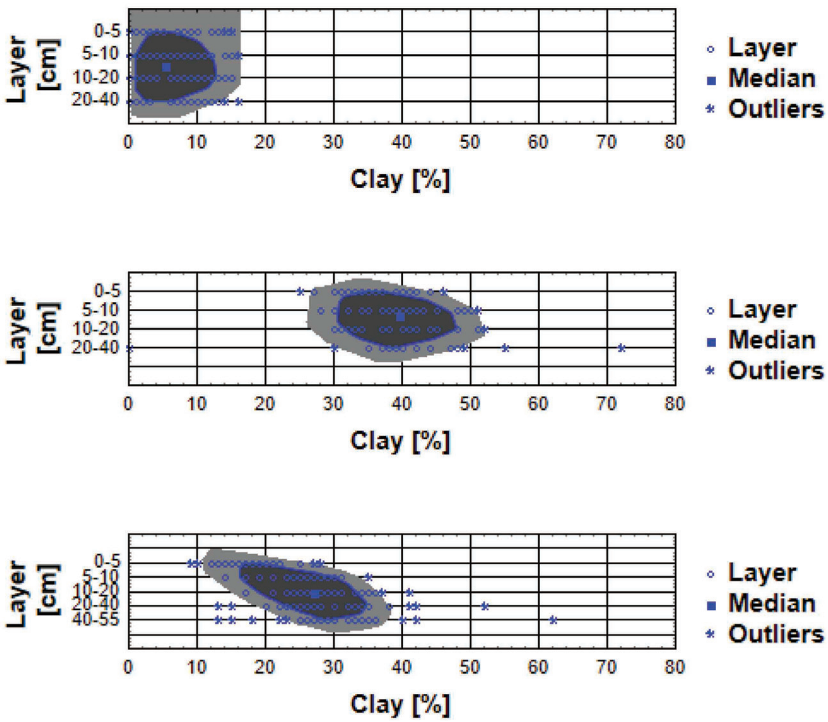

Figure 1. Colloidal clay content in the objects soil – bagplot

The charts in Figure 2 show the scope of variability of some properties of the soils at objects. The content of nitrogen in the soils is usually relatively low, however, in the case of the Turów heap, this property is subject to heavy variation depending on the location. Sulphur concentration and carbon content in the mineral layer 0 – 5 cm are highly correlated. The reaction of the Machów soils shows a significant content of carbonates, in Bełchatów – the reaction varies depending on the location, in Turów – there is a tendency for acidity.

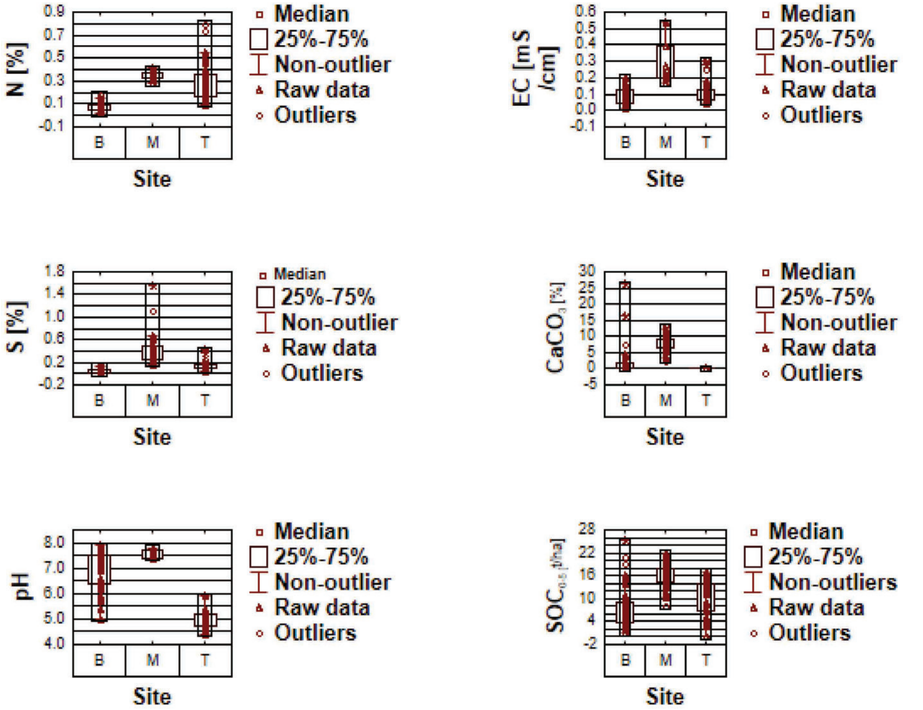

Figure 2. Variability of several properties of soils from different objects. Bottom and top quartile positions are marked

RESULTS

A total of 109 soil profiles (points) were tested, mostly for organic carbon content (Bełchatów – 45 profiles, Machów – 30, Turów – 34).

