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Soil Chemistry

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SOIL ORGANIC MATTER IN AFFORESTED POST-AGRICULTURAL SOILS

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Abstract. The studies were carried out in central Poland. Total organic carbon (C_{org}), total nitrogen (Nt) and C of humus fractions in uppermost soil horizons were analyzed in afforested meadow soils in first and fifth year of afforestation (2 profiles) and compared to about 70-year-old continuous forest soils. Soil was collected from 0-5, 5-10, 10-15 and 15-20 cm layers depth. The results showed that the soil Corganic (C_{org}) and Ntotal (Nt) decreased with depth in both studied periods. The C_{org} amounts were higher in the second period (5 years after afforestation) in almost every layer of the humus horizons in comparison to the first year of afforestation. The Nt content rather decreased in particular layers during five years, but mean values of 0-20 cm depth were lower or higher in dependence on soil type. The content of both elements in the studied layers was lower in the 5-year afforested soils than in the continuous forest soils. The results indicated changes in organic matter properties too, but the distribution of the different soil organic matter fractions in humus layers in time was dependent on soil properties.

Soil plays a significant role in carbon sequestration. A few comparative studies of organic matter in forest, grassland, arable, former grassland and post arable soils do not supply an unequivocal answer on the influence of afforestation on the organic carbon and organic matter content in soils. Most research is focused on soil quality after land use change from arable to forest. This is because this land management conversion is most common.

Studies conducted by the team of Szujecki [23] indicate that C_{org} content in the sub-surface soil horizons of younger forest stands is higher in post-arable soils than in forest soils. In turn, in deeper horizons an opposite trend is observed and the forest soils are characterized by a higher content of C_{org} and Nt in comparison to post-arable soils. Other studies evidence an increasing C_{org} content subsequently

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in arable < afforested < forest soils [1] and in the humus horizons of post-arable soils with gradually older afforestation [19]. There is, however, no data on the transformation of organic matter from the first year of afforestation, analyzed in subsequent years in the same study areas.

The studies were focused on the recognition of organic matter in soils in the first years after afforestation. This information may serve as source data for future analyses. Comparison of the properties of humus compounds of freshly afforested meadow soils and continuous forest soils in their vicinity may allow conclusions on the dynamics of the transformation of soil humus.

MATERIAL AND METHODS

The studies were carried out on post-agriculture soils in the Garwolin Forest Division in the first years after afforestation (in the third month after afforestation in 2003 and after 5 years in 2008). Samples for analyses were collected from two prepared soil pits (5z and 6z). In order to check the vertical variability of humus compounds, soils samples were collected from the depths of 0-5, 5-10, 10-15 and 15-20 cm. Mixed samples were collected in all cases. Additional samples were collected in 2008 from the adjacent forest areas with about 70-year old tree stands.

The ground is covered by glacial till of the Middle-Polish Glaciations, Mazowsze-Podlasie stadial with residual lag in the top or by sandy elluvia of glacial till lying on glacial till.

The area with profile 5z reaches 1.71 ha. The area was afforested with oak. The soil was classified as Stagnic Gleysol [4]. Profile 6z was located on an area afforested by oak with a small admixture of larch and maple-tree on an area of 3.37 ha. The soil was classified as Stagnic Luvisol [4]. Profile 5z forest was made in a 70-year old fresh mixed forest; the soil was Stagnic Luvisol [4]. Profile 6z forest was located under a 74-year old forest stand (fresh mixed forest) with the dominance of oak. The soil was classified as Podzolic Stagnic Gleysol [4]. The studied soils were bi-partite. Their lower part was represented by loam, but the upper parts were sandy. The reaction was acid and strongly acid in the upper parts of the profiles, and acid to slightly acid in the lower parts (data in press).

The following properties were determined in the collected samples:

– Organic carbon (C_{org}) – by catalytic burning to CO_2 in 900°C in a Shimadzu 5 000A apparatus;
– Total nitrogen (Nt) – using the modified Kjeldahl method in a Kieltec-Tecator analyzer;
– humus fraction content using the Kononowa and Bieliczkowa method. The analysis is focused on the separation of particular fractions using the following solvents:

a) C_{Py} – in a mixture of 0.1M $Na_4P_2O_7$ + NaOH (free humus compounds, compounds bound by non-siliceous forms of Fe and Al, and calcium connections); humic acids were separated from the solution and carbon determined quantitatively (C_{HA}). Carbon of fulvic acids (C_{FA}) was calculated: C_{Py} - $C_{HA.}$ The C_{KH}/C_{FA} ratio was also calculated.

b) C_{Lwp} – in 0.05M H_2SO_4 (low weight particles).

c) C_R – C residuum (i.e. post-extraction remain) was determined as a result of a subtraction C_{org} – C_{Py}.

