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Soil Biology

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ACTIVITY OF PHOSPHATASES IN HUMUS HORIZONS OF UNISŁAW BASIN ARABLE SOILS

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Abstract. The paper presents the results of research into the activity of alkaline and acid phosphatase against selected chemical parameters in the selected humus horizons of arable soils of the Unisław Basin. It was found that the soil demonstrated a higher activity of alkaline phosphatase by 35% on average, compared with the activity of acid phosphatase, which is due to the high soil richness in $CaCO_3$. Considerable amounts of calcium carbonate determined the neutral or slightly alkaline reaction of the horizons. The soil investigated represented the soils of a low or average content of available phosphorus, which classifies it to classes IV and III of richness in that element. Changes in the activity of the enzymes were found depending on the horizon the soil was sampled from on which various crop species were grown.

Enzymes are special molecules determining all the chemical processes which occur in the cells of plants and soil fauna. Dick *et al*. [4] claim that soil enzymes play essential functions as they are included in the cycle of nutrients for plants and reflect the biochemical and microbiological soil activity, at the same time being its fertility measure [16]. Investigating the enzymatic activity, one can define the direction and the intensity of transformations of organic and mineral substances of the soil environment. Fertility conditions the co-participation of soil in plant growth and development and is connected both with its richness and capability [11]. The enzymatic soil activity is, to a great extent, conditioned by its chemical properties which, in turn, are a result of the agrotechnical practices applied exposed to a varying intensity of fertilization and tillage methods. The useful 'fertility indices' of soil include alkaline phosphatase, amidase and catalase,

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showing a strict relationship with respiration and the biomass of soil microorganisms [7]. Phosphomonoesterases are enzymes playing an essential role in soil, stimulating the transformations of organic phosphorus compounds into inorganic phosphates (HPO_4^{2-} and $H_2PO_4^-$), available directly to the plants and soil organisms [1]. Acid phosphatase is positively correlated with the biomass of bacteria and the total length of mycelium in soil [12]. Determining the activity of soil phosphatases facilitates evaluation of the degree of mineralization of organic phosphorus forms as well as securing the crops with available phosphorus.

The aim of the present paper was to define changes in the activity of alkaline (EC 3.1.3.1) and acid (EC 3.1.3.2) phosphatase against the selected chemical properties of soils of the Unisław Basin.

MATERIALS AND METHODS

The research material of the present paper involved arable soils forming the soil cover of the Unisław Basin. The area is a part of the Southern Baltic microregion of the Fordon Valley, stretching from the Toruń Basin to Grudziądz Basin. The Unisław Basin was formed as a result of the lateral erosion of the Vistula meander. It is formed mostly by floodplains and biogenic plains. The parent formations of the soils of the region are mostly varied alluvia deposited as a result of the alluvial process. The area is under agricultural use, especially under field cultivation of vegetables, wheat and rape. For the purpose of the research 7 soil profiles were selected. The mineral surface samples (Apca) were sampled from the depth of 0-30 cm and subsurface (Aaca) 30-60 cm.

The soil samples were dried and screened through a sieve with a mesh diameter of 2 mm, and then their basic physicochemical properties were determined using the methods commonly applied in soil science.

In the appropriately prepared material, the following were determined: the content of available phosphorus (P_{E-R}) with the Egner-Riehm method – DL [13], the activity of alkaline (AlP) and acid (AcP) phosphatase with the Tabatabai, Bremner method [17].

To identify the potential correlations between soil parameters a statistical analysis of the results was made applying the Statistica software.

RESULTS AND DISCUSSION

The horizons investigated showed a high homogeneity in terms of colour, structure and grain size composition. They showed a well-developed thick durable crumb structure, which can be seen by the occurrence of a high number of earthworms. The colour of those horizons was similar (7.5YR 2/3 and 7.5YR 2/2 determined with the Munsell scale) [14]; it pointed to a high content of iron oxides.

The soil samples analyzed demonstrated a high content of calcium carbonate. Considerable amounts of $CaCO_3$ were also found in the surface horizons (from 15.9 to 26.5%) and subsurface horizons (from 5.3 to 69.3%) (Table 1). Such a large accumulation of carbonates in those horizons could have been due to the permeating of ground water oversaturated with calcium ions since the litter is made up of gytias varied in terms of mineral and organic parts. Considerable amounts of $CaCO_3$ determined the neutral or slightly alkaline reaction of the horizons analysed. In the surface horizons Apca the value of pH_{H_2O} ranged from 7.03 to 7.41, and in subsurface horizons Aaca from 7.12 to 7.27 pH units. The comparison of the exchangeable acidity between profiles in Apca horizons showed that the highest value of 7.03 pH units was recorded in profile No. 1 and the lowest – in profile No. 3 (pH_{KCl} –7.41).

The content of total organic carbon (TOC) ranged from 5.1 g kg^{-1} to 80.3 g kg^{-1}. The lowest value was reported in horizon Aaca profile No. 6, and the highest – in Apca horizon, profile No. 5. The average content of total organic carbon in surface horizons was 62.0 g kg^{-1}, and in subsurface – 49.7 g kg^{-1}.

The total content of phosphorus (P_{tot}) in the soil researched was, on average, 0.336 g kg^{-1}. As reported by Borie and Rubio [2], the content of P_{tot} in arable soils was 0.258 g kg^{-1} and was 28% higher than the total phosphorus content in

TABLE 1. SOME PHYSICOCHEMICAL PROPERTIES OF SOILS

Profile	Horizon	Plant	pH		Content			
			H_2O	KCl	TOC	P_{tot}	$CaCO_3$	P_{E-R}
					(g kg^{-1})		(%)	(mg kg^{-1})
1	Apca	Wheat	7.67	7.03	55.8	0.305	16.2	29.75
2	Apca	Carrot	7.59	7.13	63.9	0.349	21.8	39.25
	Aaca		7.68	7.15	65.9	0.349	27.2	25.75
3	Apca	Carrot	7.84	7.41	60.9	0.480	24.4	28.65
	Aaca		7.57	7.27	65.7	0.174	25.6	41.35
	Aaca		7.26	6.96	63.1	0.174	5.3	39.50
4	Apca	Carrot	7.60	7.30	59.4	0.480	26.5	37.50
	Aaca		7.68	7.23	19.7	0.087	6.7	35.45
5	Apca	Onion	7.60	7.33	80.3	0.305	23.6	33.45
	Aaca		7.53	7.26	78.0	0.436	24.9	45.90
6	Apca	Wheat	7.38	7.20	50.2	0.480	15.9	40.90
	Aaca		7.37	7.30	5.1	0.218	69.3	28.55
7	Apca	Rape	7.23	7.20	64.9	0.567	25.0	48.80

non-arable soils. The highest content of total phosphorus (0.567 g kg^{-1}) was recorded in horizon Apca profile No. 7, while the lowest (0.087g kg^{-1}) – in horizon Aaca profile No. 4 (Table 1).

The content of available phosphorus in soil throughout the research years ranged from 25.75 to 48.80 mg P kg^{-1} of soil (on average 36.6 mg P kg^{-1}) (Table 1), which, according to PN-R-04023 [1996], classifies it as soils of low and average content of phosphorus (IV-III class). Bearing in mind the environmental aspect, the optimum state of phosphorus in soil should fall within the class of an average richness. Fotyma *et al*. [6] claim that the optimal content of available phosphorus (determined with the Egner-Riehm method) should be 105-108 mg P kg^{-1}. The critical content of phosphorus for plants is assumed as 30 mg P kg^{-1} of soil. Considering the phosphate economy, it is well known that a high concentration of Ca in soils results in the precipitation of insoluble and hard-to-absorb calcium phosphates. The alkaline reaction and a high abundance of carbonates (Table 1) modify the phosphorus economy which, in such soils, undergoes the processes of retrogradation transforming into sparingly soluble tricalcium phosphates $Ca_3(PO_4)_2$. The highest content of available phosphorus (48.80 mg P kg^{-1}) was found in the Apca horizon profile No. 7 where rape was grown, while the lowest (25.75 mg P kg^{-1}) in horizon Aaca profile No. 2 where carrot was cultivated.

The differences in the content of $P_{E\text{-}R}$ across respective horizons were inconsiderable, which was due to the mobility of phosphorus in the soil profile being lower than that of other elements (Table 1).

The availability of phosphorus is one of the factors limiting the development of plants whose response to the deficit of this macronutrient in soil is the synthesis of phosphatases, stimulating the hydrolysis of organic compounds of phosphorus in the forms directly available to plants [3]. The activity of alkaline phosphatase ranged from 1.505 to 1.771 mM pNP kg^{-1} h^{-1} and was, on average, 35% higher, compared with the activity of acid soil phosphatase (0.909-1.287 mM pNP kg^{-1} h^{-1}) (Fig. 1). Phosphatases, being enzymes which are very sensitive to changes in the soil pH, demonstrate a wide pH range for their optimal activity. The acidic reaction (pH 4-6) is optimal for acid phosphomonoesterase, while alkaline (pH 7-11) – for alkaline phosphomonoesterase which is a good indicator of the soil reaction [18, 1]. The alkaline reaction of the soil (Table 1) weakened the activity of acid phosphatase by destroying ionic and hydrogen bonds and in the active enzyme centre, and since the catalytic efficiency of enzymes is strongly connected with the chain conformation, even slight changes in pH can decrease the activity of soil biocatalysts considerably [8].

The highest activity of alkaline phosphatase (1.771 mM pNP kg^{-1} h^{-1}) was recorded in horizon Aaca profile No. 6 where wheat was grown, while the lowest (1.505 mM pNP kg^{-1} h^{-1}) in the horizon Apca profile No. 2 where carrot was cultivated. The activity of soil enzymes depends on the species composition of the

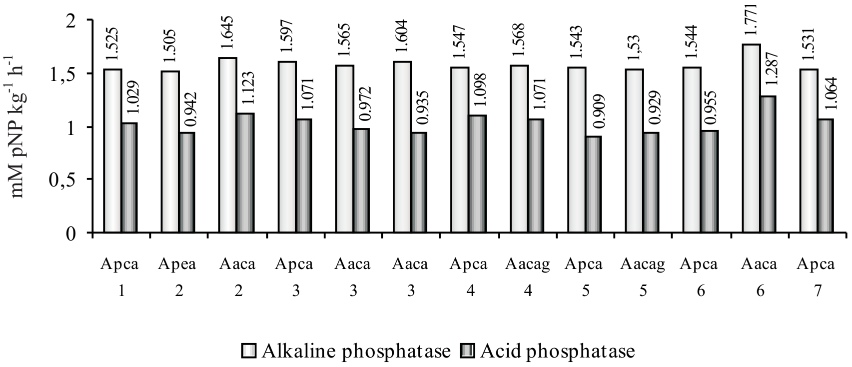

Fig. 1. Activity of alkaline and acid phosphatases in soil. Explanations: 1,2...7 – soil profiles.

plant cover. The individual effect of respective plant species on the enzymatic activity of soil is with a different species composition of bacteria infesting plant roots, much dependent on the enzymatic activity.

A significant negative value of the coefficient of correlation between the activity AlP and the content of $P_{E\text{-}R}$ in soil ($r= -0.56$, $p<0.05$) was shown, which suggest that under the conditions of available phosphorus deficit in the substrate there is an increase in the activity of phosphatases. Similarly, an excess of available phosphorus forms acts as a competition inhibitor inhibiting the synthesis of phosphatases [10, 19], while Gilewska and Płóciniczak [5] report on a lack of a relationship between the activity of alkaline phosphatase and the content of available phosphorus forms ($r=0.21$); however, a high and low content of $P_{E\text{-}R}$ did not result in the inhibition of the activity of alkaline phosphatase in the soil.

The activity of the enzymes in soils can also be affected by an abundance of caterpillars, enhancing the aeration, structure and reaction of soil. Produced by caterpillars, coprolites which occur in the soil surface layer are a good substrate for the development of microorganisms which are a source of enzymes [9].

The presented results of the alkaline and acid phosphatase activity facilitated calculating the value of the AlP:AcP ratio, referred to as the enzymatic pH indicator. The value adequate for plant growth and development can be considered the soil pH under the conditions of which there occurs the adequate activity ratio of AlP:AcP [4]. According to those authors, a value of the AlP:AcP ratio lower than 0.50 points to acid soil reaction and calls for liming. The values of the AlP:AcP ratio were 1.38-1.72 (Fig. 2), which suggests that the reaction of the soils is alkaline and that they are rich in $CaCO_3$.

Significant positive values of the coefficients of correlation between the content of $CaCO_3$ and the activity of alkaline phosphatase in soil ($r=0.72$, $p<0.05$) suggest that an increased content of calcium carbonate in the soil of the Unisław Basin enhances the activity of the enzyme investigated.

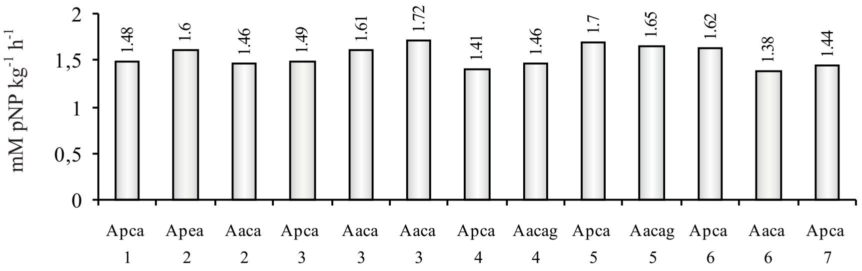

Fig. 2. Ratio of alkaline to acid phosphatase AlP:AcP.

CONCLUSIONS

1. The soils researched were identified with a low and average content of available phosphorus, which calls for soil fertilization with that nutrient.

2. Changes in the activity of alkaline and acid phosphatase catalyzing the key processes of transformation of soil phosphorus point to their potential use in monitoring and developing basic soil fertility components.

3. The activity of alkaline phosphatase was higher than the activity of acid soil phosphatase.

4. The enzymatic indicator of the soil pH (AlP:AcP) can be used as an alternative method to determine the soil reaction as well as changes which occur in it.

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AKTYWNOŚĆ FOSFATAZ W POZIOMACH PRÓCHNICZNYCH GLEB UPRAWNYCH BASENU UNISŁAWSKIEGO

W pracy przedstawiono wyniki badań nad aktywnością fosfatazy alkalicznej i kwaśnej na tle wybranych parametrów chemicznych w wytypowanych poziomach próchnicznych gleb uprawnych Basenu Unisławskiego. Stwierdzono, że badana gleba wykazywała wyższą aktywność fosfatazy alkalicznej średnio o 35% w porównaniu do aktywności kwaśnej fosfatazy. Wynika to z faktu dużej zasobności gleby w $CaCO_3$. Znaczne ilości węglanu wapnia decydowały o obojętnym bądź słabo alkalicznym odczynie analizowanych poziomów. Badana gleba należy do gleb o niskiej i średniej zawartości fosforu przyswajalnego, co klasyfikuje ją do IV i III klasy zasobności w ten pierwiastek. Stwierdzono zmiany aktywności badanych enzymów w zależności od poziomu, z którego pobrano próby glebowe, na których uprawiano różne gatunki roślin.

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ROLE OF *APORRECTODEA CALIGINOSA* IN THE PROCESSES OF SOIL ORGANIC MATTER TRANSFORMATION UNDER THE CONDITION OF MONOCULTURE AND MULTISPECIES PLANT COMMUNITY***

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Abstract. The study has been carried out in the experimental field of the Centre for Ecological Research of the Polish Academy of Sciences, PAN, located in Dziekanów Leśny (north of Warsaw). Six hundred lysimeters were installed covering the experimental area. The surface of the experimental plots (both lysimeters and their vicinity) was sown with either one grass (*Festuca rubra*) on half of the area, or with a mixture of 8 grass species on the other half of the area. In the next year, geophagous earthworms *A. caliginosa* were introduced to half of the lysimeters. The content of C-org, N-total, and the fractional composition of soil humus, were first determined at the beginning; at the end of the experiment also pH and the capacity of sorption complex were identified. The empirical results were subject to statistical analyses. After two years of the study, in comparison to red fescue sodding, the grass mixture sodding caused an increase in the content of organic carbon, total nitrogen and carbon of the humus fraction. The differences between the mean values of both soddings were not statistically significant. In soils under grass mixture, *A. caliginosa* caused an increase in the contents of organic carbon and fulvic acids carbon in relation to the initial soil; the CHA/CFA ratio significantly decreased. A slight increase in the degree of organic matter humification was observed in both soddings in combination with earthworms.

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The diversity of organism assemblages dwelling in soil is determined by the physical and chemical properties of the habitat, climate, vegetation and interrelationships between the particular components [15]. Both in a global and regional scale, vegetation is considered the crucial factor shaping soil biodiversity. Numerous studies indicate that reduction of plant species diversity in the ecosystem causes depletion of the edaphone composition [1, 10]. Other studies show that this fact is probably related only to higher trophic levels [14]. This is evidenced by the decrease in the density and biomass of earthworms in monocultures in comparison to variable systems and the preference of the latter by rodents. A rich and diverse assemblage of soil organisms has a very strong influence on the formation of plant communities and their production. In this case, a unique role is played by earthworms, a soil engineering species, that may cause significant changes in the physical, chemical and biotic properties of a habitat.