The assessment of the dependency between the factors and SOC accumulation was provided using the MARSpline non-parametrical, iterative algorithm (Jekabsons 2003, Friedman 1991). It enables the selection of factors with significant effect on the process – these can be continuous or discrete (nominal) variables. The algorithm enables the inclusion of the interaction of the variables and the non-linearity is approximated by splining linear functions. The non-randomness of the selection of observation points' locations as well as the limited variability of factors (e.g. from the end of the reclamation) precludes treating the presented models as a typical regularity.

C stocks in the O (organic) level

The plant litter (O level, ectohumus, mor) and the residues of dead underground plant parts are the precursors of the specific organic substance of soils. In all objects included in the study, the mass of organic carbon in the ectohumus amounted to approximately 33% of the plant litter mass (figure 3). Observations show that this feature is more or less stable for all three objects.

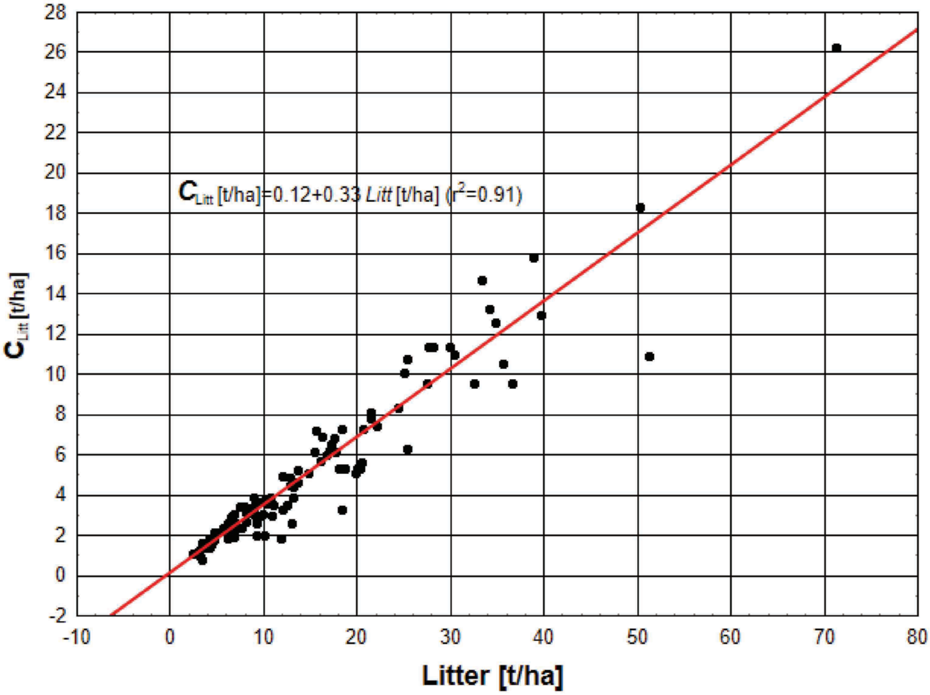

Figure 3. Dependence between the mass of C and mass of plant litter

Figure 4 shows the variability of the current C pool contained in the ectohumus of different objects. This variability is relatively high: the lowest (1 – 7 t C/ha) observed on the surface of the Machów spoil heap, slightly higher (1 – 10 C t C /ha) in Bełachtów and the largest (3 – 18 t C/ha with the extreme of approx. 26 t C /ha) for the Turów heap. Taking into account the dominant tendencies (area between the bottom and top quartile – 50% of the observations around median), the differences between the Bełchatów and Machów spoil heaps are not large (50% of the observations, is in the 2 – 4.5 t/ha and 2.2 – 3.5 t/ha ranges, respectively). In comparison, the C deposition in the plant litter for the Turów heap is higher (50% of observations in the 6.5 – 11.5 t/ha range). Several reasons can be given to explain the observed variations. The first possibility is the time from afforestation; taking into account the different susceptibility of DPM and RPM to decomposition, it can be assumed that with age, with the transition of forest stands into the medium age class, the DPM/RPM proportion decreases, which with the stable level of annual deposition may result in the increase of plant litter mass (and the mass of accumulated carbon). Another reason for the difference may be biochemical conditions related to soil richness, graining, reaction and location. Yet another reason for the variation can be the species composition of the forest stands. The impact of this factor may be hidden by the differences in the subsoil which is a decisive factor for the selection of the species composition of the pioneer vegetation introduced as part of the reclamation. One of the key factors is the time passed from the afforestation as well as ecological factors (species composition, density of the forest stand).