The following step was determining the carbon content in the obtained fractions after evaporation of the solvents using the Tiurin method.

All the results of the organic matter fractions analysis are focused on 4 layers down to 20 cm; however, in some cases the terms 'in the profile' or 'in the soil' will be used in the description.

RESULTS

During five years of afforestation the C_{org} content in studied soils from the Garwolin Forest District increased in every layer with only one exception, the layer 0-5 in profile 5z.

The mean values of C_{org} in four layers (up to 20cm depth) of soils increased from 0.64% (2003) to 0.65% (2008) in the Stagnic Gleysol (5z) and from 0.74% to 1.35% respectively, in the Stagnic Luvisol (6z) (Table 1). The C_{org} content in soil decreased with depth (from 0-5 to 15-20 cm) in both soils and each study intervals. Only at 5-10cm depth in profile 6z this value was higher than in the upper layer. A higher amount of C_{org} in Stagnic Luvisol than in Stagnic Gleysol was noticed.

In the case of Nt, a slightly different trend was observed. The content of this element in some layers was lower in 2008 than in 2003 but in some layers it was higher or on the same level. The mean value of Nt (0-20 cm depth) after five years of afforestation was lower in Stagnic Gleysol (0.06% in soil in 2003 and 0.05% in soil in 2008) and higher in Stagnic Luvisol (0.08% in soil and 0.09% in soil respectively).

Both element content (C_{org} and Nt) in adjacent continuous forest soils (5z forest and 6z forest) was higher in comparison to young afforested soils (Table 1).

The C:N ratio was higher in most cases in 2008 (10.1-16.3 in all layers) in comparison to 2003 (8.3-11.4 in all layers). The mean ratios in 2008 were 12.3 in Stagnic Gleysol and 15.0 in Stagnic Luvisol and were much lower than in continuous forest soils.

The content of humus compounds extracted by a mixture of 0.1M $Na_4P_2O_7$ + 0.1M NaOH – C_{Py} was the highest in the 0-5 cm layer and decreased with depth in profile 5z. In profile 6z the most abundant in C_{Py} was 5-10cm layer. The quantity of this element in other layers was much lower (Table 2). This reflected the total

TABLE 1. CARBON AND NITROGEN CONTENT (% IN SOIL)

Profile	Layers depth	C organic		N total		C/N ratio	
		2003	2008	2003	2008	2003	2008
5z Stagnic Gleysol	0-5	1.09	0.87	0.10	0.09	10.7	10.1
	5-10	0.65	0.78	0.06	0.06	11.4	12.4
	10-15	0.46	0.55	0.05	0.04	8.7	14.1
	15-20	0.37	0.39	0.04	0.03	8.7	12.7
	Mean	0.64	0.65	0.06	0.05	9.9	12.3
5z forest Stagnic Luvisol	0-5	-	1.80	-	0.10	-	17.9
	5-10	-	1.21	-	0.06	-	20.4
	10-15	-	0.99	-	0.05	-	20.2
	15-20	-	0.81	-	0.04	-	20.7
	Mean	-	1.20	-	0.06	-	19.4
6z Stagnic Luvisol	0-5	0.98	1.60	0.11	0.10	8.7	16.3
	5-10	0.76	2.00	0.09	0.13	8.3	14.9
	10-15	0.66	1.05	0.07	0.07	9.0	14.0
	15-20	0.56	0.77	0.06	0.05	9.7	14.5
	Mean	0.74	1.35	0.08	0.09	8.9	15.0
6z forest Podzolic Stagnic Gleysol	0-5	-	9.31	-	0.43	-	21.7
	5-10	-	9.58	-	0.37	-	26.0
	10-15	-	11.90	-	0.52	-	23.1
	15-20	-	8.20	-	0.34	-	24.4
	Mean	-	9.75	-	0.41	-	23.6

C_{org} content in the profile. The C_{Py} content was higher in 2008 than in 2003 in the particular layers in both soils. On average in all layers this content was 0.26% in 2003 and 0.37% in 2008 in the case of the Stagnic Gleysol, and 0.47% in 2003 and 0.79% in 2008 in the case of the Stagnic Luvisol. The carbon content of these compounds in all layers from the forest soil was much higher in comparison to related post-agricultural soil.