The role and significance of various earthworm species may vary in an ecosystem. The most important differences occur between detritophags and geophags. Detritophags, represented by Poland common species *Lumbricus rubellus* (Hoffm.), dwell in the litter or the sub-surface part of soil, feeding on partly decomposed plant material with a small admixture of mineral parts. In comparison to the surrounding soil, coprolites of this species are enriched in organic carbon, total and mineral nitrogen, soil humus, macro- and microelements, as well as microorganisms. They become centres of mineralization and humification of the organic matter [5, 6, 8, 9].

A typical geophagous species in Polish fauna is *Aporrectodea caliginosa* (Sav.), a common organism of arable soils. It dwells down to a depth of 20 cm and feeds on strongly decomposed organic matter, including parts of root systems and humus from the consumed soil [12]. Food intake is linked with continuous burrowing activities in the soil. The low energetic value of the food means that 24-hour consumption often exceeds the body mass of an individual. The short passage of the food mass through the intestine (1 h) does not favour the growth of microflora in it [3].

The objective of this paper is an attempt to check if food intake by *A. caliginosa* may cause a decrease in humus resources, particularly in light soils, and what the contribution of plant biodiversity in this phenomenon is.

MATERIAL AND METHODS

The experiment was carried out in 2004 in the Centre for Ecological Research, Polish Academy of Sciences in Dziekanów Leśny under Project No. PBZ-KBN-087/P04/2003. About 600 lysimeters were installed; each was 30 cm in diameter and 45 cm in height with a double perforated bottom allowing gathering of the filtered material and its transportation to the surface. Lysimeters were filled with homogenous soil removed from the study field to the depth of 30 cm. Prior to inserting in the lysimeters, the soil was cleaned of earthworms, cocoons, root fragments and stones. Earlier the soil had neither been treated with fertilizers nor pesticides. The soil is represented by light soil – slightly clayey sand texture, organic carbon content 6 g kg^{-1}, total nitrogen content 0.5 g kg^{-1} and low pH values – pH_{KCl} 4.45. Lysimeters were inserted in the soil and in Spring 2004, half of them were sown with red fescue grass (*Festuca rubra*) and the other half with a mixture of 8 grass species, comprising: *Festuca pratensis* (15%), *Phleum pratense* (20%), *Dactylis glomerata* (10%), *Festuca arundinacea* (5%), *Bromus inermis* (5%), *Lolium perenne* (10%), *Poa pratensis* (15%), and *Festuca rubra* (20%). Both sowings were made from an identical number of seeds. In May 2005, the earthworm *A. caliginosa* at 15 individuals per lysimeter was introduced to half of the lysimeters in each sowing combination. Lysimeters without earthworms were treated as the control batch.

Samples for analysis were collected in the beginning of the experiment (initial soil) and from the lysimeters in September 2006 after the experiment. The samples were collected randomly, 10 samples per combination.

The following parameters were determined in the soil samples: soil reaction in 1M KCl, sorption capacity, organic carbon and total nitrogen contents; extraction of humic acids was made using the simplified method of Kononowa-Bieliczkowa [2]. Carbon in soils and in particular fractions was determined using the Tiurin method, total nitrogen was determined using the Kjeldahl method with the use of the Kieltec-Tecator apparatus. The results were analyzed using the ANOVA variance analysis (Statgraphic Plus 5.1 software), and the mean values were compared using the Tukey test.

RESULTS AND DISCUSSION

Changes in some chemical properties of the soil were noted after the 2.5-year experiment (Table 1). The reaction of soils with mono- and multispecific sodding had increased by 0.35 in comparison to the initial soil. The difference between the soils of both soddings was insignificant in ANOVA; the influence of earthworms on pH was not observed. More significant changes took place in the soil sorption capacity. In relation to the initial soil, sodding with red fescue caused a 3.5-fold increase in the sum of alkaline cations (S), whereas the multispecific sodding caused 2.9-fold increase. The difference between the sodding systems was statistically significant. In the combination with earthworms no significant changes in the S value were found in either of the soddings. Hydrolytic acidity (Hh) was higher than in the soil before the treatment and significantly higher in comparison to the S values, in soils with multispecific sodding. Earthworms did not cause any significant change in this characteristic. In consequence, in

TABLE 1. CHEMICAL PROPERTIES OF SOIL FROM LYSIMETERS AFTER 30 MONTHS OF SODDING FORMATION AND 18 MONTHS AFTER THE EARTHWORM *APORRECTODEA CALIGINOSA* INTRODUCTION

Sodding	pH_{KCl}	BEC	Hh	CEC	BS (%)
		(cmol (+) kg^{-1})			
Without earthworms					
Red fescue	4.79	6.01	2.43	8.44	71.21
Grass mixture	4.81	5.01	2.52	7.53	66.53
$LSD_{0.05}$	n.s.	0.405	0.061	0.370	1.810
With earthworms					
Red fescue	4.78	6.15	2.44	8.59	71.59
Grass mixture	4.82	5.03	2.49	7.52	66.89
$LSD_{0.05}$	n.s.	0.626	n.s.	0.627	2.250
Initial soil (before treatment)					
Without sodding	4.45	1.75	1.84	3.59	48.75

x – mean values from 10 lysimeters, BEC – base exchange capacity, Hh – hydrolytic acidity, CEC – cation exchange capacity, BS – base saturation.

comparison to the initial soil, the total sorption capacity (T) was over 2.5-fold higher under monospecific sodding, reaching 8.44 $cmol^{+}$ kg^{-1}, and 2 times higher under multispecific sodding, reaching 7.53 $cmol^{+}$ kg^{-1}. The difference between the sodding systems was statistically insignificant. The soil under monospecific sodding had higher saturation of the sorption complex by alkaline cations (71.06%) in comparison to the soil under multispecific sodding (66.51%). The difference between the soddings was significant but no earthworm influence was found in this case either.

With regard to the content of organic carbon, total nitrogen and the fraction content of humus (Table 2) in soil under soddings without earthworms, it is to be concluded that values of all the parameters are higher under the grass sodding (except for total nitrogen and CHA). The content of organic carbon in soil under grass mixture exceeds that in soil under monospecific sodding (*Festuca rubra*) by 6.4%, CFA – by 12.5% and CR – by 5.7%. The differences are, however, statistically not significant. The increase in organic carbon content was probably caused by higher biomass production in relation to monospecific sodding [11].

A fact worth noting is that the organic carbon content under red fescue and in the initial soil were maintained at the same level. The 2.5-year lasting red fescue sodding formation did not cause any increase in the organic carbon content in the

TABLE 2. CONTENT OF ORGANIC CARBON AND TOTAL NITROGEN AND FRACTION COMPOSITION OF THE SOIL HUMUS IN TWO SODDING SYSTEMS WITH EARTHWORMS (g kg^{-1})

Sodding	C-org	N-total	C:N	CHA+CFA	CHA	CFA	CR	CHA+CFA
Without earthworms								
Red fescue	6.08	0.69	8.81	2.56	1.12	1.44	3.52	0.78
Grass mixture	6.47	0.72	8.99	2.75	1.13	1.62	3.72	0.70
LSD$_{0.05}$	n.s.							
With earthworms								
Red fescue	5.93	0.81	7.32	2.59	1.14	1.45	3.34	0.79
Grass mixture	6.55	0.68	9.63	2.86	1.08	1.78	3.69	0.61
LSD$_{0.05}$	0.337	0.105	1.10	0.14	n.s.	0.13	0.27	0.09
Initial soil (before treatment)								
Without sodding	6.00	0.50	12.00	2.71	1.15	1.56	3.29	0.74

CHA – C humic acids, CFA – C fulvic acids, CR – C residuum.

TABLE 3. PERCENTAGE CONTENT OF SELECTED CARBON FRACTIONS IN SOIL ORGANIC CARBON

Sodding	CHA	CFA	CR	HS
Without earthworms				
Red fescue	18.42	23.68	57.90	42.10
Grass mixture	17.47	25.04	57.49	42.51
LSD$_{0.05}$	n.s.			
With earthworms				
Red fescue	19.22	24.45	56.33	43.67
Grass mixture	16.49	27.18	56.33	43.67
LSD$_{0.05}$	1.77	1.54	n.s.	n.s.
Initial soil (before treatment)				
Without sodding	19.17	26.00	54.83	45.17

HS – degree of humification (CHA+CFA)/C-org 100%.

soil of the lysimeters; only slight changes in the fraction content of humus were observed. A characteristic feature of the fraction composition is the prevalence of fulvic acids over humic acids, which was testified by CHA/CFA values below 1.

Most probably, an increased mineralization of the decomposed organic matter and the biomass of fresh undecomposed grass roots takes place in the first stages of sodding formation. This is evidenced by the 2.5-fold increase of exchangeable cations in the soil that are released during this process (Table 1).

The introduction of *A. caliginosa* earthworms into the soddings caused an insignificant increase in the organic carbon content in the soil, under the grass mixture only. The content of carbon of fulvic acids (CFA) rose also in this combination, resulting in a significant decrease in the CHA/CFA ratio in comparison to the control batch. In soil with red fescue the earthworms caused a decrease in the residual carbon content (CR). In this combination all the differences (except CHA) between the average values from both soddings were statistically significant.

The percentage content of particular humus fractions in the soil organic carbon indicates slight changes that took place in the soil of both soddings following the introduction of *A. caliginosa* earthworms. In comparison to the initial soil (Table 3), the combinations of both soddings with earthworms showed a 1.0–1.5% increase in organic matter humification, and a similar increase in the content of carbon from fulvic acids (CFA); the content of residual carbon (CR) in organic carbon decreased in the same time. In relation to the initial soil, the content of carbon from humic acids (CHA) increased under red fescue and decreased under the grass mixture.

Such slight changes in the content and quality of soil humus under the influence of *A. caliginosa* earthworms result from the feeding strategies and digestion physiology of this species. Typically, 2 to 6 species of *Lumbricidae* occur in meadow areas [4]. In the early stages of the meadow succession *Aporrectodea caliginosa* dominates, whereas in the progressed succession the assemblage is dominated by *Lumbricus rubellus,* a species characteristic of a completely different trophy pattern. In comparison to *A. caliginosa*, its coprolites are enriched in organic matter at different decomposition stages and contain high amounts of various bacterial flora, thus favouring humus formation. The age of the soddings is also an important factor. According to Makulec and Kusińska [4, 6], the organic carbon content grows with meadow maturity, as well as the content of carbon of fulvic acids in the earthworm coprolites. The 2.5-year long experiment represents a very early stage of the succession with only one geophagous species of the *Lumbricidea*, therefore it seems that the type of sodding is much more influential for the soil organic matter than the presence of *A. caliginosa*. The life activity of this species causes an improvement in the physical properties of soil (aeration, structure improvement), which ensures better development of the grass root system and larger biomass increase [11], and leads in consequence to the observed increase of organic matter in the soil (mainly under grass mixture sodding).

CONCLUSIONS

1. Following the formation of soddings composed of red fescue and a mixture of 8 grass species, the soil pH and its sorption capacity, particularly with regard to alkaline cations, increased in relation to the initial soil. Both T and BS were significantly higher in soil under red fescue. No influence of *A. caliginosa* on these properties was observed.
2. In comparison to red fescue sodding, the grass mixture sodding caused an increase in the content of organic carbon, total nitrogen and carbon of the humus fraction. The differences between the mean values of both soddings were statistically insignificant.
3. In soils under grass mixture, *A. caliginosa* caused an increase in the content of organic carbon and fulvic acids carbon in relation to the initial soil; the CHA/CFA ratio significantly decreased.
4. In soil covered with red fescue, *A. caliginosa* caused a decrease in the residual carbon (CR) and C:N ratio.
5. A slight increase in the degree of organic matter humification was observed in both soddings in combinations with earthworms.

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ROLA *APORRECTODEA CALIGINOSA* W PRZEMIANACH MATERII ORGANICZNEJ W GLEBIE W WARUNKACH MONOKULTURY I WIELOGATUNKOWEGO ZESPOŁU ROŚLINNEGO

Badania przeprowadzono na poletku doświadczalnym w Centrum Badań Ekologicznych PAN w Dziekanowie Leśnym. Na powierzchni około 200 m^2, po uprzednim zdjęciu wierzchniej warstwy gleby do głębokości 30 cm, ustawiono 600 lizymetrów. Lizymetry o podwójnym dnie uzupełniono glebą z tego poletka po uprzednim wybraniu dżdżownic, ich kokonów i resztek systemu korzeniowego. Jest to gleba lekka o składzie granulometrycznym piasku gliniastego lekkiego. Podwójne dno lizymetrów pozwalało na odprowadzenie nadmiaru odcieków i skierowanie ich powrotnie na ich powierzchnię. Powierzchnia lizymetrów oraz ich otoczenie zostały obsiane trawą – połowa jednym gatunkiem (*Festuca rubra*) a pozostałe ośmioma gatunkami. Po ukształtowaniu się darni w następnym roku do połowy lizymetrów wprowadzono dżdżownice geofagiczne *A. caliginosa*. Lizymetry bez dżdżownic stanowiły kontrolę. Na początku i pod koniec doświadczenia przeprowadzono oznaczenie zawartości C-org, N-og i składu frakcyjnego humusu glebowego. Wykonano także oznaczenie pH i pojemności kompleksu sorpcyjnego. Wyniki opracowano statystycznie wykorzystująca analizę wariancji ANOVA w programie Statgraphics Plus 5.1, do porównania średnich zastosowano test Tukey'a.

Po dwóch latach obserwacji stwierdzono zdecydowanie wyraźniejsze zmiany pod wpływem dżdżownic w glebie o zadarnieniu wielogatunkowym w porównaniu do monokultury. Zadarnienie mieszanką spowodowało w stosunku do zadarnienia kostrzewą czerwoną wzrost zawartości C-org, N-og i C frakcji próchnicy. Różnice między średnimi z obu zadarnień nie były jednak istotne statystycznie. Pod wpływem *A. caliginosa* w glebie pod mieszanką traw nastąpił wzrost, w stosunku do kontroli, zawartości C-org oraz węgla kwasów fulwowych i istotne obniżenie wartości CHA/CFA. W kombinacji z dżdżownicami stwierdzono nieznaczne zwiększenie stopnia humifikacji materii organicznej w obu zadarnieniach. Tak niewielkie zmiany w zawartości materii organicznej w tym eksperymencie wynikają ze specyficznego rodzaju trofii *A. caliginosa* i bytowania w glebie tylko tego gatunku.

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Soil Biology

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MEASUREMENT OF BIOLOGICAL DIVERSITY OF ARTHROPODS AND RESPIRATION IN SOILS MANAGED UNDER TIME-CONTROLLED AND SET-STOCKED GRAZING PRACTICES IN CENTRAL-WEST NEW SOUTH WALES, AUSTRALIA

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Abstract. In this study we compare the effects of two contrasting grazing regimes (time-controlled grazing (TCG) vs set-stocked grazing (SSG)) on selected parameters of soil biological health**.** The purpose of the study was to evaluate these soil parameters as potential indicators of soil health and thence sustainable soil management. Two parameters, viz., arthropod biological diversity and soil respiration were chosen as reliable indicators of soil health. Samples of pasture cover, arthropod populations, and soil from varied depths were obtained in spring (September-November 2010) and autumn (March-May 2011). Results from the autumn showed a strong effect of time-controlled grazing with increased arthropod abundance and enhanced soil biological respiration while in spring the differences were not significant. It was concluded that a change to short-duration rotational grazing can be beneficial to soil biological health in the longer term and that the measurement of arthropods present in the litter and topsoil can be a simple yet effective indicator of the impact of grazing regime on soil health.

Time-controlled grazing (TCG) [high density-short duration rotational grazing] is becoming a more prevalent practice to manage livestock in key beef-exporting nations such as Australia and New Zealand [19]. Time-controlled grazing is a practice in which large numbers of livestock graze a paddock intensively over 4-7 days (short-term grazing) at stocking rates of 200-250 DSE/ha

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and are then removed allowing the pasture lengthy rest periods. This contrasts with the traditional practice of set-stocked grazing (SSG) in which smaller numbers of livestock are stocked continuously for 3-6 months (long-term grazing) at a low-stocking rate (8-9 DSE/ha) allowing little time for pastures to rest. Agricultural practices, such as grazing, impact on soil health by altering soil-biological properties [2]. However, the ratio between 'grazing duration' and 'intensity of livestock' and the 'rest-period involved' in TCG practice is likely to have varying effects on soil properties. Therefore, a need exists to characterize the impacts of TCG management practices on pasture soil enabling farm managers to choose sustainable-management efforts in the context of specific characteristics of their lands and preferred production levels. An understanding of how such grazing practices modify the biology of the soil helps in improving it by either amending some of its components or changing some of the practices. Soil as living medium [8] needs to be characterized as well; different soil microbiota are equally vital elements to be factored in the understanding and quantifying impacts of TCG on soil health.

Grazing livestock influences soil by their actions involving treading, defoliation, and excretal returns. These influence physical properties of the soil either directly; for example, treading alters soil structure; or indirectly, for instance, defoliation and excretal returns influence natural regeneration and nutrient cycling. Because soil provides habitat, space, food supply, and balanced water-oxygen supply to soil organisms, any change to the soil alters soil-faunal elements including the soil invertebrates [2, 9]. Soil-invertebrate populations (e.g., litter and topsoil-dwelling microarthropods) play a critical role in the decomposition of litter by regulating microbial populations by their trophic action and thus influencing nutrient cycling [3]. Impacts of grazing by measuring soil-faunal elements indicate substantial drops in the biodiversity of oribatid mites [15] and other invertebrates [20]. Grazing density affects the biological diversity of soil-microbial communities negatively [4], but show a positive effect on the biological diversity of Collembola [5] and nematodes [22], which were more similar to in natural prairies in North America than in the modified-prairie agroecosystems. Qi *et al*. [16] have compared microbial biomass by measuring microbial respiration and found a decrease in soil biomass with increased intensities of grazing. Fluctuations in soil and litter factors influence invertebrate communities [14]. These studies reinforce that impacts of different pasture-management techniques on soil health could be measured using diversity and abundance of soil invertebrates as a reliable index.