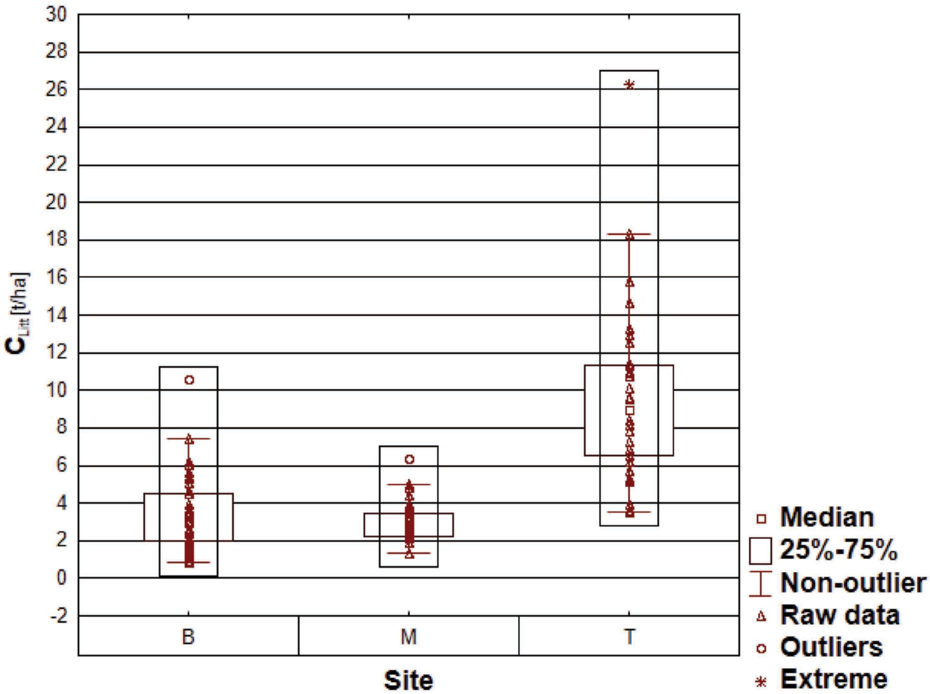

Figure 4. Range of variability of the mass of carbon accumulated in the plant litter (O level) for individual objects

The MARSpline model presented below is somewhat helpful in the assessment of the effect of various factors on the mass of carbon accumulated in the organic layer:

$$C_{Litt} = 7.6 + 11.1 \times BF1 - 0.34 \times BF2 - 2.22 \times BF3 - 2.69 \times BF4 \quad (6)$$

where:

- C_{Litt} – mass of C contained in the plant litter, in tonnes per hectare,
- $BF1$ = 1 for Turów, 0 for the rest
- $BF2$ = max(0; *age*-11), where the age is time passed from the beginning of rehabilitation, in years,
- $BF3$ = 1 for ash and alder forest stands, 0 for other types for forest stands,
- $BF4$ = 1 for birch forest stands, 0 for other types for forest stands.

This model, in relation to data, yields the following statistics: observed mean 5.3 t C /ha, standard observation deviation 4.14 t C /ha, model prediction mean 5.3 t C /ha, standard prediction deviation 3.38 t C /ha, the average residual – 0, standard deviation of residues – 2.38 t C/ha, coefficient of determination R^2 = 0.67, adjusted coefficient of determination = 0.65. The shape of this relationship (Figure 5) shows a stronger tendency for plant litter accumulation at the Turów spoil heap (differs from the rest with graining and forest stand age) and the generally increasing age, ash and alder as well as birch forest stands result in a lower deposition of plant litter (and carbon).