A similar distribution was observed in the case of C_{Lwp} extracted 0.05M H_2SO_4, C_{HA} and C_{FA} content. All were higher in 2008 than in 2003. The mean values of each were higher in Stagnic Luvisol. Fulvic acids prevail over humic acids in the studied soils. The humic to fulvic acids ratio in pyrophosphate extract was low and within 0.66-0.59 in soil 5z and 0.46-0.57 in soil 6z. The average ratio in all layers increased in 2008 in relation to 2003 in the Stagnic Luvisol, while it decreased in the Stagnic Gleysol (Table 2).

The C residuum (C_R) content in 2008 was on average lower in 5z and on average higher in 6z.

TABLE 2. SOIL ORGANIC MATTER FRACTIONS CONTENT (% IN SOIL)

Year	Profile	Depth (cm)	C extracted					CR
			0.1M $Na_4P_2O_7$+0.1M NaOH C_{Py}				0.05M H_2SO_4 C_{Lwp}	
			Total	C_{HA}	C_{FA}	C_{HA}/C_{FA}	Total	
2003	5z Stagnic Gleysol	0-5	0.37	0.17	0.20	0.86	0.05	0.71
		5-10	0.30	0.09	0.20	0.46	0.03	0.36
		10-15	0.21	0.07	0.14	0.51	0.03	0.25
		15-20	0.18	0.08	0.09	0.89	0.02	0.19
		Mean	0.26	0.11	0.16	0.66	0.03	0.38
	6z Stagnic Luvisol	0-5	0.65	0.21	0.45	0.46	0.09	0.33
		5-10	0.48	0.18	0.31	0.58	0.07	0.28
		10-15	0.42	0.12	0.30	0.38	0.06	0.25
		15-20	0.31	0.08	0.23	0.37	0.05	0.25
		Mean	0.47	0.15	0.32	0.46	0.07	0.28
2008	5z Stagnic Gleysol	0-5	0.57	0.20	0.37	0.54	0.08	0.30
		5-10	0.41	0.13	0.28	0.45	0.05	0.37
		10-15	0.29	0.11	0.18	0.60	0.04	0.26
		15-20	0.22	0.12	0.10	1.15	0.04	0.18
		Mean	0.37	0.14	0.23	0.59	0.05	0.28
	5z forest	0-20	0.62	0.17	0.45	0.38	0.07	0.58
	6z Stagnic Luvisol	0-5	0.97	0.36	0.61	0.58	0.07	0.64
		5-10	1.18	0.44	0.75	0.59	0.09	0.81
		10-15	0.59	0.20	0.39	0.51	0.07	0.46
		15-20	0.42	0.15	0.27	0.56	0.05	0.35
		Mean	0.79	0.29	0.50	0.57	0.07	0.57
	6z forest	0-20	3.60	2.41	1.19	2.02	0.20	6.15

C_{HA} – C humic acids, C_{FA} – C fulvic acids, CR – C residuum.

Due to changing total carbon content in the soil, more reliable data for the discussion on the transformation of organic matter is supplied not by the absolute content of particular compounds, but by their percentage in total C_{org}.

The C_{Py} percentage in the C_{org} was different in the Stagnic Gleysol (profile 5z) and the Stagnic Luvisol (profile 6z). In the first case it was bigger after 5 year of afforestation, in the second case it was smaller (Fig. 1). In the first year of afforestation, the percentage in 5z was below 50% of C_{org} and increased with depth. In both study intervals in 6z it decreased with depth.

Forest soils featured a lower percentage of C_{Py} in the C_{org} in comparison to former meadow soils.

The opposite may be observed in the case of compounds permanently bound with the mineral part of soil – C_R (Fig. 1c).

The C_{Lwp} percentage in C_{org} was different in two studied soils too. In profile 5z it considerably increased in every layer in 2008 but in profile 6z it considerably decreased in 2008 (Fig. 1b).