In general, impacts of diverse grazing practices have been thoroughly investigated, but only a few have specifically focused on comparing TCG and SSG practices. TCG practice increased soil-organic carbon and nitrogen and the ground-litter accumulation [17] and also that of productivity of annual pastures [1].

Moreover, Sanjari *et al*. [18] showed that TCG reduced losses of soil material either through sediment loss or through runoff and that the maintaining of the ground cover which was greater under TCG [19] is the main profit of the rest period characteristic of TCG. A comparison of porosity under TCG and SSG showed that three years of set-stocked and rotationally grazed fields with sheep had topsoil affected by the tested management practice: total macroporosity decreased in SSG regimes, whereas stable structural conditions prevailed in TCG regimes [7].

Trials made in the Central-western New South Wales soils comparing TCG and SSG practices show that after four years of commencement of grazing earthworm numbers remained unaffected, whereas arthropod abundance at 0-10 cm depths was directly proportional to changes followed in grazing management; arthropod abundance was greater in TCG regime, whereas microbial biomass and respiration remained unaffected in comparisons between TCG and SSG regimes [20]. In keeping with the above, the goal of the present study was to verify the previously established findings by comparing arthropod biodiversity and soil respiration in pastures that have consistently remained under SSG and TCG regimens for the past ten years and as an indicator of soil health. In this study, we tested the following hypothesis: in TCG management, compared with SSG management, greater levels of microbial activity (measured overall as soil respiration) and arthropod abundance and biological diversity occur at the soil surface (litter layer) and in the topsoil (0-20 cm depth).

MATERIALS AND METHODS

The site

A 3825 m^2 block on an easterly slope in Orange campus farm of Charles Sturt University, separated by a fence (Fig. 1), was chosen as the study site, because both TCG and SSG practices have been ongoing uninterruptedly from the year 2000. On the northern part of the field block (CSU-Orange campus farm) TCG has been the practice. On the southern part of the field block (property owned by a neighbouring grazier), on the same slope, SSG has been the practice. Broad similarities of physical and chemical features of the soil from each grazing paddock were established after analysis of randomly collected topsoil (1-10 cm) and subsoil (10-20 cm) samples by a commercial soil laboratory on 17 November 2010 (Table 1). Soils of the site were generally Brown Dermosols with loams to clay loams overlying well structured yellow-brown medium clays [14].

Because the sites were under different ownership and management, modest differences in the fertilizer regimes occurred. The TCG study site had received no synthetic amendments until 2008. In 2008, 18% single superphosphate $(CaH_2PO_4)_2$ embellished with molybdenum (Mo), was applied at the rate of 160 kg ha^{-1}.

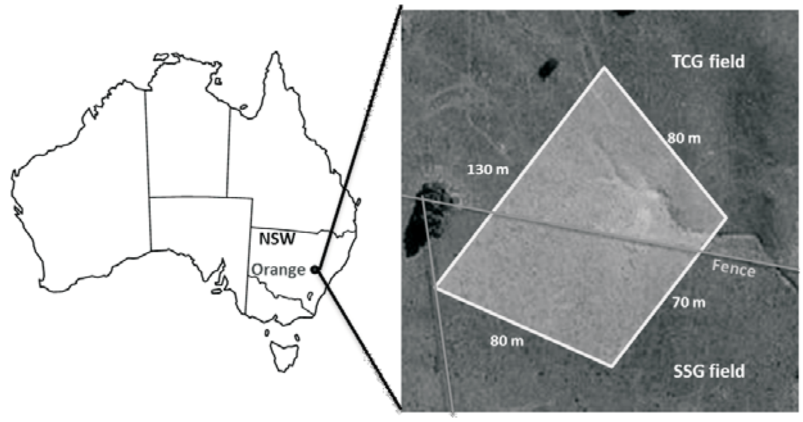

Fig. 1. Outline of the experimental site (trapezoidal) divided by a fence as marked). (Not to scale). Ten plots in each experimental block (on both sides of the fence) were randomly chosen to obtain soil samples, by throwing a 30×30 cm quadrat.

TABLE 1. SOIL-TEST REPORT (NUTRIENT ADVANTAGE ADVICE) FROM INCITEC PIVOT FERTILIZERS, WOOLONGONG, NEW SOUTH WALES, NOVEMBER 17, 2010

Analyte/Assay	SSG site (cm)		TCG site (cm)	
	0-10	10-20	0-10	10-20
pH (1:5 Water)	5.6	5.5	5.6	6
pH (1:5 $CaCl_2$)	4.8	4.5	4.8	4.8
Aluminium saturation (%)	1.6	13	1.6	3.1
Organic carbon (OC) (%)	2.6	0.56	2.8	0.59
Nitrate nitrogen (NO_3) (mg kg^{-1})	6.8	2.7	17	1.8
Phosphorus (Colwell) (mg kg^{-1})	19	8	14	6
Available potassium (mg kg^{-1})	110	61	98	40
Sulphate sulphur (MCP) (mg kg^{-1})	11	6.4	8	4.4
Electrical conductivity (dS m^{-1})	0.06	0.03	0.07	0.05
Electrical conductivity (saturated extract) (dS m^{-1})	0.5	0.2	0.6	0.4
Cation exchange capacity (meq 100 g^{-1})	6.21	2.59	6.41	3.92
Soil colour	Brown	Orange/ Yellow	Brown	Orange/ Yellow

In 2010, 160 kg ha^{-1} of Mo-$(CaH_2PO_4)_2$ was again applied. The SSG site received an application of 160 kg ha^{-1} of Mo-$(CaH_2PO_4)_2$ in 2008. Despite this variation in fertilizer application, soil analysis (Table 1) revealed only a minor difference in soluble P at 0-10 cm depth (TCG 19 mg kg^{-1} P; SCG 14 mg kg^{-1} P).

Pasture composition was assessed by 125 randomized-plant collections from each block. Because the TCG and SSG sites were on the same slope and also because similar land management practices are being followed, irrespective of different ownerships, the results show that similar pasture composition existed in both sites: *Trifolium repens* (*Fabaceae*), *Phalaris aquatica, Lolium perenne* and *Dactylis glomerata* (all *Poaceae*) were the dominant elements, whereas, *Holcus lanatus* (*Poaceae*), *Medicago polymorpha* and *Trifolium subterraneum* (both *Fabaceae*), *Echium plantagineum* (*Boraginaceae*), *Vulpia bromoides* (*Poaceae*), and a mix of *Bromus wildenowie* and *Bromus hordeaceus* (*Poaceae*) occurred in lesser frequency (Table 2). Prevalent climate data during the study period are supplied in Table 3.

Grazing treatments

Grazing at TCG site involved an average time of three days of intensive grazing by a combined mob of sheep and cattle. The animal loading was 200 DSE/ha. The chosen TCG block is a part of the 36 blocks of the farm; therefore, the rest period was between 80 and 100 d. Sampling occurred at approximately mid-time between grazing periods. At the SSG site, continuous grazing occurred at 8 DSE/ha throughout the year apart from short periods when stock was removed for shearing and other routine operations.

TABLE 2. PASTURE COMPOSITION IN BOTH SSG (SET-STOCKED GRAZING) AND TCG (TIME-CONTROLLED GRAZING) FIELDS

Species	(%)
Trifolium subterraneum	2.5
Trifolium repens	12.4
Echium plantagineum	3.3
Dactylis glomerata	10.7
Lolium perenne	17.4
Phalaris aquatica	19.8
Holcus lanatus	9.1
Medicago polymorpha	4.1
Vulpia bromoides	5.8
Bromus wildenowie	5.8
Bromus hordeaceus	9.1

TABLE 3. MEAN CLIMATE DATA DURING STUDY PERIOD

Parameters	Spring 2010	Autumn 2011
Rainfall	346.8 mm	257.2 mm
Maximum temperature	16.9°C	17.2°C
Minimum temperature	7.2°C	6.9°C
Average rainfall (last 44 years)	245.6 mm	184.0 mm
Average max. temperature (last 44 years)	17.5°C	18.4°C
Average min. temperature (last 44 years)	6.7°C	7.5°C

Grass cover

Samples of grass shoots from the 30×30 cm^2 quadrats were obtained by cutting them close to ground level with a hand-held mechanical clipper. Each of the 10 samples collected were weighed individually immediately to obtain fresh-mass data and after drying for 24 h at 50°C to obtain dry-mass data. The results were then converted into t ha^{-1}.

Arthropods

Litter and soil samples for spring 2010 were obtained on 8, 19, and 26 October 2010, and 4 November 2010. Litter and soil samples for autumn 2011 were obtained on 29 March, 8 April, 2 and 13 May 2011. Sampling included litter and soils from 0-10 cm and 10-20 depths. Two litter samples were taken from each plot with a vacuum sampler (Weed Eater®, Model GB1 30v, Poulan Co., Shreveport, Louisiana, USA). Two soil samples from each depth were taken with a 10 cm diameter auger in each plot. Each sample was placed in a Berlese-Tullgren funnel system (funnel ∅: 22 cm). After 7 days, the separated arthropods in the flask that contained 90% ethyl alcohol (100 ml), were separated on a blotting paper for identification up to Orders (following [11]), and taxa of the same order were counted; wherever necessary, taxa were determined as a ‘recognizable taxonomic unit’ (RTU) and numbered 1, 2, 3, and so on.

Soil respiration and soil temperature

Soil respiration and temperature were measured with a LI-COR 6400-09. Soil CO_2 Flux Chamber fitted to a LI-6400XT Portable Photosynthesis System (Lincoln, Nebraska, USA), following Zhang *et al*. [21]. Measurements were taken two times in every nominated plot in SSG and TCG blocks. All measurements were made with the flux chamber resting on collars installed at least 24 h earlier thus ensuring no seepage of gases occurred. Spring 2010 measurements were obtained on October 10 and November 20, 2010 and autumn measurements on April 15 and May 19, 2011. Measurements were obtained in both treatment sites the same day and two times in each season.

Statistics

Analysis was done using R statistical software for WINDOWS®. To obtain a normality assumption of arthropods, a square-root transformation was made. Data were analysed using a one-factor analysis of variance (ANOVA).

RESULTS AND DISCUSSION

The spring samples (n = 10 in each treatment) showed no significant differences between SSG and TCG in mean arthropod abundance, soil respiration and pasture cover (Table 4). However, at 1-10 and 10-20 cm soil depths, the mean-arthropod abundance were 1226 and 44 arthropods/m^2, respectively, under SSG, and 621 and 257 arthropods/m^2, respectively, under TCG, which indicated that there could be some grazing regime effect, which could also vary with soil depth. Species mainly found were taxa belonging to the *Thysanoptera* and *Acarina*, which together accounted for more than 68% of arthropod abundance. Taxa of the *Coleoptera*, *Hymenoptera, Araneae*, *Collembola*, and *Isoptera* constituted 30%. The 2% remaining concerns species that were found occasionally. It was observed that arthropod abundance in term of species was greater in SSG treatment litter, whereas a greater arthropod abundance at both 0-10 and 10-20 cm depths was found for TCG treatment (Fig. 2a,b,c).

On the other hand, autumn 2011 sampling revealed significant increases in mean arthropod abundance and soil CO$_2$ efflux in TCG compared with SSG (Table 5). Arthropod abundance was greater under TCG in the pasture-litter layer and at both soil depths. Although soil-physical parameters were not measured in the present study, a previous experiment comparing TCG and SSG at a different part of the Orange campus farm (but on a similar soil) found that total soil macro-porosity

TABLE 4. MEAN ARTHROPOD ABUNDANCE/m^2 IN LITTER AND TWO SOIL DEPTHS, SOIL RESPIRATION, PASTURE COVER AMONG TREATMENTS (SSG: SET-STOCKED GRAZING, TCG: TIME-CONTROLLED GRAZING, SPRING 2010)

		SSG	TCG	Results ANOVA
Mean arthropod abundance/m^2	Litter (0 cm)	1941±237	1579±538	$p>0.05$
	1-10 cm	1226±292	621±217	$p>0.05$
	10-20 cm	44±15	257±211	$p>0.05$
Soil CO$_2$ efflux (μmol/m^2/s)		12.33±0.50	11.39±0.47	$p>0.05$
Pasture cover (t ha^{-1})		4.6±0.47	4.43±0.34	$p>0.05$

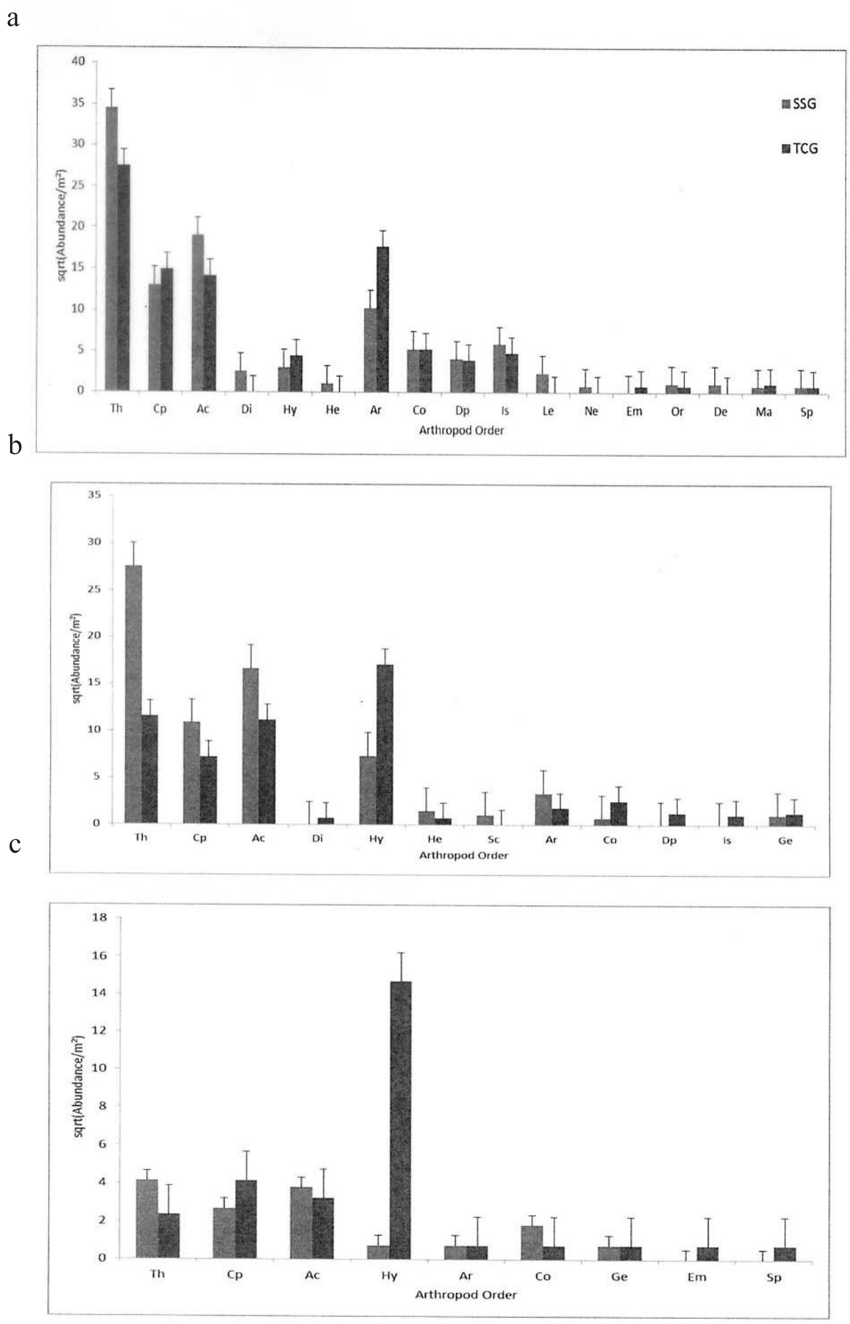

Fig. 2. Square-root mean abundance/m^2 of arthropods in SSG and TCG treatments (mean data from two replicates/treatment) in Spring 2010: a – litter – 0 cm, b – 1-10 cm, c – 10-20 cm. Ac – *Acarina*, Ar – *Araneae*, Co – *Collembola*, Cp – *Coleoptera*, Di – *Diplura*, De – *Dermaptera*, Dp – *Diptera*, Em – *Embioptera*, Ge – *Geophilomorpha* (*Geophilidae*), Hy – *Hymenoptera*, He – *Hemiptera*, Is – *Isoptera*, Le – *Lepidoptera*, Ma – *Mantodea*, Ne – *Neuroptera*, Or – *Orthoptera*, Sp – *Sphaerotheriida*, Th – *Thysanoptera*.