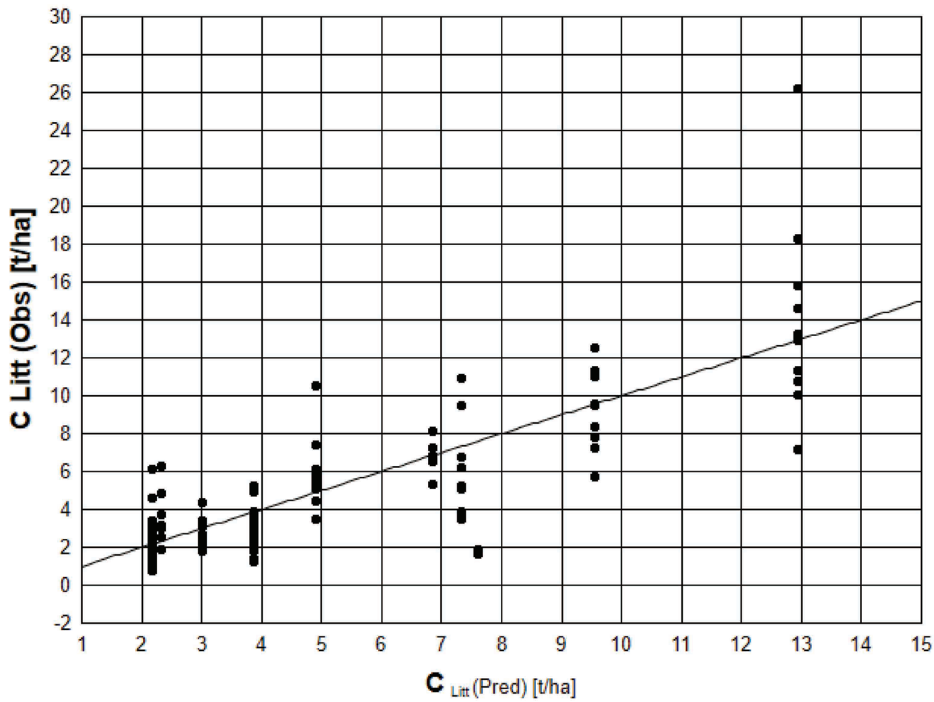

Figure 5. Comparison of the mass of carbon in the plant litter of objects with MARSpline model values

The model obtained by using the MARSpline algorithm allowing for interaction yields different conclusions:

$$C_{Litt} = 2.87 + 3.5 \times BF1 + 7.7 \times BF1 \times BF2 + 3.1 \times BF3 \quad (7)$$

- C_{Litt} – mass of C contained in the plant litter, in tonnes per hectare,
- $BF1 = 1$ for Turów, 0 for the rest
- $BF2 = 1$ for pine forest stands, 0 for other types for forest stands,
- $BF3 = 1$ for larch forest stands, 0 for other types for forest stands.

This model, in relation to data, yields the following statistics: observed mean 5.3 t/ha, standard observation deviation 4.14 t/ha, model prediction mean 5.3 t/ha, standard prediction deviation 3.56 t/ha, standard deviation of residues 2.11 t/ha, coefficient of determination $R^2 = 0.73$, adjusted coefficient of determination 0.73.

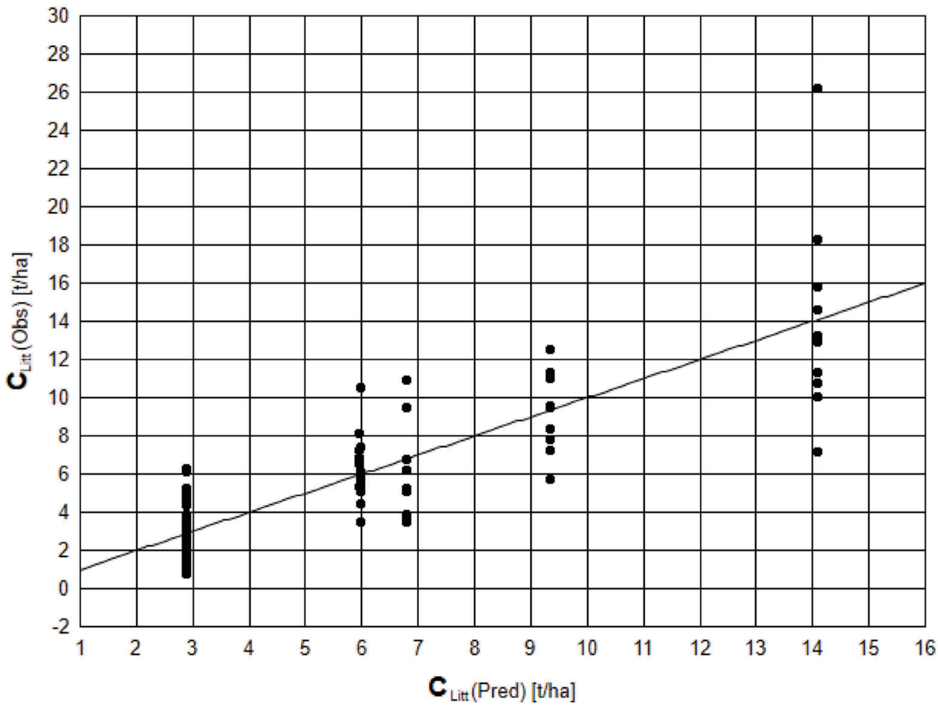

Figure 6. Comparison of the carbon content in the plant litter of objects with MARSpline model values – version two

This model, including only the qualitative variables (the age variable was removed from the model in the course of its iterative optimisation), is arithmetically "better" than the model without interactions. Its interpretation may be as follows: for the Bełchatów and Machów objects, there are similar levels of C deposition in the plant litter (approx. 2.9 t C /ha), with the exception of larch forest stands, where the deposition is significantly higher (approx. 6 t C/ha). The weakness of this proposition is the presence of larch forest stands only at the Bełchatów spoil heap (there are no singular larch forest stands in Machów). The Turów spoil heap is a separate category with much larger carbon deposition in the plant litter for pine forest stands (12 – 15 t/ha) and (as described before) – for larch forest stands (approx. 10 t/ha). In general, independently from the species composition, carbon deposition in the plant litter in Turów is higher by approximately 3.5 t/ha compared to the other objects.