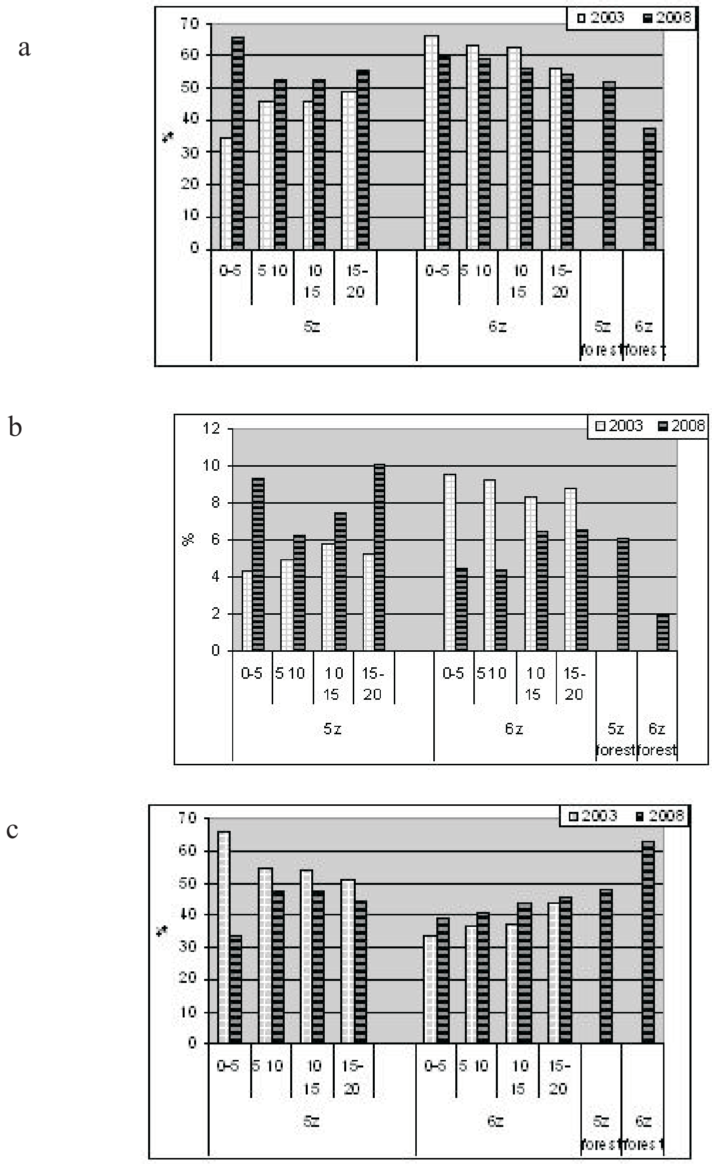

Fig. 1. Percentage of: a – C_{Py}, b – C_{Lwp}, c – C_R in C_{org}.

DISCUSSION

The content and quality of humus in soil depends on many different factors: temperature, humidity, soil reaction, nutrient availability, as well as the type of soil management [9, 10]. In arable soils, the humus composition is influenced by the type of mechanical cultivation, type of crop rotation and the applied mineral and fertilizers [17]. Even larger differences in soil properties may be observed among soils with agricultural, grassland and forest management [5, 6, 7, 16, 21].

Studies of the afforested meadow soils from the Garwolin Forest District showed changes in the organic carbon and total nitrogen five years after afforestation. The character of changes was modified by the soil properties. In both studied soils C_{org} increased in the 0-20 cm soil layer. In the Stagnic Luvisol this increase was much more distinct. C_{org} and Nt values varied depending on the soil type. The average content from four layers in both study intervals was: 0.64 and 0.65% of C_{org} in the Stagnic Gleysol, and 0.74 and 1.35% of C_{org} in the Stagnic Luvisol. These values are typical of such soils in Poland [3, 15]. The changes were not considerable in profile 5z.

Also, Nt (average from 4 layers) increased in soil profile 6z: 0.08 to 0.09% of Nt, whereas in the Stagnic Gleysol it decreased from 0.06 to 0.05% of Nt. In both cases we can assume that changes were not important. Both the C_{org} and Nt contents rather decreased with depth in both study intervals. Changes in C_{org} and Nt in afforested soils were noted by Smal, Olszewska [22]. They noticed a decrease in C_{org} in afforested post arable soils in comparison with the arable soils. In turn, Vesterdal *et al*. [25] observed an increase in carbon concentration in the 0-5 cm layer and decrease in the 5-15 and 15-20 cm layers. A decrease in the carbon content was noted jointly in all horizons for 29 years. C_{org} decrease in the first years after afforestation was also pointed out by other authors [14].