TABLE 5. MEAN ARTHROPOD ABUNDANCE/m^2 IN LITTER AND TWO SOIL DEPTHS, SOIL RESPIRATION, PASTURE COVER AMONG TREATMENTS (SSG: SET-STOCKED GRAZING, TCG: TIME-CONTROLLED GRAZING, AUTUMN 2011)

		SSG	TCG	Results ANOVA
Mean arthropod abundance/m^2	Litter (0 cm)	1765 (±308)	3702 (±562)	p>0.05
	1-10 cm	504 (±53)	1226 (±299)	p>0.05
	10-20 cm	37 (±7)	96 (±21)	p>0.05
Soil CO_2 efflux (μmol/m^2/s)		2.93 (±0.25)	3.65 (±0.21)	p>0.05
Pasture cover (t ha^{-1})		9.97 (±0.33)	7.33 (±0.34)	p>0.05

decreased in SSG fields, whereas stable structural conditions prevailed in TCG fields [7]. The observed reduction of arthropod numbers observed in our study could thus be attributed to a decrease in pore space for the decomposer microarthropods in SSG fields. Greater macroporosity in TCG fields allowed the development and establishment of micoarthropod populations. A decrease in arthropod abundance also occurred with depth, which matched the findings of Tom *et al*. [20].

Our observed seasonal differences contrast with those of Tom *et al*. [20], who in an earlier study located in another part of the Campus farm found no significant changes in autumn, but significant changes in spring. This could be due to an atypical high rainfall during the study period (2010-2011), which could have affected the arthropod community (e.g., intense trampling by high density stock on wet soil under TCG) and thus impacting on the build up of their populations in spring. There may however be seasonal patterns of arthropod abundance due to species adaptation. In an exhaustive study made at the Northern Tablelands of New South Wales in 1976, King *et al*. [12] showed that the arthropod population and abundance evolve with seasons; particularly populations of *Acarina* and *Collembola* occurred in greater abundance in autumn than in spring. The results of our study also reinforce that the populations of *Acarina* and *Collembola* peaked in autumn and a better total-number of arthropods occurred in TCG field. Species mainly found in autumn were *Acarina* and *Collembola* which together accounted for 93%. *Thysanoptera, Coleoptera, Hymenoptera* and *Hemiptera* constituted the remaining 7%. Numbers of *Collembola* and *Acarina* were higher in each depth for TCG management (Fig. 3). Arthropod abundance - one index of diversity – appeared better in the litter and 0-10 cm depth of the SSG paddock. It is the same between the two treatments in the 10-20 cm depth. Soil respiration in TCG paddock is higher in autumn than spring. This is despite the fact that sampled pasture biomass was less, suggesting the increase may be due to greater microbial activity rather than root respiration.

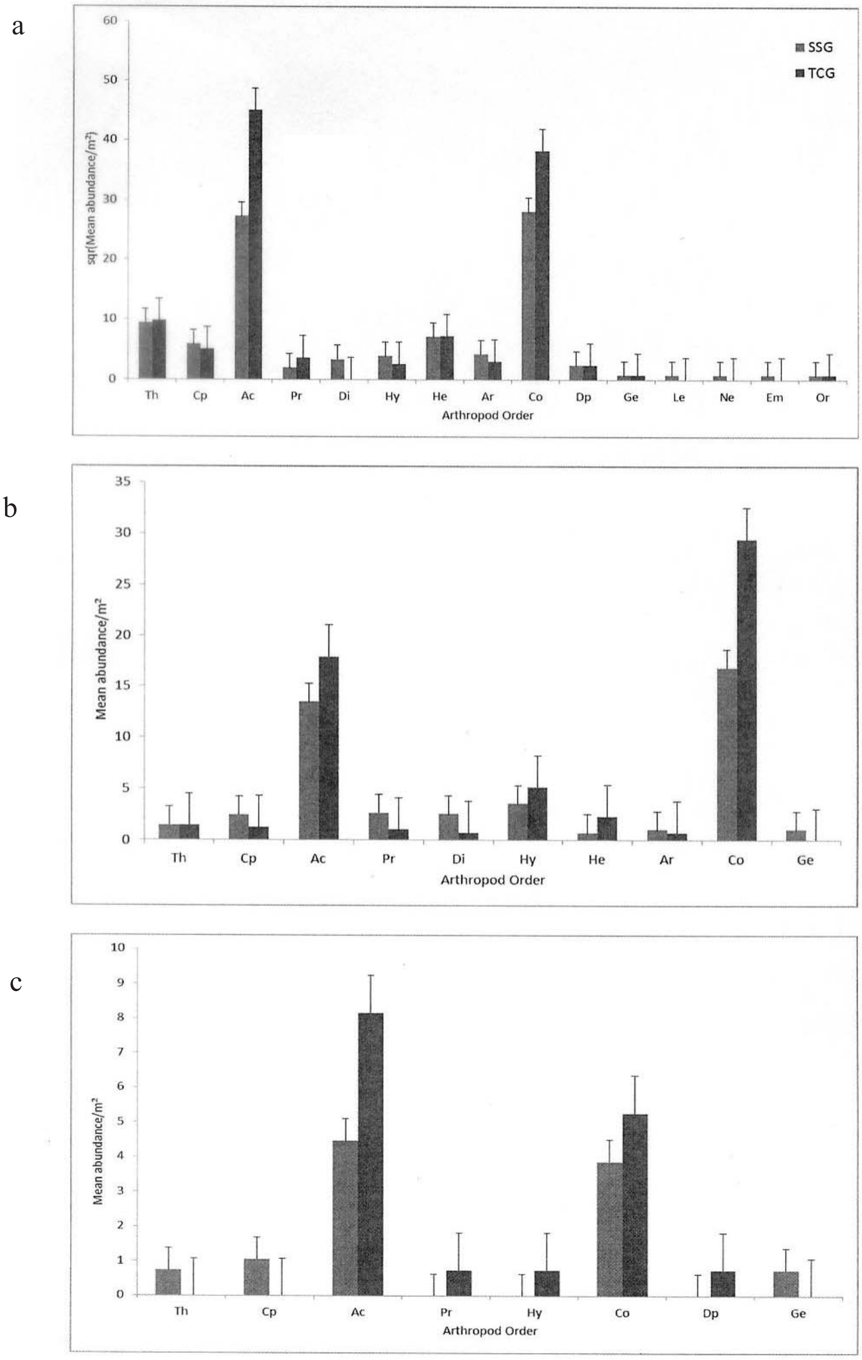

Fig. 3. Square-root mean abundance/m^2 of arthropods in SSG and TCG treatments (mean data from two replicates/treatment) in Autumn 2011: a – litter – 0 cm, b – 1-10 cm, c – 10-20 cm. Explanations as in Fig. 2.

CONCLUSIONS

Our results suggest a partial confirmation of the hypothesis. There is an indication that during autumn, the effect of TCG, when compared with SSG, is to increase arthropod abundance, diversity in the soil and surface litter and soil respiration in the topsoil. These improvements were however not consistent across both seasons which may indicate that the benefits of TCG to these soil parameters are seasonally dependent, with climatic conditions (e.g., rainfall and temperature) mediating these effects. These results, when combined with earlier studies [7] showing increased macro porosity under TCG, give increased confidence that TCG can confer improvements to soil physical and biological parameters and thus be considered as a more sustainable grazing strategy in terms of soil health. Seasonal shifts and changes in precipitation may, however, change soil cycles, suggesting that agriculture is highly vulnerable to climate changes and newer forms of grazing practice must be evaluated carefully in the context of continuing climatic variability.

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BADANIA RÓŻNORODNOŚCI BIOLOGICZNEJ STAWONOGÓW I ODDYCHANIE W GLEBACH O ODMIENNYCH SYSTEMACH WYPASANIA W CENTRALNO-ZACHODNIEJ NOWEJ POŁUDNIOWEJ WALII, AUSTRALIA

Badania dotyczyły porównania skutków oddziaływania dwóch odmiennych systemów wypasania (systemu o kontrolowanym czasie wypasu – TCG *vs* wypasu stada o określonej liczebności – SSG) na wybrane parametry biologicznej zdrowotności gleb. Celem badań była ocena tych parametrów, jako potencjalnych wskaźników zdrowotności gleby i zrównoważonego użytkowania gleb. Za wiarygodne wskaźniki zdrowotności gleby przyjęto dwa parametry, tj. zróżnicowanie biologiczne stawonogów i oddychanie gleby. Próby runi pastwiskowej, populacji stawonogów i gleby pobrano wiosną (wrzesień-listopad 2010) i jesienią (marzec-maj 2011). Wyniki z jesiennego poboru wskazują na silne oddziaływanie systemu TCG na wzrost liczebności stawonogów i zwiększoną aktywność biologiczną. Różnice w próbach z okresu wiosennego były nieistotne. Stwierdzono, że zmiana systemu w kierunku krótkotrwałego rotacyjnego wypasu może być korzystna dla zdrowotności biologicznej gleby w dłuższym okresie oraz, że pomiary stawonogów obecnych w darni i powierzchniowej warstwie gleby może być prostym, ale efektywnym wskaźnikiem wpływu systemu wypasu na zdrowotność gleby.

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CONTENT OF SULPHATE SULPHUR IN DIFFERENT TYPES OF SOILS IN THE PODKARPACKIE REGION

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Abstract. The aim of the investigation was the estimation of sulphate sulphur in soils in the Podkarpackie Province. The content of sulphate sulphur within the soils developed on flysch works subject to strong spatial variability of 0.87 g kg^{-1} in the Przemyśl Foothills to 2.00 g kg^{-1} in the Cieżkowickie and Strzyżowskie Foothills. The content of sulphate sulphur in soils is positively correlated with the content of humus in the Western Bieszczady Mountains and the content of colloidal clay fraction within the Tarnogrodzki Plateau and Rzeszów Foothills. In soil types: Haplic Cambisol, Haplic Cambisol (Dystric), Haplic Cambisol Podzolised, Haplic Podzol and Haplic Luvisol found in the Podkarpackie Province there is no significant variation of the sulphate sulphur content (average 1.73-1.93 mg $100g^{-1}$), but less sulphur was found in Haplic Cambisol (Eutric) soils.

Sulphur is an element which commonly occurs in nature and is necessary for proper functioning of living organisms. Its total content in the soils of Poland ranges from 70 to 1070 mg kg^{-1} [11] and depends on the type of parent rock, organic matter content, as well as fertilization [18]. The greatest amounts of total sulphur are included in chernozem soils, alluvial soils and black earth. A deficit of sulphur occurs in soils derived from light loamy sands and weakly loamy sands, which is related to their small content of organic matter. The easily soluble sulphate fraction of sulphur typically constitutes a small percentage of its total content. Some researchers have investigated the problem of sulphur shortages in soils under heavy agricultural usage [10]. Others have researched the anthropogenic emission of sulphur into the atmosphere, which induces local soil contamination and, in consequence, leads to chemical degradation of soils [21]. The aim of this research was to assess the content of sulphate sulphur in the soils of the Podkarpackie Region in the regional and typological sense according to the physical and physical-chemical properties of these soils.

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MATERIAL AND METHODS

The analysis of the spatial differentiation of the content of sulphate sulphur in the soils of the Podkarpackie Region was carried out based on the results of tests of 2061 soil samples taken at the Regional Chemical-Agricultural Station in Rzeszów (Fig. 1). These samples were taken from the soils of agricultural areas (arable and permanent grassland) and the specific location of the sample was determined by the knots of the square-based net with 2 km long sides. During the field work, the soil type was determined acc. to FAO classification [4] and the samples were taken from the 0-20 cm (n = 1 678), and 20-40 cm (n = 383) depths.

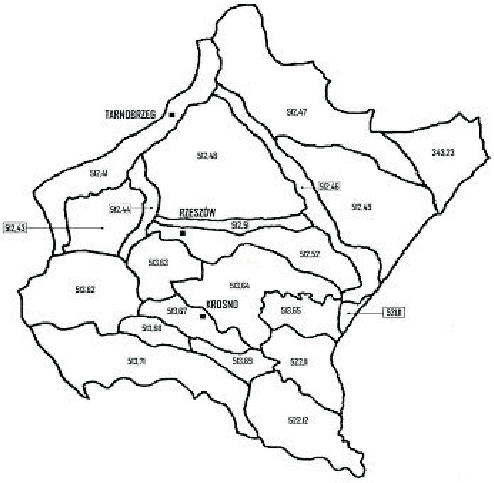

Fig. 1. Mezoregions in Podkarpackie Province according to Kondracki [7] – with modification. Explanations: Roztocze Wschodnie – 343.23 (n=10); Pogórze Strzyżowskie – 513.63 (n=33); Nizina Nadwiślańska – 512.41 (n=24); Pogórze Synowskie – 513.64 (n=414); Płaskowyż Tarnowski – 512.43 (n=5); Pogórze Przemyskie – 513.65 (n= 60); Dolina Dolnej Wisłoki – 512.44 (n=40); Kotlina Jasielsko-Sanocka – 513.67 (n=49); Dolina Dolnego Sanu – 512.46 (n=62); Pogórze Jasielskie – 513.68 (n=70); Równina Biłgorajska – 512.47 (n=5); Pogórze Bukowskie – 513.69 (n=78); Płaskowyż Kolbuszowski – 512.48 (n=184); Beskid Niski – 513.71 (n=59); Płaskowyż Tarnogrodzki – 512.49 (n=106); Płaskowyż Chyrowski – 521.11 (n=3); Pradolina Podkarpacka – 512.51 (n=62); Góry Sanocko-Turczańskie – 522.11 (n=74); Podgórze Rzeszowskie – 512.52 (n=242); Bieszczady Zachodnie – 522.12 (n=72); Pogórze Ciężkowickie – 513.62 (n=25); n – number of samples.

The mean content of sulphate sulphur in the particular soil types and physiographic units are presented in Table 1. The types and units with the count below 10 were excluded from further statistical analysis or were incorporated into the adhering units.

The Podkarpackie Region shows a clear differentiation in terms of climate conditions and the landscape, which is related to its genesis. The northern part of the region, with the exception of Roztocze, is located within the Sandomierska Basin macro-region and is of a plain character formed by glacier sediments and is

TABLE 1. MEAN (A) AND RANGE (B) OF CONTENTS OF SULPHATE SULPHUR IN SELECTED SOIL TYPES AND MEZOREGIONS (mg 100 g^{-1} OF SOIL)

Physico-geographical regions		Soil types										Mean
		1	2	3	4	5	6	7	8	9	10	
Nizina Nadwiślańska and Dolnej Wisłoki	A	1.38	-	-	1.63	-	-	2.36	-	1.81	2.29	1.89
	B	1.38-1.38	-	-	0.17-3.0	-	-	2.13-2.65	0.37-3.76	0.12-2.88	1.2-5.13	0.12-5.13
Dolina Dolnego Sanu	A	1.80	-	-	1.58	-	-	0.75	0.90	0.17	1.76	1.07
	B	0.42-3.70	-	-	0.05-3.87	-	-	0.75-0.75	0.12-1.67	0.17-0.17	0.3-4.0	0.05-4.0
Płaskowyż Kolbuszowski	A	1.59	-	0.77	1.65	3.38	-	2.85	1.56	2.45	1.93	2.02
	B	0.15-4.35	-	0.62-0.92	0.17-4.0	2.5-4.25	-	1.62-5.50	0.5-3.62	0.3-4.25	0.17-6.0	0.15-5.50
Płaskowyż Tarnogrodzki	A	1.90	-	-	1.32	-	-	3.09	3.25	-	1.91	2.29
	B	0.12-8.12	-	-	0.2-2.55	-	-	0.43-7.50	1.2-7.33	-	0.43-4.30	0.12-8.12
Pradolina Podkarpacka	A	1.58	-	-	1.69	-	0.12	1.22	1.32	1.51	1.60	1.29
	B	0.1-3.8	-	-	0.12-7.63	-	0.12-0.12	0.8-1.50	0.12-2.62	0.07-5.75	0.3-0.3	0.07-7.63
Podgórze Rzeszowskie	A	1.80	-	2.29	1.68	2.18	1.81	2.12	1.19	1.80	1.75	1.85
	B	0.12-6.12	-	0.75-2.37	0.11-8.25	1.87-2.87	0.05-5.37	2.12-2.12	0.15-7.5	0.13-12	0.17-2.37	0.05-12
Pogórze Ciężkowickie And Strzyżowskie	A	2.02	2.47	-	1.91	1.71	-	-	2.38	-	1.53	2.00
	B	0.1-4.07	1.5-3.4	-	0.37-4.5	0.3-2.4	-	-	0.15-3.25	-	0.8-2.3	0.1-4.5
Pogórze Dynowskie	A	1.68	1.97	2.30	1.51	1.72	2.10	0.13	1.65	1.43	1.28	1.58
	B	0.1-4.25	0.5-5.5	2.30-2.30	0.07-5.12	0.3-4.25	2.10-2.10	0.13-0.13	0.05-4.76	0.05-3.5	0.12-6	0.05-6
Pogórze Przemyskie	A	0.89	-	-	1.22	-	1.31	-	0.05	-	-	0.87
	B	0.15-2.50	-	-	0.12-4.12	-	0.2-2.42	-	0.05-0.05	-	-	0.05-4.12

TABLE 1. CONTINUATION

Physico-geographical regions		Soil types										Mean
		1	2	3	4	5	6	7	8	9	10	
Kotlina Jasielsko-Sanocka	A	1.74	1.74	0.08	1.82	1.68	-	2.12	1.66	-	2.37	1.65
	B	0.92-2.37	0.87-3.5	0.05-0.1	0.25-3.8	0.05-3.0	-	2.12-2.12	0.25-3.25	-	2.37-2.37	0.05-3.8
Pogórze Jasielskie	A	2.00	1.37	1.50	1.32	1.75	-	1.37	2.82	-	1.87	1.75
	B	0.65-3.25	1.37-1.37	1.50-1.50	0.12-6.5	0.05-7.25	-	1.37-1.37	0.2-7.12	-	1.87-1.87	0.05-7.25
Pogórze Bukowskie	A	0.12	1.70	1.19	1.17	1.67	-	-	0.51	0.20	1.64	1.03
	B	0.12-0.12	1.07-2.33	0.25-2	0.05-3	0.05-6.37	-	-	0.2-1.25	0.20-0.20	1.3-2.12	0.05-6.37
Beskid Niski	A	-	-	-	1.61	1.40	-	-	1.29	1.60	1.08	1.40
	B	-	-	-	0.12-5	0.5-3.17	-	-	0.89-2.05	0.25-2.9	0.2-1.55	0.12-5
Góry Sanocko-Turczańskie	A	1.62	1.82	0.15	1.45	1.70	-	-	1.22	-	-	1.32
	B	0.12-3.12	1.37-2.37	0.15-0.15	0.12-3.7	0.1-5.5	-	-	0.37-2.12	-	-	0.1-5.5
Bieszczady Zachodnie	A	0.13	1.29	2.35	1.25	1.94	-	-	1.22	1.45	-	1.38
	B	0.13-0.13	0.37-3.75	0.25-4.75	0.18-3.5	0.25-5.24	-	-	0.17-2.45	0.8-2.3	-	0.13-5.24
Mean		1.35	2.00	1.27	1.52	1.91	1.34	1.78	1.50	1.38	1.75	1.56

*Soil types: 1 - Haplic Podzol, n=271; 2 – Haplic Luvisol, n= 48; 3 - Haplic Cambisol, n= 41; 4 - Haplic Cambisol (Eutric), n= 609; 5 - Haplic Cambisol (Dystric), n= 157; 6 - Haplic Chernozem, n=40; 7 - Gleyic Chernozem, n=21; 8 - Haplic Fluvisol, n=138; 9 - Endofluvic Phaseozem, n= 98; 10 - Haplic Cambisol (Spodic), n=210. n – numer of samples.

characterized by long warm summers, relatively mild winters and a small yearly sum of precipitation (700 mm in the Kolbuszowski Plateau). Within its area, there are wide river valleys of the Vistula, Wisłoka and San. The southern part is composed of the Karpathian flysh detritus with a hilly terrain (Pogórze Środkowobeskidzkie) and mid-range mountain terrain (Beskidy Środkowe and Beskidy Lesiste).