C stocks in the mineral-humus level

Table 1 presents a statistical characteristics of the SOC stocks status for the mineral layer, 0 – 30 cm of the soils of the objects. The figures show, as follows: SOC content variability in the soils of individual objects and SOC stock distribution in the analysed layer.

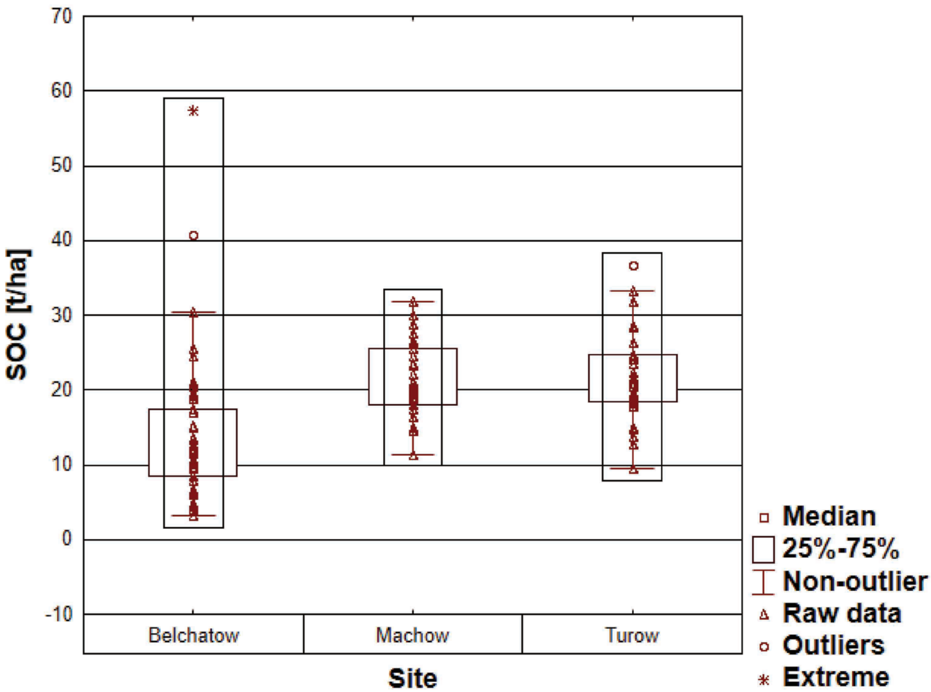

Figure 7. SOC stocks range of variability in the mineral layer of the objects' soils

Table 1. Some SOC mass statistics [t C /ha] in the mineral layer of the objects' soils

Site	Number of observation	Average	Minimum	Maximum	First Quartile	Third Quartile	Coefficient of variability [%]
Bełchatów	45	14.1	3.1	57.4	8.5	17.3	71.1
Machów	30	21.5	11.4	31.9	18.1	25.5	24.1
Turów	34	21.7	9.5	36.8	18.4	28.2	28.2