An increase of C_{org} or decrease of Nt resulted in a wider range of the C:N ratio. In the first and fifth years after afforestation we can observe a varied C:N ratio. At first, it was 9.9 and 8.9 in 5z soil and 6z soil, respectively, and was characteristic for agricultural soils. As a result of afforestation it increased to 12.3 and 15.0, respectively. Other authors noticed changes in soil quality after afforestation of grassland too [8, 26]. The effect of grassland afforestation on C_{org} and Nt varied with tree species, soil type and slope position [26].

The percentage of humus compounds extracted by the mixture 0.1M $Na_4P_2O_7$ + 0.1M NaOH in the C_{org} in layer 0-20cm of Stagnic Gleysol reached *ca*. 30-50 in 2003 and increased in 2008 over 60% of C_{org}. It was much higher in Stagnic Luvisol in both studied years. This indicates that in this case free humus compounds and those bound with non-siliceous forms of Fe, Al and Ca were the dominating group. The opposite situation occurs in the case of compounds permanently bound to the mineral part of soil (i.e. post-extraction remains). Fulvic acids dominated in the studied soils. The ratio of humic to fulvic acids in the pyrophosphate extract was low, typically within 0.4-0.6. This ratio measured on average from all layers was higher in 2008 than in 2003, pointing to the higher content of humic acids 5 years after afforestation. The influence of change in land-use from pasture to eucalypt plantation had an impact on soil organic matter quality in Australian soil [13]. Authors noticed a decrease in aromatic carbon ten year after management conversion.

There are not many studies about soil organic matter quality changes after afforestation of former agricultural land. Comparative studies of different soil types occurring in different climatic zones show that in comparison to arable soils, in forest soils the organic matter is poorly bound to the mineral part of soil and they have a lower degree of humification [18], lower total acidity of the humic acids which have smaller molecular mass [12]. However, in contrast to arable soils, forest soils have a higher C_{org} content [2, 11, 20, 24]. Even if the mineral horizons in some forest soil types contain lower quantities of carbon in comparison to relevant arable soils, their litter horizons have quantities of organic carbon several, or up to several dozen, times higher.

CONCLUSIONS

The afforestation of meadow ground influenced soil organic matter quantity and quality. The changes depended on soil type. Five years after afforestation we observed:

1. Increase in the C_{org}; in Stagnic Luvisol this increase was much more distinct.
2. Decrease in Stagnic Gleysol and increase in Stagnic Luvisol of Nt content, but the changes were not considerable.
3. Increased C:N ratio. The C_{org}, Nt and C:N ratio were lower in freshly afforested soils than in the mature continuous forest soil.
4. The C amount of particular organic matter fractions differed with soil type. A greater quantity of C_{PY}, C_{Lwp} and C_R was observed in the case of Stagnic Luvisol. Even the percentage of C_{Py} in C_{org} was greater in this soil in comparison to Stagnic Gleysol in both studied years. The percentage of CLwp in C_{org} differ in the examined period – it was greater in Stagnic Luvisol in the first year of afforestation and lower in the fifth year after afforestation.
5. The mean C_{HA}/C_{FA} ratio from four layers was higher after five year of afforestation in Stagnic Luvisol but lower in Stagnic Gleysol.

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MATERIA ORGANICZNA W ZALESIONYCH GLEBACH POROLNYCH

Badania prowadzono w centralnej Polsce. Badano zawartość węgla organicznego, azotu ogółem i węgiel poszczególnych frakcji humusu glebowego w powierzchniowych poziomach gleb porolnych w pierwszym i piątym roku od zalesienia i porównywano z glebami pod około 70-letnim drzewostanem. Glebę pobierano z czterech głębokości: 0-5, 5-10, 10-15 i 15-20 cm. Badania wykazały malejącą ilość zarówno węgla organicznego jak i azotu ogółem wraz z głębokością w obu badanych terminach. Zawartość węgla organicznego była większa w drugim terminie badań (5 lat po zalesieniu) w porównaniu z pierwszym rokiem. Ilość azotu zmalała po pięciu latach zalesienia. Zawartość obu pierwiastków była mniejsza w pięcioletnich zalesionych glebach porolnych w stosunku do gleb leśnych. Badania wykazały również wpływ zalesienia na niektóre właściwości materii organicznej, głównie na rozmieszczenie różnych jej frakcji w poziomie próchnicznym z upływem czasu.