The climate becomes more raw (daily and yearly air temperature amplitudes increase) with the increasing elevation above sea level, where the rainfall reaches 1200 mm. The grain size distribution was assessed in the soil samples using the Cassagrande method as modified by Prószyński, the reaction using the potentiometer method in a 1 M KCl solution, the content of organic carbon using the Tiurin method and the content of sulphate sulphur using the Bardsley and Lancaster method used in monitoring research [1].

The results were statistically analyzed including the calculation of correlations between the content of $S\text{-}SO_4$ in the investigated soils and the basic properties of these soils. In cases of significant correlations, regression equations were estimated using linear and multiple regression at the significance level of $p=0.05$. The regression equations containing the reaction (pH) can only be used for estimating the direction of the changes in the content of sulphate sulphur in the soils and cannot be used to assess its content. In addition, an analysis of variability was carried out and the significance of the differences between the sulphur content in the region, types of soils and the particular groups of soil reaction were assessed. The analyses were performed using Statistica 8 software.

RESULTS AND DISCUSSION

The soils of the northern part of the Podkarpackie Region, derived from post-glacial formations, are classified as light soils in terms of their grain-size distribution. In the Kolbuszowski Plateau, representative for this region, sands constitute 81%, loams 14% and silt formations 5%. The light post-glacial sediments are intensely washed out; therefore, the highly acidic and acidic soils dominate in these areas. In the relatively big region of the Tarnogrodzki Plateau, the percentage of highly acidic soils is 33%, acidic 33%, neutral 16% and there are no soils with a basic reaction. In the soils of the northern part of the Region, organic matter is subject to processes of intensive decomposition, which leads to the relatively fast mineralization. The content of humus in the surface horizon of these soils is, on average, from 1.27% in Roztocze to 1.88% in the Kolbuszowski Plateau.

The southern part of the Podkarpackie Region, covered by the *in situ* detritus of the Karpathian flysh, is characterized by a high content of heavy soils. In the Beskid Niski area, clay formations constitute 36%, loams 61% and the remaining

3% are silts. The soils derived from the flysh detritus have lower acidity than those derived from post-glacial sediments. In some regions, areas of basic reaction soils occur. In the region of Pogórze Jasielskie, adhering to Beskid Niski, the content of highly acidic soils is 33%, acidic 36%, while neutral and basic soils represent 18%. In the conditions of a more extreme climate and at higher humidity levels compared to the northern part of the Region, the greatest content of organic matter becomes humified. Thus, the content of humus in the soils of the southern part of the Region reaches 3.57% (in Beskid Niski).

The climate-flora-soil conditions promote the occurrence of the zonal brown soils in the Podkarpackie Region. Local rainfall and temperature, as well as the permeability of the parent rock differentiate the morphological picture of the brown soil profile, which is accompanied by further features of the other soil-formation processes (Table 1).

In the northern part of the Region, in the Kolbuszowski Plateau, the highest content is that of brown soils Haplic Cambisol – 51%, brown leached soils Haplic Cambisol (Eutric) – 19% and proper podzolic soils Haplic Podzol – 16%. In the southern part, in Beskid Niski, brown leached soils Haplic Cambisol (Eutric) represent 56% and the acidic brown soils Haplic Cambisol (Dystric) – 10%.

The content of sulphate sulphur in the soils of the selected regions of the Podkarpackie Region, measured in the surface horizon 0-20 cm was differentiated (Table 1). The highest mean values of $S\text{-}SO_4$ occurred in the soils of the northwestern part of the Region, in the Tarnogrodzki Plateau – 2.29 mg 100 g^{-1} of the soil, as well as in the Kolbuszowski Plateau – 2.02 mg 100 g^{-1}. The lowest mean values were observed in the southeastern part of the Region, in the soils of the Przemyskie Foothills - 0.87 mg 100 g^{-1} of the soil, Bukowskie Foothills – 1.03 mg 100 g^{-1} and the Lower San River Valley – 1.07 mg 100 g^{-1} (Table 1).

The collected analytical material, after verifying the counts, allowed for distinguishing three groups of uniform regions. The group with the lowest sulphate sulphur content in the soil (below 1.5) included Przemyskie Foothills, Bukowskie Foothills, Beskid Niski, Sanocko-Turczańskie Mountains and the Podkarpacka Proglacial Stream Valley. Higher sulphur contents (1.6-1.7 mg $S\text{-}SO_4$ g^{-1}) were found in the soils of the Western Bieszczady, Jasielsko-Sanocka Basin, Lower San River Valley and Jasielskie Foothills. The highest sulphate sulphur contents (above 1.8 mg 100 g^{-1}) were observed in the soils of the Kolbuszowski Plateau, Tarnogrodzki Plateau, Ciężkowicko-Strzyżowskie Foothills, Nadwiślańska Valley and Wisłoka Valley.

Motowicka-Teralak and Terelak [11] stated that the mean content of sulphate sulphur in Polish soils is 17.9 mg kg^{-1} of soil. Other research [17, 18] indicates much higher contents (up to 500 mg kg^{-1}) of this fraction of sulphur in the soils. Koter *et al*. [8] found from trace amounts to 15 mg $S\text{-}SO_4$ kg^{-1} of soil. Values similar to the above literature were obtained by Rejman-Czajkowska [12].

Wlaśniewski *et al*. [19], while investigating the soils of the Kolbuszowski region, stated that the measured mean content of sulphate sulphur 2.19 mg 100 g^{-1} is a low natural content, while in the soils of the Kolbuszowa county the value of 3.15 mg 100 g^{-1} is a high natural content. The content observed in the town of Zarębki (>3.5 mg 100 g^{-1}) was described as elevated due to anthropogenic pressure. According to these authors, this zonal differentiation is a result of the activity of local sources of SO_2 emission. Szulc *et al*. [16] investigated the content of sulphate sulphur according to the systems of soil cultivation and showed that the highest content of $S\text{-}SO_4$ in the soil (34 mg g^{-1}) occurred in the conditions of deep tillage performed every 5 years. The lowest content (27.2 mg g^{-1}) was found in the combination, in which simplified cultivation with direct sowing was used.

In the authors research on the soils of the Podkarpackie Region it was found that there was a great differentiation of the mean contents of sulphate sulphur depending on the genetic type of the soil. The highest means were found in grey-brown podzolic soils (Table 1), in which it was 2.00 mg 100 g^{-1} of soil. In acidic brown soils, this content was 1.91 mg 100 g^{-1} g and in proper black earth 1.78 mg 100 g^{-1} g. In the remaining soil types, these values were as follows: 1.75 mg in brown podzolic soils; 1.52 in brown leached soils; 1.50 in proper alluvial soils; 1.38 in chernozem alluvial soils; 1.35 in proper podzolic soils; 1.34 in proper chernozems; and 1.27 mg 100 g^{-1} of soil in proper brown soils.

The analysis of the variability on the verified count of the analytical material showed significant differences in the content of sulphate sulphur in the selected soil types of the Podkarpackie Region. Lower contents of sulphate sulphur were observed in brown leached soils (mean of 1.52 mg 100 g^{-1}), while a significantly higher content (1.73-1.93 mg 100 g^{-1}) was found in the uniform group of the following types: acidic brown, proper and podzolized brown, and proper and grey brown podzolic soils.

The content of sulphate sulphur is influenced by numerous processes occurring in the soil, such as the process of washing. Measurement of the loss of sulphur caused by washing is difficult due to the fact that the intensity of washing depends on many factors, such as: soil type; content of iron and aluminum oxides; concentration of sulphates; pH of the soil; and the amount of atmospheric precipitation [15]. In general, it is assumed that the process of washing of sulphur is the most intensified in sandy soil, which is related mainly to their low sorptive capacity [6]. The distribution of sulphate sulphur in the soil profile may be related to the process of pedogenesis. While investigating podzolic soils in the Tatra Mountains, Zadrożny *et al*. [20] showed that the sub-surface levels spodic contained much higher amounts of this element than the surface levels albic.

The high number of the analyzed soil samples allowed also a more detailed interpretation of the content of sulphate sulphur based on the basic physical-chemical properties. This interpretation is limited to the statistically significant relationships.

In the group of highly acidic soils, the mean content of sulphate sulphur was the highest – 2.02 mg 100 g^{-1} regardless of the type of the soil process or mezoregion (Fig. 2). In the group of acidic soils, it was 1.59 mg 100 g^{-1} and was higher than the sulphur content in the group of lightly acidic and neutral soils (which did not show significant differences), in which it was 1.42 and 1.24 mg 100 g^{-1} respectively.

In the soils of the following regions, a negative correlation between the content of sulphate sulphur and the soil reaction was found: Dynowskie Foothills (-0.25); Przemyskie Foothills (-0.25); Rzeszowskie Foothills (-0.30); Sanocko-Turczańskie Mountains (-0.40); Kolbuszowski Plateau (-0.21); Podkarpacka Proglacial Stream Valley (-0.44); and Lower San River Valley (-0.26). This corresponds with the results presented by Motowicka-Terelak and Terelak [11] in terms of the strong correlation between these soil properties. Singh *et al.* [14] explain that lowering the soil pH leads to an increase in the sorption of sulphate ions by the particles of the solid phase. Opposite results were obtained by Kulczycki and Patorczyk-Pytlik [9], who observed a significant positive relationship between the content of sulphate sulphur and the reaction in the 5-20 cm soil horizon (the reaction represented 12% in the assessment of the components of the variance).

In the soils of Western Bieszczady, a positive correlation between the content of sulphate sulphur and humus was stated. This is in accordance with the thesis of Eriksen *et al*. [3], who stated that the amount of easily soluble sulphates in the soil profile is dependent upon the content of organic matter. Diamond and Hanley [2] and Kulczycki and Patorczyk-Pytlik [9] indicated the high correlation between the content of sulphate sulphur and the organic carbon in the surface horizon (up to 20 cm). Similar relationship was observed by Terelak *et al.* [17].

Moreover, in the cultivated soils of Western Bieszczady, in the region characterized by one of the highest mean contents of humus (3.27%), the content sulphate sulphur was negatively correlated with the soil reaction. This relationship may be described by the following regression equation: $S\text{-}SO_4 = 3.70 + 0.13\%$ humus-0.38 pH. From the analysis of the soils of the Tarnogrodzki Plateau

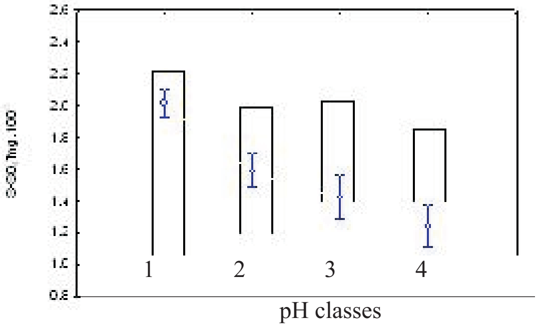

Fig. 2. The average standard deviation and content of sulphate sulphur in soils of Podkarpackie Province. Explanations: 1 – very acid soils, 2 – acid soils, 3 – weakly acid soils, 4 – neutral soils.

and Rzeszowskie Foothills, a positive correlation was observed between the content of sulphate and the content of the fraction of colloidal clay, which allowed to formulate the following regression equation: $S\text{-}SO_4$=1.41+0.04% of the fraction of colloidal clay. Jakubus and Czekała [5] and Koter *et al*. [8] did not find a relationship between the content of sulphate sulphur and the amount of washable parts.

Among the following soil types: proper podzolic; proper brown; leached brown; acid brown; and podzolized brown of the Podkarpackie Region, there was a negative correlation between the content of $S\text{-}SO_4$ and the pH. Moreover, in the grey-brown podzolic soils and acid brown soils, the content of sulphur sulphate was positively correlated with the humus content.

In the soils of the Podkarpackie Region, the mean content of sulphate sulphur in the 0-20 cm soil horizon is, on average, higher by about 10% than that of the 20-40 cm horizon. In the soils of the Dynowskie Foothills, in the 20-40 cm layer, the content of sulphur is negatively correlated with the pH and the regression equation is as follows: $S\text{-}SO_4$=2.35-0.17 pH. In addition, in the brown leached soils in that region, there was a negative correlation between the content of sulphate sulphur with the pH in both layers and a stronger relationship was observed in the surface horizon: $S\text{-}SO_4$=3.19-0.32 pH as compared to the 20-40 cm layer: $S\text{-}SO_4$=2.45-0.22 pH. In the Kolbuszowski Plateau mezoregion, in the 20-40 cm layer, there was a positive correlation between the content of sulphate sulphur with the content of the colloidal clay fraction, which allowed to formulate the following regression equation: $S\text{-}SO_4$=1.40+0.03% of the colloidal clay fraction. Investigating the relationships between the content of sulphate sulphur and the particular features of the soil types, it was stated that in the proper podzolic soils, in the surface horizon, the content of sulphate sulphur could be described with the following equation: $S\text{-}SO_4$=2.21-0.23 pH+0.04% of the colloidal clay fraction, while in the 20-40 cm layer the equation is: $S\text{-}SO_4$= 2.71-0.31 pH+0.03% of the colloidal clay fraction. In addition, in the surface horizon of the leached brown soils, a negative correlation between the content of sulphur and pH was stated, which is described by the following equation: $S\text{-}SO_4$=2.78-0.25 pH.

CONCLUSIONS

1. The content of sulphate sulphur in the 0-20 cm horizon in the soils derived from the flysh formation is highly differentiated: on average, 0.87 mg kg^{-1} in the Przemyskie Foothills to 2.00 mg kg^{-1} in the Ciężkowickie and Strzyżowskie Foothills.
2. In the soils derived from the sediments of the Karpathian Flysh, the content of sulphur is negatively correlated with their reaction, while in post-glacial sediments the sulphur content is not correlated with the pH.
3. The content of sulphate sulphur in the soils is positively correlated with the content of humus in Western Bieszczady and the content of the colloidal clay fraction in the Tarnogrodzki Plateau.

4. In the proper brown, acidic and podzolized, as well as proper podzolic and grey-brown podzolic soils, occurring in the Podkarpackie Region, there was no significant differentiation in the content of sulphate sulphur (1.73-1.93 mg 100 g^{-1}, on average). Less sulphur was stated in the leached brown soils – 1.52 mg 100 g^{-1}.

5. In the most highly represented soil types: brown leached; proper podzolic; and brown podzolized, regardless of the region, the content of sulphur could be described with the following multiple regression equations: S-SO_4=2.89-0.26 pH; S-SO_4=2.88-0.21 pH+2.02% colloidal clay fraction; S-SO_4= 2.90-0.24 pH.

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ZAWARTOŚĆ SIARKI SIARCZANOWEJ W RÓŻNYCH TYPACH GLEB PODKARPACIA

Celem badań była ocena zawartości siarki siarczanowej w różnych typach gleb woj. podkarpackiego. Zawartość S-SO_4 w glebach wytworzonych z fliszu karpackiego była bardzo zróżnicowana i wynosiła średnio od 0,87 g·kg^{-1} na Pogórzu Przemyskim do 2 g·kg^{-1} na Pogórzu Ciężkowickim i Strzyżowskim. W glebach wytworzonych z osadów fliszowych zawartość siarki siarczanowej była ujemnie skorelowana z odczynem. Zależności takiej nie stwierdzono w glebach wytworzonych z utworów polodowcowych.