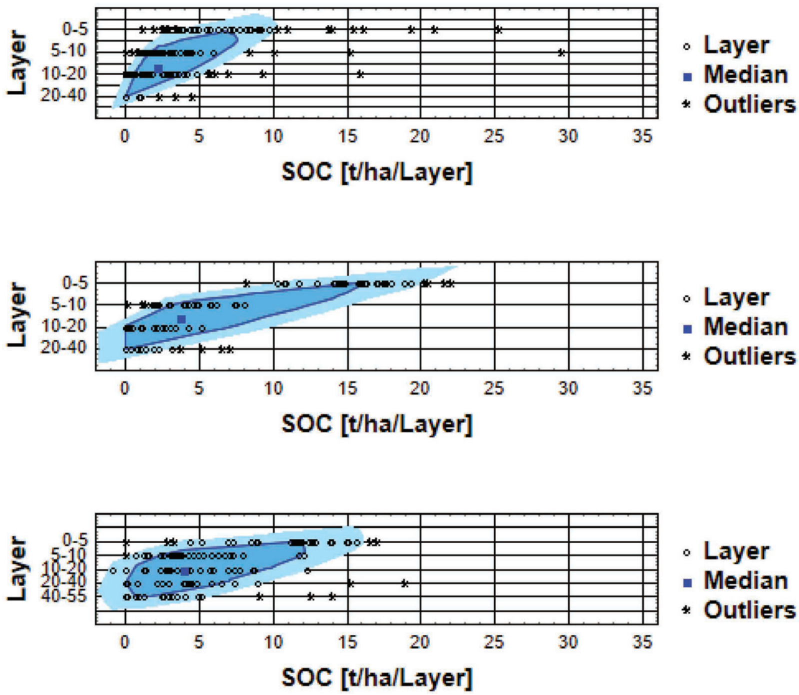

Figure 8. SOC content in object profiles – bagplot

The largest variability of the SOC pool was observed for the soils of the Bełchatów spoil heap, also characterised by the lowest mean organic carbon content in the analysed layer. 50% of the SOC observations are within the 8.5-17.3 t SOC/ha range. The mean time from the completion of forest rehabilitation to the observation time is around 20 years. It is to be noted that the top quartile of the SOC pool in the Bełchatów heap soils is lower that the bottom quartiles of this characteristic for the Machów heap (respectively: 18.1 t SOC/ha after the mean time of 20 years), and the Turów heap (18.4 t SOC/ha after the mean time of 35 years). The statistical distribution of the SOC pool observations in Machów and Turów soils is similar..

Table 2. Mean SOC stocks increase [t/ha/year] in objects' soils

Site	Number of observation	Average	Minimum	Maximum	First Quartile	Third Quartile	Coefficient of variability [%]
Bełchatów	45	0.52	0.11	1.11	0.36	0.70	46.2
Machów	30	1.08	0.52	1.60	0.87	1.25	26.2
Turów	34	0.63	0.24	1.31	0.51	0.74	31.0

Due to the probably variable dynamics of SOC accumulation in the mineral layer, the key role in its formation should be played by time, at least in the phase leading to the equilibrium. The table contains the statistical characteristics of the average annual SOC pool increase for individual objects, based on the current SOC stock and time from the end of afforestation. The value is showed in its graphical form in Figure 9.

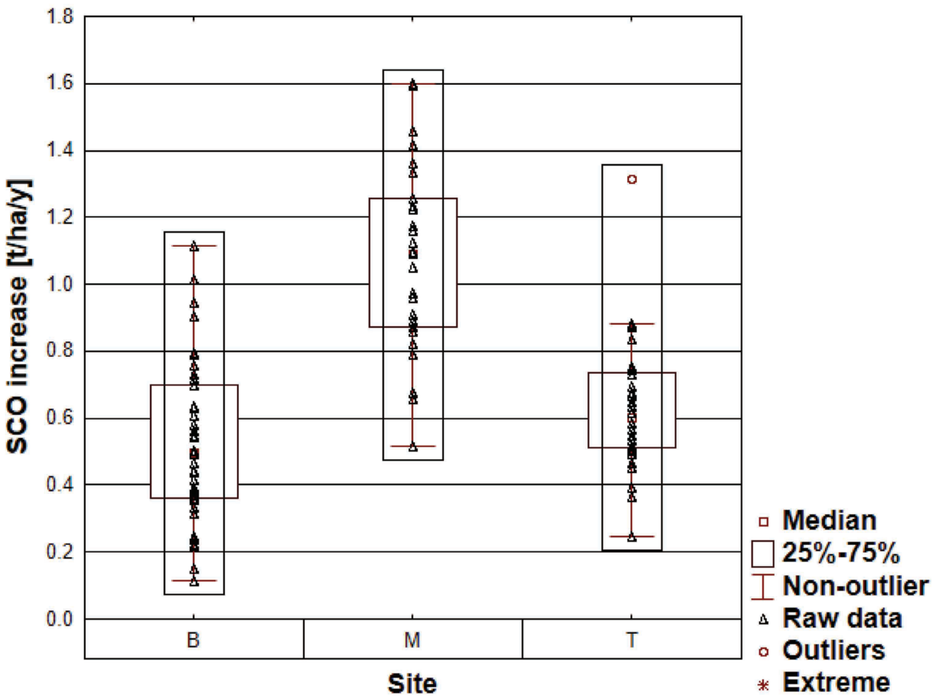

Figure 9. Mean SOC stocks variation in objects' soils

The relation between the mean annual increase in the organic carbon pool ΔC and the physiographic factors is presented by the model:

$$\Delta C_y = 0.71 + 0.77 \times BF1 - 0.41 \times BF2 + 4.35 \times BF3 + 0.98 \times BF4 - -0.1 \times BF5 - 0.07 \times BF6 + 0.1 \times BF7 + 0.005 \times BF8 \quad (7)$$

where:

- $BF1$ =1 for Machów, 0 for other locations, $BF2 = \max(0; 3.77 - C_{Litt})$,
- $BF3$=1 for ash forest stands, 0 in other cases, $BF4 = \max(0; 2.5\text{-}C_{Litt}) \times BF1$,
- $BF5$ =1 for forest stands on slopes, 0 in other cases,
- $BF6 = \max(0; s\%\text{-}1) \times BF3$; $s\%$ – percent of <0.02 mm fraction,
- $BF7 = \max(0; s\%\text{-}69)$ for forest stands in flat areas, 0 in other cases,
- $BF8 = \max(0; 69\text{-}s\%) \times \max(0; 3.41\text{-}C_{Litt})$.