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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).

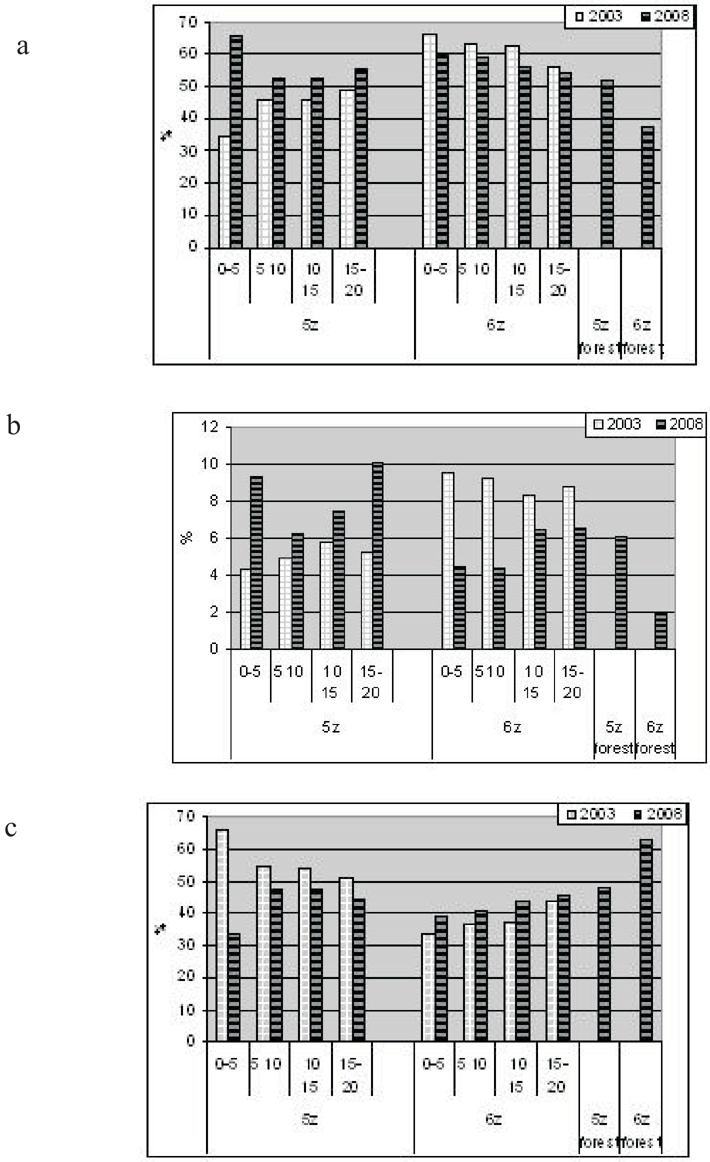

Fig. 1. Percentage of: a – C_{Py}, b – C_{Lwp}, c – C_R in C_{org}.

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.

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Soil Genesis

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CHARACTERISTICS OF SOIL ORGANIC MATTER IN ECTOHUMUS HORIZONS OF FOREST SOILS IN THE STOŁOWE MOUNTAINS**

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Abstract. This paper describes the fractional composition of humus substances and physico-chemical properties of ectohumus horizons in forest soils (Haplic Cambisols (Distric) and Albic Podzols) developed from various parent materials and in various forest sites: mountain mixed forest witch beech tree, spruce forest witch spruce monoculture, mountain mixed forest witch beech, sycamore maple and larch and mountain mixed forest witch spruce and larch. Reactions of the analyzed soils were strongly acidic. Organic C content was in the range of 21-48% and total N reached values between 0.68-1.63%. The fractional composition of humus substances was analyzed using the Tiurin method. Fraction Ia (extracted with 0.05 mol dm^{-1} H_2SO_4) constituted a rather insignificant part (1.03-3.63% of C_{org}) of humus compounds. Humus was dominated by fraction I (extracted with 0.1 mol·dm^{-1} NaOH) (27.4 - 42.5% of C_{org}). The ratio of C_{HA}:C_{FA} was within the range of 0.75-1.35 and increased in deeper organic subhorizons. Non-extracted C was within the range of 55.7-69.7% of C_{org}. In all the ectohumus samples investigated, the highest humification degree was found in the deepest organic subhorizon.

The amount and quality of organic matter and the directions of its transformation play an important role in the functioning of forest ecosystems [5, 6]. Plant remains that are present in forest soil horizons are a store of nutrients, determine their availability and determine ecosystem stability [3, 4]. The basic source of organic matter in forests is the overground fall of plants, trees and bushes, and ground cover, and also the withering of the underground parts of plants. Plant fall is

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an important element since a considerable amount of nutrients returns to the soils with the fall [18, 20]. Quantitative analysis of fractional composition of humus substances in forest soils of mountain areas has been presented in the works of Kowaliński *et al*. [15], Niemyska-Łukaszuk [19], Licznar and Mastalska-Cetera [16], Drozd *et al*. [2-4], Licznar *et al*. [17], and Jamroz [10,11]. In soils of the Stołowe Mountains, quantitative and qualitative studies concerning humus substances have so far not been conducted on a wider scale.

The aim of this paper is an attempt to determine the influence of tree stand species on the physico-chemical properties and fractional composition of humus substances of the ectohumus of selected types of mountain soils present in the area of the Stołowe Mountains National Park. Also, the properties of ectohumus under various geological conditions have been taken into consideration in the study.

MATERIAL AND METHODS

The study included the following subhorizons of ectohumus: Ol – raw, Of - fermentation, Ofh - detritus and Oh – epihumic of 2 profiles of podzols formed from Cretaceous sandstones (profile 1 and profile 2) and 2 profiles of acid brown soils formed from Permian sandstones (profile 3 and profile 4). The analyzed soils were accepted as Albic Podzols (profile 1 and profile 2) and Haplic Cambisols (Distric) (profile 3 and profile 4) following the WRB classification [22].

Profile 1. Mountain mixed forest with beech tree stand and ectohumus of moder type.

Profile 2. Spruce forest with spruce monoculture and ectohumus of mor type.

Profile 3. Mountain mixed forest with beech, sycamore maple and larch and ectohumus of mull-moder type.

Profile 4. Mountain mixed forest with spruce and larch tree stand, and ectohumus of moder-mor type.

Genetic soil horizons were separated according to Annex 1 of the Systematics of Polish Soils [21], where the following indices were determined: organic C_{org} using the Tiurin oxidometric method, pH using the potentiometry method in 1mol KCl dm^{-3} and in distilled water, the content of total N using the Kjeldahl method on a Buchi analyzer, total content of Ca^{+2} and Mg^{+2} dissolved in 70% $HClO_4$ and analyzed using the AAS method, fractional composition of humus substances using a modified Tiurin method [7] separating the following groups of humus substances:

- fraction Ia (fulvic) - substances passing to solution while treating the soil with 0.05 mol H_2SO_4 dm^{-3};
- fraction I - humic substances separated by multiple soil treatment with 0.1mol NaOH dm^{-3} and humic acids (C_{HA}) and fulvic acids (C_{FA}) were isolated.

Non-extracted C – including so-called post-extraction residue including non-humificated organic residues. This fraction was calculated from the difference: Non-extracted C = organic C - ($C_{fraction\ Ia} + C_{fraction\ I}$).

Absorbance with wavelengths of 464 and 665 nm was determined for humic acid extracts, and also the absorbance coefficients $A_{4/6}$ were calculated.

RESULTS AND DISCUSSION

The analyzed subhorizons of ectohumus, i.e. Ol, Of, Ofh and Oh, of profiles under beech tree, spruce monoculture or mixed forest differed both morphologically and as regards the analyzed physico-chemical parameters. The thickness of ectohumus was noticeably higher at sites where coniferous (spruce or spruce-larch) fall predominated, irrespective of soil type and bed-rock character. The reaction in all the profiles analyzed, according to forest soils classification [12], was determined as highly acidic and demonstrated lower pH values under spruce (profile 2) and spruce-larch tree stands (profile 4) (Table 1). Differences were also observed in terms of organic C content. Higher C_{org} contents were noted under spruce and spruce-larch tree stands where, due to the chemical composition of conifer needles rich in lignins, the ectohumus formed was less susceptible to

TABLE 1. PHYSICO-CHEMICAL AND CHEMICAL PROPERTIES OF SOILS

Profile No.	Soil horizon	Depth (cm)	pH		TOC	Ntot	C/N	Ca^{+2}	Mg^{+2}
			H_2O	1MKC1	(g kg^{-1})			(mg kg^{-1})	
Mountain mixed forest (beech tree) / Albic Podzols									
1	Ol	6-4	4.7	3.9	357	12.6	28	5 075	665
	Of	4-1	4.1	3.2	424	15.8	27	3 360	595
	Oh	1-0	3.8	2.8	281	11.6	24	1 950	1 045
Spruce forest (spruce monoculture) / Albic Podzols									
2	Ol	10-8	4.2	3.5	480	14.3	34	4 500	447
	Of	8-3	3.6	2.8	468	16.3	29	3 060	640
	Oh	3-0	3.6	2.3	231	8.3	28	1 160	805
Mountain mixed forest (beech, sycamore mapie, larch) / Haplic Cambisols (Distric)									
3	Ol	4-3	5.0	4.4	463	15.2	30	9 570	1 220
	Ofh	3-0	4.8	3.9	396	15.1	26	8 530	1 360
Mountain mixed forest (beech, larch) / Haplic Cambisols (Distric)									
4	Ol	10-9	4.3	3.7	472	13.6	35	7 020	1 050
	Of	9-7	3.8	3.0	456	14.9	31	6 440	1 210
	Oh	7-0	3.6	2.7	210	6.82	31	1 400	1 830

mineralization processes and was characterized by a wider C/N ratio when compared to ectohumus with a predominant deciduous fall. Lower content of organic C, and also a narrower C/N ratio in profiles under beech (profile 1) and beech-sycamore maple-larch tree stands (profile 3) are the result of an intense period of the mineralization process of plant fall that was more susceptible to decomposition. Maciaszek *et al*. [18] and Gonet *et al*. [9] noted that ectohumus, where predominant plant residues are spruce and pine needles, are usually characterized by base reaction, a high content of organic C, a low content of organic N and a wide C/N range reaching even values of 50 or more, especially in the Ol or Ofh subhorizons. This leads to a distinct increase in the abundance of organic matter at sites with a predominant coniferous tree stand, a fact which was also observed in the present study. The differences in pH values, amount of organic C and C/N ratio values observed both in ectohumus of podzols and acid brown soils confirm the thesis that physico-chemical features of ectohumus are substantially influenced by plant fall character, which may in particular be observed in profiles 1 and 2. Less clear differences in the content of organic C in profiles 3 and 4 are probably the effect of the addition of larch needles to beech and sycamore maple fall.

The analysis of the total content of Ca^{+2} and Mg^{+2} cations in subhorizons of soil ectohumus demonstrated a clear tendency towards a decrease in the amount of Ca^{+2} cations and an increase in the amount of Mg^{+2} cations in deeper layers (Table 1). In the case of calcium this is the result of its intense elution from subhorizons of soil ectohumus irrespective of plant fall, soil type and bed-rock character. The most abundant Ca^{+2} was ectohumus formed on acid brown soils. The rate of calcium elution was connected to ectohumus thickness. The lowest amounts of Ca^{+2} cations were accumulated in subhorizons Oh of ectohumus characterized by high thickness, and under a coniferous tree stand. The total content of Mg^{+2}, similar to the content of Ca^{+2}, was considerably higher in the ectohumus of acid brown soils when compared to podzols. Accumulation of Mg^{+2} cations was observed in the deepest subhorizons of ectohumus in all the analyzed sites, while the lowest amounts of Mg^{+2} were accumulated in ectohumus under spruce monoculture on podzol.

The differences in the amount of organic carbon, pH values and C/N ratios between the analyzed ectohumus samples influenced the differentiation in the contribution of particular fractions of humus compounds in the organic carbon pool. Quantitative changes of the analyzed fractions of humus compounds were seen very clearly between the analyzed subhorizons. The analysis of fractional composition demonstrated a low contribution of low-molecular, highly mobile organic compounds (fraction Ia) (Table 2). The highest content of this fraction was noted in raw subhorizons Ol with predominant residues of spruce and larch needles both in podzols and acid brown soils. The distinct decrease in the contribution of fraction Ia in fermentation subhorizons Of and their re-increase in epihumus subhorizons Oh confirms the mobility of those kinds of organic compounds. An increase in

TABLE 2. FRACTIONAL COMPOSITION OF HUMUS IN % OF ORGANIE C (TOC)

Profile No.	Soil horizon	TOC (g kg^{1})	Fraction Ia	Fraction I			CHA: CFA	C-non extracted	IH*	A 4/6
				C-extracted	CHA	CFA				
			(%)					(%)		
Mountain mixed forest (beech tree) / Albic Podz										
1	Ol	357	2.84	27.46	11.58	15.87	0.73	69.70	30.30	7.50
	Of	424	1.70	35.32	16.07	19.24	0.84	62.99	37.01	7.03
	Oh	281	1.81	42.48	23.93	18.55	1.29	55.71	44.29	6.41
Spruce forest (spruce monoculture) / Albic Podzols										
2	Ol	480	3.38	29.31	13.03	16.28	0.80	67.30	32.70	8.19
	Of	468	1.40	37.71	18.92	18.78	1.01	60.89	39.11	7.11
	Oh	231	1.50	39.28	20.71	18.57	1.12	59.22	40.78	6.78
Mountain mixed forest (beech, sycamore mapie, larch) / Haplic Cambisols (Distric)										
3	Ol	463	2.59	29.07	12.34	16.73	0.74	68.35	31.65	7.62
	Ofh	396	2.16	36.23	15.82	20.40	0.78	61.61	38.39	6.37
Mountain mixed forest (beech, larch) / Haplic Cambisols (Distric)										
4	Ol	472	3.63	29.46	12.62	16.83	0.75	66.92	33.08	8.04
	Of	456	1.03	36.01	17.99	18.02	1.00	62.96	37.04	6.65
	Oh	210	1.65	42.48	24.40	18.08	1.35	55.86	44.14	6.28

IH* – humification index (100%-C non extracted).

fraction Ia contribution was also observed in spruce woods of the Karkonosze [3, 15], in moder beddings of brown soils in the area of the Jaworowy Wood [10] and in mor beddings of podzols in the area of the Śnieżnik Mountains [11].

The dominant group in the fractional composition of humus compounds was represented by fraction I. The contribution of fraction I, in all analyzed profiles, increased from subhorizon Ol towards Oh, according to the humification index (HI). An increase in the contribution of fraction I, C_{HA} fraction and also the value of the C_{HA}:C_{FA} ratio in subhorizons pF, Ofh and Oh, irrespective of the character of plant residues, was also emphasized in the study by Dziadowiec [6]. The lowest values of the C_{HA}:C_{FA} ratio in subhorizons Ol are connected first of all to an inflow of fresh organic matter to the soil, which leads to formation of a considerable amount of organic connections of a simple molecular structure [1, 2]. The lowest humification degree in raw horizons Ol was confirmed by the highest contribution of non-extracted carbon fraction including above all non-humificated plant residues. The observed decrease in non-extracted carbon fraction content in deeper ectohumus horizons has already been noted by Kowaliński *et al.* [15], Niemyska-Łukaszuk [19], Drozd *et al.* [4], Gonet *et al.* [9] and Jamroz [10, 11]. The relatively higher value of the humification index HI in ectohumus under spruce and spruce-larch tree stands, especially in horizons Ol, was mainly connected to the higher amount of organic C, and also to the higher contribution of low-molecular organic compounds (fraction Ia). Similar to the cases of both fraction I and C_{HA} of that fraction, a distinct differentiation in non-extracted carbon fraction content between ectohumus of podzols and acid brown soils could not be demonstrated.

One of the basic physico-chemical properties determining the internal structure of humic acids is optical density. As was demonstrated by Kononowa [14], optical density of humus substances depends on the ratio of carbon content in the aromatic nucleus to carbon in lateral radicals. The author revealed that 'younger', as regards their chemistry, humic acids are characterized by lower optical density when compared to 'mature' acids. This results from a high condensation of the aromatic nucleus in 'mature' humic acids, and the predominance of lateral chains in 'younger' acids. Changes in the optical density of sodium humates solutions from subhorizons Ol, Of and Oh were expressed by absorbance values with wavelengths of 465 nm and 665 nm, and the absorbance ratio A_{465}:A_{665} ($A_{4/6}$), (Table 2). It is accepted that the A_{465} value determines the absorbance of the substances in an initial humification stage, and A_{664} of the substances of a high humification degree [8, 13]. Lower values of the ratio of absorbance $A_{4/6}$ in subhorizons Of, Ofh and Oh, when compared to Ol, confirm an increase in the degree of humification of horizons lying deeper in all the sites analyzed. The calculated values of the ratio of absorbance $A_{4/6}$ indicate, moreover, that ectohumus of soils on the beech site (profile 1) and on the beech-sycamore maple-larch site (profile 3) is characterized by the presence of humic acids of higher molecular weight and a higher degree of condensation of aromatic structure when compared to humus of soils in the spruce (profile 2) and the spruce and larch sites (profile 4).

CONCLUSIONS

1. Differentiated forest habitats with beech tree, spruce tree or mixed forest with various kinds of formed forest humus with clearly marked raw Ol, fermentation Of, detritus Ofh and epihumic Oh are observed in the area of the Stołowe Mountains.

2. The analyzed ectohumus subhorizons under coniferous, deciduous or mixed tree stands differed in terms of their physico-chemical parameters. Higher values of organic C content and a wider C/N ratio show a flower mineralisation process and a higher accumulation of organic matter on spruce and spruce-larch sites when compared to beech and beech-sycamore maple-larch sites.

3. Quantitative analysis of fractional composition did not demonstrate any distinct differentiation between humus compounds of Ol, Of, Ofh and Oh subhorizons in the analyzed ectohumus. Only negligible higher amounts of released low-molecular organic connections (fraction Ia) were noted in raw subhorizons Ol with predominant residues of spruce and spruce and larch needles both on podzols and acid brown soils.

4. The higher value of the humification index HI in ectohumus under spruce and spruce-larch tree stands, especially in Ol horizons, was first of all connected to a higher content of organic C, and also to the higher contribution of low-molecular organic compounds.

5. Clear differentiation in the fraction of humus compounds was noted within the particular soil profiles. An increase in C_{HA}:C_{FA} ratio, decreases in non-extracted carbon fraction contributions, and a lower value for the absorbance ratio $A_{4/6}$ in subhorizons Ofh and Oh prove the higher intensity of the humification process in those horizons when compared to subhorizons Ol.

6. The humus formed under deciduous and mixed tree stands is characterized by the presence of humic acids of higher molecular weight and a higher degree of aromatic structure condensation when compared to humus of soils under coniferous tree stands, which is reflected by lower values for the absorbance ratio $A_{4/6}$.

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CHARAKTERYSTYKA SUBSTANCJI ORGANICZNEJ POZIOMÓW EKTOHUMUSOWYCH GLEB LEŚNYCH GÓR STOŁOWYCH

Badania obejmowały analizę ilościową substancji humusowych na tle właściwości fizykochemicznych próchnic nadkładowych gleb leśnych (Haplic Cambisols (Distric) and Albic Podzols) występujących na terenie Parku Narodowego Gór Stołowych. Materiał do badań pobrany został z obszarów zróżnicowanych pod względem składu gatunkowego drzewostanów: bór mieszany górski, bór świerkowy, las mieszany górski. W zabranym materiale glebowym oznaczono: pH w 1 mol KCl·dm^{-3}, zawartość C_{org}, zawartość Nog, całkowitą zawartość Ca^{+2} and Mg^{+2} oraz skład frakcyjny związków próchnicznych metodą Tiurina. Odczyn analizowanych gleb był silnie kwaśny. Zawartość C_{org} kształtowała się w zakresie od 21 do 48 %, a zawartość Nog w zakresie 0,68 – 1,63 %. W składzie związków próchnicznych niewielki udział stanowiła frakcja Ia (1.03 - 3.63 % C_{org}). Wśród związków próchnicznych dominującą grupą była frakcja I, której udział mieścił się w zakresie 27,4 – 42,5% C_{org}. Wartość stosunku Ckh:Ckf kształtowała się w zakresie 0,73 – 1,35 i wzrastał w głębiej zalegających podpoziomach ektopróchnicy. Udział węgla poekstrakcyjnej pozostałości mieścił się w zakresie 55,7 – 69,7% C_{org}. We wszystkich badanych ektopróchnicach najwyższy stopień humifikacji występował w najgłębszych jej podpoziomach.

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Soil Genesis

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PROPERTIES OF HUMUS HORIZONS OF SOILS DEVELOPED IN THE LOWER MONTANE BELT IN THE TATRA MOUNTAINS**

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Abstract. The aim of the study is to evaluate differences occurring in the soil humus horizons between different types of forests. Soil samples were collected from spruce monoculture and natural beech sites within the lower montane zone in the Tatra Mountains. They were analyzed for organic carbon (OC), loss on ignition in ectohumus horizons, pH, fractional composition of organic matter and cellulose decomposition rate. The objects of investigation are two profiles representing Rendzic Leptosols under spruce and beech, one profile formed on cover bed, which can be classified as Haplic Leptosol under spruce forest and one Haplic Cambisol under the beech site. It is shown that different tree species strongly affect features of both ectohumus and endohumus horizons. This is visible in morphology of humus horizons as well as humus fraction composition which leads to acidification and to a descending cellulose decomposition rate. Another factor controlling features of humus horizons is parent material. It seems to be possible to separate effects which are results of vegetation and parent material features.

This paper is a part of wider investigations continuing estimating the influence of spruce on the soil properties in the Tatra Mountains. A part of that investigation is to compare the humus horizons developed under spruce monoculture and natural beech forest. Many authors claim that coniferous trees affect the soil properties leading to their acidification [1, 2, 12, 20] and intensify weathering processes [2]. The depth and intensity of those processes depend on the parent material features and the time of duration.

The humification rate and humus features depend on the plant material. The chemical composition of a plant remnants leads to releasing different amounts of humus substances to the soil's environment. Needles of coniferous trees which

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contain more lignins and less nitrogen release more humus acids in comparison to broadleaf trees [6, 11]. On the other hand, decomposition of needles causes a slowdown of the mineralization processes which leads to development of thick row humus horizons [10]. Production of humic acids is claimed to be the main process causing acidification [1, 4, 12]. The depth of the acidification depends on the type of parent material and age of the monoculture [1, 2, 12]. In some cases acidification by coniferous trees can lead to development podzolization processes [5].

The fractional composition of humus substances is strongly connected with the type of parent material [15, 17]. Generally speaking, in soil developed on limestone, the ratio of humic acids to fulvic acids is relatively high in comparison to soils formed on other materials, which is connected with higher biological activity in Rendzic Leptosols. The mentioned authors reported that fractional composition of humus substances differs within similar limestone parent material. Binding humic acids by abundant active carbonates protect them from further transformation and decreases the humic to fulvic acids ratio [15, 17].

The aim of this paper is to compare the humus horizons developed under spruce monoculture and natural beech sites in the lower forest belt in the Tatra Mountains. The second question is whether it is possible to determine these differences from the influence of parent material.

MATERIAL AND METHODS

Forest soil samples from under natural beech (*Fagus silvatica*) sites and spruce (*Picea abies*) monocultures were taken into consideration. Four profiles are located in the lower montane belt of the Tatra Mountains in Dolina Chochołowska and Dolina Białego. Characteristics of the profiles are given in Table 1. Profiles Nos 5 and 6 are classified as Rendzic Leptosols with a high amount of $CaCO_3$. Profile No. 3 is classified as Haplic Leptosol and profile No. 1 is classified as Cambisol, both developed on sediments with a relatively small amount of $CaCO_3$ covering limestone. The analyzed soils are representative of the lower montane belt in the West part of the Tatra Mountains [14].

The following were assayed in the soil samples:

- pH in water and 1M KCl (1:2.5);
- organic carbon content (OC), with the Tiurin method modified by Oleksynowa;
- loss on ignition at 550°C;
- fractional composition of organic with the Duchafour and Jacquin method modified by Skłodowski [22, 24] in endohumus horizons (A) and adjacent ectohumus subhorizons (Of, Ofh). This method allows dividing density fractions: free humus fractions (the light one) and bound with mineral particles (the heavy one). It enables measuring insoluble fraction content represented by

humines and non-extracted strong mineral-organic complexes as well as non-humus material (residuum) [16]. In following extractions, the humus acids with different polymerization index and degree of binding with the mineral part of soil are released. These are the most active fulvic and humic acids which are claimed to be responsible for podzolization processes in some kind of soils [22] in the first extraction (I). In the second and third extraction (II, III) there are more stable acids (Table 4). As unbound with mineral particles, humic acids released from free fraction, especially the fulvic ones, can be treated as relatively moveable;

– cellulose decomposition using cellulose filters method. As an accurate factor of biological activity, the cellulose filter method was used for the ectohumus horizons [3]. Cellulose filter decomposition was measured in 10 replicates in two analyzed soils – Cambisol under the beech site and Haplic Leptosol under the spruce forest. Cellulose filters were placed in fermentation sub-horizon (Of) in profile No. 1, and fermentation-epihumus sub-horizon (Ofh) in profile No. 3.

TABLE 1. POINTS OF INVESTIGATION

Profile No.	Location	Soil (WRB, 2006)	Parent material	Vegetation	Type of humus horizon
1	Dolina Białego, 980 m a.s.l., slope 10-15°N	Haplic Cambisol (Dystric)	Shales and sandstones on limestones	*Dentario glandulosae-Fagetum*	Moder-mull
3	Dolina Chochołowska, 960 m a.s.l., slope 8-10°N	Cambic Leptosol (Calcaric, Skeletic)	Shales and sandstones on limestones	*Piceetum* (adm. *Abies alba*)	Protomor
5	Dolina Białego, 970 m a.s.l., slope 20-25°W	Rendzic Leptosol (Eutric, Skeletic)	Dolomites, limestones	*Dentario glandulosae-Fagetum*	Moder-mull
6	Dolina Białego, 1 070 m a.s.l., slope 30° W	Rendzic Leptosol (Eutric, Skeletic)	Dolomites, limestones	*Piceetum* (*adm.Acer pseudoplatanus, Fagus silvatica, Picea abies, Sorbus aucuparia*)	Moder-mor

RESULTS

Basic features of soils

Basic features of analyzed soils with humus horizons are given in Table 2. The thickness of ectohumus horizons is comparable to profiles 1,3,5 and 6 irrespective of the tree species and measure 6 cm in profiles 1, 3, 5 and 9 cm in profile 6.

Differentiation between analyzed horizons is visible in the sequence of ectohumus sub-horizons as well as morphology of endohumus horizons.

The organic matter content within ectohumus horizons ranges from approx. 90% in the uppermost weakly decomposed leaf and fermentation sub-horizons (Ol, Of) of all profiles to approx. 30% in well-humificated fermentative-humic (Ofh) sub-horizons in Rendzic Leptosols (Table 2). Organic carbon content within endohumus horizons Ah ranges from approx. 3% to approx. 4%.

Morphological features and pH of the ectohumus and endohumus horizons presumed classifying them as moder-mull (profiles 1, 5), moder-mor (profile 6) and protomor (profile 3) [13].

Cellulose decomposition

The amount of decomposed cellulose within a 10 week period during the growing season (VI-X) was measured. The results are given in Table 3: in the Cambisol under beech on average (from 10 replicates) 64% of all cellulose was decomposed; in the profile no. 3 under spruce that amount was on average 47%.

Fractional composition of humus

The results of fractional composition of humus are given in Table 4. In Table 5 the main indexes of humification process are given.

Ectohumus horizons

Humification index in analyzed ectohumus horizons range from 2.27 to 19.50%. The fulvic acids prevail on humic acids in all analyzed profiles among the humus acids extracted from ectohumus horizons. The Ch/Cf ratio range from 0.32 to 0.64 and is higher under spruce forest (0.44-0.64) than under the beech site (0.32-0.35).

There are more humus acids released from spruce litter than from beech leaves. The important fact is that fulvic acids of the first and the second extraction in the light fraction prevailed (Fig. 1). This means that higher amounts of movable reactive fractions are released from spruce litter than from the beech litter. Fulvic acid content ranges from 0.56 and 0.58% under beech and 0.70 and 0.86% under spruce. Humic acid content was the same in both soils under beech (0.19%) and higher in soils under spruce (0.29 and 0.50%).

TABLE 2. SELECTED PROPERTIES OF SOILS

Profile No.	Horizon	Depth (cm)	Total organic carbon (%)	Organic matter (%)	eq$CaCO_3$ (%)	pH	
						Water	1M KCl
1	Ol	0-1		95.2		5.3	4.5
	Of	1-6		82.9		5.0	4.3
	Ah	6-15	3.02		0.16	4.8	3.6
	AB	15-30	0.56		0.24	5.1	3.7
	Bw	30-55	0.34		0.24	5.2	3.9
	B2	55-80	0.33		0.44	5.4	4.0
	BC1	80-100	0.24		0.21	5.5	4.0
	BC2	100-120	0.37		0.35	5.6	4.2
3	Of	0-2		90.9		4.0	3.1
	Ofh	2-6		56.3		3.6	2.8
	Ah	6-10	4.15		0.56	4.3	3.3
	B1w	10-20	1.58		1.10	4.9	3.7
	B2w	20-35	1.17		0.92	6.7	5.8
	BC1ca	35-50	1.38		2.42	7.4	6.9
	BC2ca	50-(70)	1.35		11.15	7.6	6.9
5	Ol	0-2		92.3		6.4	5.7
	Of	2-5		89.5		6.6	5.9
	Ofh	5-6		37.0			
	A1h	6-20	4.42		54.57	7.9	7.5
	A2	20-28	2.81		57.80	7.8	7.3
	AC1ca	28-35	1.96		62.97	7.9	7.6
	AC2ca	35-(45)	0.67		76.95	8.2	7.9
6	Olf	0-2		88.1		5.6	4.6
	Of	2-4		75.4		4.8	4.2
	Ofh	4-9		33.5		6.0	5.7
	A1h	9-15	4.38		29.25	7.7	7.0
	A2	15-25	1.86		46.31	7.9	7.2
	A3	25-35	1.36		38.18	8.0	7.2
	AC1Ca	35-40	0.90		48.66	8.1	7.3
	AC2Ca	40-(45)	0.85		57.97	8.0	7.3

TABLE 3. THE RATE OF CELLULOSE DECOMPOSITION

Profile No.	Rate of cellulose decomposition within 10 weeks - average (%)
1	63.80
3	46.83

TABLE 4. FRACTIONS OF HUMUS COMPOUNDS

Horizon (depth, cm)	Organic carbon (%)	Free fraction						Bound fraction								Σ Kh	Σ Kf	Humines	Residuum
		Humic acids (Kh)			Fulvic acids (Kf)			Humic acids (Kh)				Fulvic acids (Kf)							
		I	II	Σ	I	II	Σ	I	II	III	Σ	I	II	III	Σ				
In relation to carbon content (%)																			
Profile No. 1. Haplic Cambisol (Dystric), beech forest																			
Of 1-6	48.05	0.28	0.07	0.35	0.45	0.54	0.99	0.00	0.00	0.04	0.04	0.03	0.02	0.08	0.13	0.39	1.12	0.75	97.74
Ah 6-15	3.02	0.91	1.11	2.02	1.42	0.83	2.25	0.93	0.65	2.32	3.90	6.49	3.18	5.10	14.77	5.92	17.03	49.82	27.23
Profile No. 3. Cambic Leptosol (Calacaric, Skeletic), spruce forest																			
Ofh 2-6	32.68	0.19	0.70	0.89	0.77	1.19	2.07	0.00	0.00	0.00	0.00	0.03	0.00	0.02	0.05	0.89	2.02	0.57	96.52
Ah 6-10	4.15	1.69	1.10	2.79	1.69	1.44	3.13	2.26	1.76	2.66	6.71	11.39	4.73	8.41	24.53	9.49	27.67	42.00	20.84
Profile No. 5. Redzic Leptosol (Eutric, Skeletic), beech forest																			
Ofh 5-6	21.48	0.22	0.34	0.56	0.70	1.14	1.84	0.05	0.07	0.17	0.29	0.32	0.16	0.36	0.84	0.86	2.67	3.30	93.17
Ah 6-20	4.42	0.00	0.00	0.00	4.09	2.60	6.69	0.77	0.77	1.52	3.06	3.52	1.52	2.93	7.97	3.05	14.66	57.08	25.21
Profile No. 6. Rendzic Leptosol (Eutric, Skeletic), spruce forest																			
Ofh 4-9	19.41	0.24	1.05	1.29	1.65	0.12	1.77	0.37	0.00	0.79	1.16	0.79	0.77	0.71	2.27	2.58	4.03	12.88	80.51
Ah 9-15	4.39	4.82	0.00	4.82	0.80	0.40	1.20	1.44	0.00	1.92	3.36	4.48	3.31	1.36	9.15	8.22	10.36	61.13	20.29

TABLE 4. CONTINUATION

Horizon (depth, cm)	Organic carbon (%)	Free fraction						Bound fraction								Σ Kh	Σ Kf	Humines	Residuum
		Humic acids (Kh)			Fulvic acids (Kf)			Humic acids (Kh)				Fulvic acids (Kf)							
		I	II	Σ	I	II	Σ	I	II	III	Σ	I	II	III	Σ				
In relation to soil mass (%)																			
Profile No. 1. Haplic Cambisol (Dystric), beech forest																			
Of 1-6	48.05	0.14	0.03	0.17	0.22	0.26	0.48	0.00	0.00	0.02	0.02	0.01	0.01	0.04	0.06	0.19	0.54	0.36	46.96
Ah 6-15	3.02	0.03	0.03	0.06	0.04	0.03	0.07	0.03	0.02	0.07	0.12	0.20	0.10	0.15	0.45	0.18	0.52	1.50	0.82
Profile No. 3. Cambic Leptosol (Calacaric, Skeletic), spruce forest																			
Ofh 2-6	32.68	0.06	0.23	0.29	0.25	0.39	0.64	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.02	0.29	0.66	0.19	31.54
Ah 6-10	4.15	0.07	0.05	0.12	0.07	0.06	0.11	0.09	0.07	0.11	0.27	0.47	0.20	0.35	1.02	0.39	1.15	1.74	0.87
Profile No. 5. Redzic Leptosol (Eutric, Skeletic), beech forest																			
Ofh 5-6	21.48	0.05	0.07	0.12	0.15	0.24	0.39	0.01	0.02	0.04	0.07	0.07	0.04	0.08	0.19	0.19	0.58	0.71	20.00
Ah 6-20	4.42	0.00	0.00	0.00	0.18	0.12	0.30	0.03	0.03	0.07	0.13	0.16	0.07	0.13	0.36	0.13	0.65	2.53	1.11
Profile No. 6. Rendzic Leptosol (Eutric, Skeletic), spruce forest																			
Ofh 4-9	19.41	0.05	0.20	0.25	0.32	0.02	0.34	0.07	0.03	0.15	0.25	0.15	0.15	0.14	0.44	0.50	0.78	2.50	15.63
Ah 9-15	4.39	0.21	0.00	0.21	0.04	0.02	0.06	0.06	0.00	0.08	0.14	0.20	0.15	0.06	0.41	0.35	0.47	2.68	0.89