This model (coefficient of determination $R^2 = 0.72$, adjusted coefficient of determination = 0.7, residual deviation 0.17, (relationship between the model and observations: Fig. 10) should be treated as indicator for the importance of factors carbon accumulation in the soils of three research objects. By finding the factors favourable to higher accumulation rate, it may be shown that:

- SOC accumulation is relatively higher (compared to the remaining objects) on the Machów heap,
- SOC accumulation in the mineral layer is higher under forest stands with high ash content; the reason may also be that this factor is rather related to higher moisture content (micro-pits), where the species with better resistance to high moisture content and lower organic carbon compounds decomposition rate were planted on purpose,
- the SOC level in the mineral layer on the Machów heap is positively correlated with the carbon stocks in the plant litter; this is contrary to the remaining objects,
- very high content of the floatable fraction, together with the high carbon content in the plant litter favours SOC accumulation,
- the general rule is the negative correlation between the carbon content in the plant litter and the SOC content in the mineral layer,
- SOC accumulation is not improved by slope locations,
- a decrease in SOC content can be observed under ash forest stands, together with the increase of the floatable fraction.

Confrontation of data with the RothC model assumptions

The RothC model is too general for use in individual cases. Its validity is better suited for a national or regional scale, since it reflects mean tendencies rather than strict dependencies, due to the very general characteristics of the climate, subsoil and approximations related to the proportions of the precursors and products of transformations of the soil carbon forms. The authors of the model propose formulas for the estimation of the individual values, but significant model input values, such as plant material deposition (especially in its underground fraction) and the proportion of compartments with high and low decomposition rates in the deposition are outside the possibility of measurement. Using the RothC model structure allows to estimate the relation of the numerical factors representing the SOC accumulation potential in relation to individual objects, characterised by mean values of soil properties. The climate data, required for the estimation of the factors are taken from the recommended Müller study (Müller 1982).

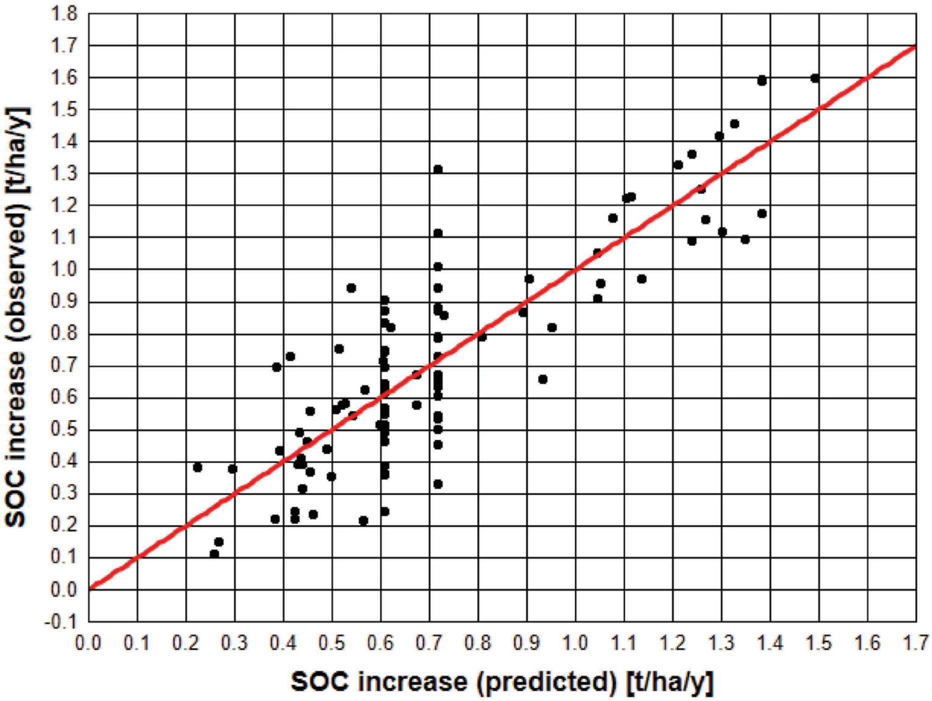

Figure 10. Comparison of the observed mean annual SOC increases in the soils of objects with MARSpline model values

Table 3 contains the values of accumulation and transformation of individual compartments of the organic carbon pool for the mean values of soil properties and the mean values of meteorological conditions for the area. The accumulation factors provide information about the participation of the specific fraction of the SOC pool within the year; after one year, a part remains from the C mass unit contained in the fraction – equivalent to the accumulation factor. The obvious requirement is the knowledge of the initial pool (at the beginning of the period) and annual deposition of the compartment. Transformation factors provide information about the proportions of the BIO, HUM and CO_2 compartments created from a unit of decomposing DPM and RPM.

Table 3. Coefficients of the potential annual transformation and accumulation of organic carbon compounds in the soils of objects, for mean soil properties and mean values of climatic factors.

Site	Accumulation coefficients				Transformations coefficients		
	DPM	RPM	BIO	HUM	BIO	HUM	CO2
Bełchatów	0.14	0.94	0.88	0.99	0.08	0.09	0.83
Machów	0.13	0.94	0.87	0.99	0.11	0.12	0.77
Turów	0.08	0.93	0.85	0.99	0.11	0.12	0.77

One inconvenience of the RothC model (Scharnagl *et al*. 2010) is the difficulty for empirical differentiation of the individual SOC fractions: the quantitative determination of SOC mass distribution into DPM, RPM, BIO and HUM in field and laboratory conditions is met with significant difficulties. The relatively easy to identify O-diagnostic level contains a part of the DPM and RPM pool. This is a part of the two compartments that is difficult to estimate, the residues of plant material also form a part of the SOC stocks in their mineral layer (dying parts of the root systems of trees and groundcover plants). Due to the character of the O level (Ol, Of and Oh), a part of its mass is also contributed by the microbial fraction – BIO. In turn, in the mineral layer of the profile – a natural environment for the accumulation of BIO and HUM – some, difficult to estimate part of the carbon stock is created by the DPM and RPM fraction in the form of the residues of underground parts of plants. This means that the modelled DPM and RPM mass should be higher than the observed mass of carbon in the plant litter and that the observed mass of SOC in the mineral layer should be higher than the model estimations for BIO and HUM.

However, it is possible to draw some conclusions, at least in relation to the estimation of the total level of accumulation. The calculated model values represent the process, in which the annual deposition of C in the form of dead plant matter is constant and equal to 1.0. In further years, as a result of the accumulation related to the non-complete decomposition of the components, the stocks forming the individual pools increase. The condition of constant deposition is not met in reality, it can be assumed that deposition grows annually, similarly to the proportion of DPM/RPM and ecological conditions (forest stand bottom cover). Due to the assumed linear character of the accumulation process, it may be estimated that the mean annual C deposition at the observed objects ranged from t/ha (Bełchatów) to 2.5 t/ha (Machów and Turów).

The differences may be a result of significantly worse properties of the subsoil in Bełchatów, compared to the Machów and Turów heaps. The age of forest stands in Turów also plays a significant role.

Table 4. Proportion of the combined mass of SOC and C in the ectohumus of objects compared to the proportions resulting from the RothC model for one unit mass deposition

Feature / Object	Bełchatów	Machów	Turów
Average age of stands [years]	23	20	35
Average, combined C mass of O and mineral layers [t C/ha]	**17.44**	**24.55**	**31.25**
The range of total C mass variation [t/ha]	3.93-58.41	13.86-38.20	15.19-46.88
Proportion of total C mass B: M: T	**1: 1.41: 1.79**		
Modelled DPM+RPM+BIO+HUM (Forest;1)	10.58	10.19	13.33
Modelled DPM+RPM+BIO+HUM (Ploughland;1)	6.06	6.56	8.33
Modelled DPM+RPM+BIO+HUM (Grassland;1)	7.75	8.29	10.21
C mass proportion between objects (Forest)	**1: 0.96: 1.26**		
Mass C proportion between objects (Ploughland)	**1: 1.07: 1.32**		
Mass C proportion between objects (Grassland)	**1: 1.08: 1.37**		

Based on the observations, the following conclusions can be made:

1. The observations show a stronger tendency for ectohumus accumulation at the Turów spoil heap.
2. The SOC accumulation in the mineral layer is higher under forest stands with high ash content; the reason may also be that this factor is rather related to higher moisture content, where the species with better resistance to high moisture content and lower organic carbon compounds decomposition rate were planted on purpose.
3. The very high content of the floatable fraction, together with the high carbon content in the plant litter favours SOC accumulation.
4. The general rule is the negative correlation between the carbon content in the plant litter and the SOC content in the mineral layer.
5. Based on the observations, the mean deposition of carbon in the soils of the studied forest stands can be estimated at the level from 1.7 to 2.5 t/ha/year.

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Prof. dr hab. inż. Stanisław Gruszczyński
AGH-University of Science and Technology
Faculty of Mining, Surveying and Environmental Engineering
sgrusz@agh.edu.pl

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