TABLE 5. SELECTED INDICATORS

Horizon (depth cm)	Total organic carbon (%)	Humification index	Ch/Cf ratio	Rate of carbon in fraction	
				Free	Bound
Profile No. 1. Haplic Cambisol (Dystric), beech forest					
Of 1-6	48.05	2.27	0.35	0.65	0.10
Ah 6-15	3.02	72.77	0.35	0.13	0.57
Profile No. 3. Cambic Leptosol (Calacaric, Skeletic), spruce forest					
Ofh 2-6	19.41	3.65	0.44	0.99	0.02
Ah 6-10	4.39	79.15	0.34	0.33	1.29
Profile No. 5. Rendzic Leptosol (Eutric, Skeletic), beech forest					
Ofh 5-6	32.68	6.84	0.32	0.51	0.26
Ah 6-20	4.15	74.79	0.20	0.30	0.42
Profile No. 6. Rendzic Leptosol (Eutric, Skeletic), spruce forest					
Ofh 4-9	21.48	19.50	0.64	0.59	0.66
Ah 9-15	4.42	79.71	0.74	0.27	0.55

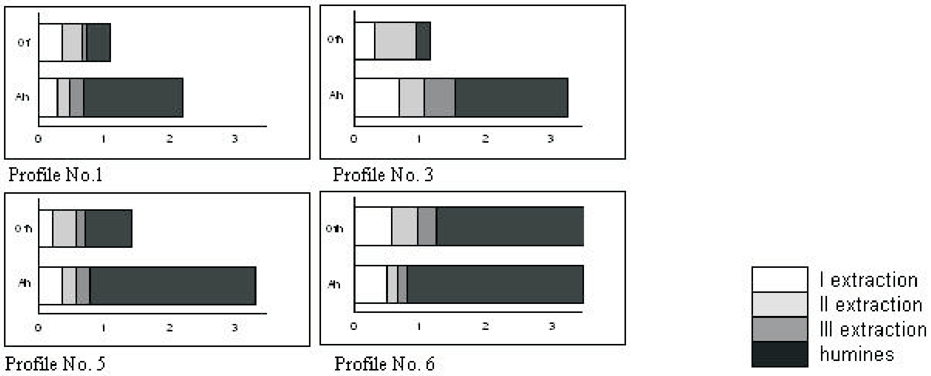

Fig. 1. Carbon content of following extractions in relation to soil mass (%).

Humines content is less than 1% in ectohumus horizons of soils developed on parent material with a small amount of $CaCO_3$. In both Ofh horizons of Rendzic Leptosols it is higher. Humines content in Ofh subhorizon in profile 6 is on average 13% of organic carbon content (Table 5) and is significantly higher in comparison to other analyzed ectohumus subhorizons.

Endohumus horizons

In the endohumus horizons the humification index ranges from 72.77% in Cambisol formed under the beech site to 79.71% in Rendzic Leptosol under spruce (Table 5).

The amount of the most movable humus acids dissoluted in the first extraction (I) is significantly higher in A horizons of profiles developed under spruce than under beech. The amount of those fractions range from 0.70% in Haplic Leptosol and 0.51% in Rendzic Leptosol under spruce to 0.30% in Haplic Cambisol and 0.37% in Rendzic Leptosol under beech (Fig. 1). Fulvic acid content is the highest in Haplic Leptosol under spruce – 1.15% in soil mass compared to less than 0.8% in other soils. Fulvic acids prevailed on humic acids.

The amount of humines ranges from 57-61% of organic carbon content in Rendzic Leptosols to 42-49% in Cambisol and Rendzic Leptosol (Table 4).

DISCUSSION

The presented results confirm early observations demonstrating specific features of organic and humus horizons in the mountain soils [9, 19, 21].

In the ectohumus horizons, pH is clearly connected with tree species. It can be observed that the spruce litter is significantly more acid than the beech litter independently on parent material. The acidification effect is also visible in endohumus horizons (Table 2).

Results of cellulose decomposition show that one kind of biological activity under spruce is noticeably lower than under beech. The results for spruce are more comparable to those from a higher montane belt in the Tatra Mountains – 41-44%, while those from under beech are similar to beech forest in the Gorce Mountains – 61% and just slightly lower than in the mixed stand in the Carpathian Foothills – 71% [7].

Humification indexes in analyzed profiles in both ectohumus and endohumus horizons are significantly lower than in comparable forest soils in the Świętokrzyskie Mountains for both Rendzic Leptosols and Cambisols [16,21]. This is probably the result of the harsh climate slowing down the organic matter decomposition processes in the Tatra Mountains [8].

Within ectohumus horizons a higher Ch/Cf ratio under spruce than under beech can be observed. Our investigations confirmed that needle decomposition leads to the production of more humic acids than leaves [10, 11]. This could be partly explained by the fact that coniferous' needles produce more bitumines than leaves, which increase the humic acid amount in the Douchafour and Jacquin method.

In endohumus horizons, the Ch/Cf rate in analyzed Rendzic Leptosols is significantly higher under spruce than under beech. In Rendzic Leptosol under spruce the Ch/Cf rate is 0.74 and is similar to values in some rendzinas with a high amount of calcium carbonate [15, 17, 19]. In Rendzic Leptosol under beech the Ch/Cf rate is 0.20 and is relatively low, but quite similar to AC horizons in Rendzic Leptosols from the Tatra Mountains [19]. Active carbonate content was not measured, but the content of calcium carbonate in this profile is extremely high (on average 55%) and comparable to AC horizons analyzed by the mentioned author. The low Ch/Cf ratio can be explained by binding humus acids, especially humic ones with clay minerals with the presence of a high amount of $CaCO_3$, which was reported by many authors [15, 17]. This can be supported by the fact that in comparison to ectohumus horizons, the amount of humic acids in endohumus horizons is significantly lower in both soils classified as Rendzic Leptosols, while in soils with a low amount of calcium carbonates differences are rather small with no visible tendency. On the other hand, the amount of humic acids under beech is lower than under spruce which can shape the Ch/Cf ratio.

Some authors [11, 15, 17] observed a decrease in the Ch/Cf ratio in transition to mineral horizon in the forest soils. Gonet *et al*. [11] claim that it is connected with displacement of movable fulvic acids into deeper soil horizons. In our investigation a decreasing Ch/Cf rate with a simultaneous increase in fulvic acids was observed in the one profile – Haplic Leptosol under spruce. Besides this profile, there is no visible tendency in transition from ectohumus to endohumus horizons. In relation to whole carbon content, the fulvic acid content is higher in Haplic Leptosol and Haplic Cambisol than in Rendzic Leptosols, which is connected with lower amounts of humines in those profiles.

As mentioned before, there is more humus acid release from spruce litter than beech litter, and fulvic acids of the first and the second extraction in the free fraction prevailed. This means that higher amounts of movable reactive fractions are released from spruce litter than from the beech litter. Licznar *et al*. [18] did not observe any differences in the amount of free fractions between different land use (arable land and meadows). They just observed a significant decrease in its amount with increasing contents of calcium carbonates and clay minerals. Our observations suggest that in contrast to those agricultural soils, vegetation type has first-rate meaning in free fraction content in the forest soils. It should be mentioned that those authors used the Kononowa and Bielczikowa method.

According to Gonet *et al*. [11], fulvic acids have a tendency to move down through the soil profile. Our observation suggests that the acids of fraction release in the first extraction (both humic and fulvic) move down the profile. The amount of humus acids dissoluted in the first extraction is significantly higher in A horizons of profiles developed under spruce than under beech.

Humines content in ectohumus horizons is relatively low. Higher humine content in both Rendzic Leptosols is probably a result of limestone admixture in those sub-horizons. Within endohumus horizons, humines content is significantly higher in Rendzic Leptosols than under Haplic Leptosol or Cambisol. Values of humines content are comparable to A horizons of Rendzic Leptosols from the Świętokrzyskie Mountains and are even higher than humines content in forest soils, but similar to arable soils [17]. Values for Haplic Leptosol and Cambisol are similar to Cambisols from the Świętokrzyskie Mountains. This can be explained by binding humus acids (especially humic acids) with clay minerals with an abundance of calcium cation [16, 17, 18]. A higher amount of humines in Rendzic Leptosol under spruce than under beech can be caused by a higher amount of humic acids released from spruce litter.

Our observations allow claiming that fractional composition of both ectohumus and endohumus horizons are determined primarily on the type of organic matter (litter). The key difference between spruce and beech is the amount of humus acids, especially moveable fraction which is higher under spruce than under the beech site. The most moveable acids containing both humic and fulvic ones migrate down the profile from O to A horizons causing acidification in both Rendzic Leptosols and soils with small amounts of carbonates in their uppermost parts. Differences observed between a similar type of litter, visible in different amounts of humines and humus acids of third extraction, can be the result of an admixture of calcareous material in Ofh subhorizons in both soils classified as Rendzic Leptosols. In endohumus horizons the influence of parent material is more significant than in ectohumus horizons and is especially visible in high amounts of humines content. The release of moveable humic acids leads to acidification visible in ectohumus and endohumus horizons. Biological activity in spruce litter is lower than in beech litter which results in the analyzed profiles to form ectohumus horizons with more features in its preliminary stage.

CONCLUSIONS

1. Tree species strongly affect properties of both ecotohumus and endohumus horizons in analyzed soils independent of the type of parent material.
2. One index of biological activity under spruce is significantly lower than under beech. The rate of cellulose decomposition under spruce is approx. 15% lower than under beech.
3. Soils under beech and spruce differ in humus fractional composition. The most important difference is the amount of humus acids, especially moveable fraction which is higher under spruce than under the beech site. This leads to acidification humus horizons under spruce.

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WŁAŚCIWOŚCI POZIOMÓW PRÓCHNICOWYCH GLEB REGLA DOLNEGO W TATRACH

Celem badań było określenie różnic pomiędzy poziomami próchnicowymi wykształconymi w glebach pod różnymi lasami. Próbki gleb zostały pobrane pod monokulturą świerka i naturalnym zbiorowiskiem buczyny karpackiej w reglu dolnym Tatr. Przeprowadzone zostały analizy następujących właściwości gleb: zawartość węgla organicznego, strata żarowa w poziomach nadkładowych, odczyn, skład frakcyjny połączeń próchnicznych oraz tempo rozkładu celulozy w poziomach próchnicowych. Obiekt badań stanowią cztery profile glebowe: dwa profile wykształcone na skałach węglanowych (Rendzic Leptosols) pod bukiem i świerkiem, oraz dwa wykształcone z utworów pokrywowych – Haplic Leptosol pod świerkiem i Haplic Cambisol pod bukiem. Wyniki badań wskazują na to, że gatunek drzewa silnie wpływa na cechy poziomów ekto- i endohumusowych. Jest to widoczne w morfologii poziomów humusowych oraz składzie frakcyjnym połączeń humusowych. Prowadzi to do zakwaszenia tych poziomów oraz spowolnienia tempa rozkładu celulozy. Czynnikiem, którego wpływ na cechy poziomów próchnicowych da się wyodrębnić, pomimo silnego wpływu roślinności, jest skała macierzysta.

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Soil Genesis

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MORPHOLOGY AND CHEMICAL PROPERTIES OF PLOUGH HORIZONS OF SOILS IN VARIOUS SLOPE POSITIONS**

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Abstract. Studies on morphological features and chemical composition of Ap horizons of soils located on gentle Narew valley-sides were carried out. The Luvisols with a texture of loamy sands and sandy loams are developed on the slope shoulder while the Mollic Gleysols of a similar texture with deposits to 110 cm thick are located on the footslope. The soil particle size distribution and total nitrogen (TN), total porosity (TP) and $K_{H_2SO_4-H_2O_2}$ content in both slope positions are similar. The mean TN, TP and $K_{H_2SO_4-H_2O_2}$ content on the slope shoulder is 0.94, 0.36 and 1.26 g kg^{-1}, respectively, while soils on the footslope are characterized with a mean content of total nitrogen, phosphorus and potassium of 1.15, 0.35, and 1.17 g kg^{-1}, respectively. Plough horizons of soils located on the footslope are more acidic with higher C_{org} content. The mean exchangeable acidity in deluvial soils (4.20 cmol(+) kg^{-1}) is higher than in soils located in upper slope positions (2.92 cmol(+) kg^{-1}). Similar texture of soils in both slope positions as well as thick deluvial deposits on the footslope is evidence of tillage erosion as the main factor of soil downslope translocation on these gentle slopes.

Agriculture is one of the main drivers of unnatural soil erosion, since many farming practices are soil-unfriendly, causing soils on arable lands more prone to erosion compared with natural undisturbed ecosystems. Soil erosion is a major cause of soil degradation in arable land, affecting soil properties and landscape processes such as nutrient redistribution, pesticide fate and greenhouse gas emission [15, 16]. In recent years, tillage erosion has been recognized as one of the most important factors in the redistribution of soils over time and in the development of morphological changes in agricultural fields and landscapes

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[5, 18, 23]. Erosion and deposition processes affect the morphological features of soils developed both in the upper position of a slope, such as the summit or shoulder, and in the lower slope position, such as the footslope and toeslope. The accumulated long-term tillage effects result in a modification of the soil profile and spatial patterns of soil variability. Moreover, soil redistribution by tillage results in a severe modification of the landscape topography as well as of the surface and subsurface hydrology (e.g., variability of infiltration and overland flow paths), causing substantial modification of geomorphic processes [5]. Tillage erosion and its impact on soil characteristics is well documented on areas covered with silty and loess soils very susceptible to erosion [17, 24], mainly on steep slopes [8, 13, 19, 25]. However, other studies reveal that despite gentle slopes of valley-sides built up of material not very prone to erosion and low phosphorus content in the topsoil, the mire in the valley margins was exposed to eutrophication resulting from erosional transport of P from arable land located on the upland [22]. Thus, the first objective of the study was the description and comparison of the morphological features of Ap horizons of soils developed from loamy sands and located in the upper and lower part of the slope, where tillage along the slope prevails. The second objective of this study was to determine differences in chemical and physicochemical properties of Ap horizons in soils located on the valley-sides, where natural and anthropogenic conditions are favourable to soil redistribution along the slope.

MATERIALS AND METHODS

The study area is located in the south-west of Białystok on the valley-sides of the Narew River within the borders of the Narew National Park (NNP) protection area. The NNP protects the swampy Narew valley and its unique anastomosing river system, rich in flora and fauna. This is one of the largest and best preserved areas of wetlands in Poland. Topography of the uplands surrounding the valley is rather moderate and the surface slope ranges between levelled plains to gentle slopes. Soils located on the valley-sides are comprised of glacial deposits, mainly sands and loamy sands and rarely loams [1]. Soils are mainly Luvisols and Arenosols. The valley is filled with organic deposits, mainly with peat. Soils in the valley are Histosols [2]. The land use on the valley-sides is dominated by agriculture. The arable fields on the valley-sides are narrow and their longer borders are parallel with the major slope, so it is common practice to conduct tillage parallel with the length of the field, which means along the slope. The major crops are rye, potato, oat and maize. The mean daily temperature ranges between -4.3°C in January and 17.3°C in July. The mean annual rainfall is 593 mm with peaks in June, July and August. Thunderstorms occur on about 25 days a year, mostly during the summer. The maximum monthly snowfall varies between 8 and 80 cm and occurs on 82-85 days a year, with midwinter thawing [7].

Eight arable fields located on the valley-sides with slopes ranging between 2.5 and 5.3% were chosen. The field sites were chosen to be representative of the landscape type and field geometry and crop production as well as tillage methods used in the region. The length of study fields varied between 96 m and 420 m; the width was 20 m. The tillage operations on all study fields were conducted along the slope gradient. A short description of the study fields is given in Table 1.

On every study field the soil profiles were described in the upper and lower parts of the slopes, and in the case of the two longest, fields Nos 5 and 10, the soil profile was also described in the middle part of the slope. In every profile soil samples were taken from a 15-20 cm layer for texture determination, which was done using the Bouyoucos method in modification by Casagrande and Prószyński. For lower horizons the soil texture was determined at the field. On every study field soil samples for chemical properties were obtained from the Ap horizon of soils occurring on the shoulder and footslope and in addition from the midslope of the two longest study fields, in total 18 soil samples were taken. Soil was sampled from a depth of 15-20 cm. For the soil analyses, pH was measured in water and in KCl, exchangeable acidity (EA) was determined by the Kappen method, exchangeable bases were determined in 1M ammonium acetate – calcium and magnesium by flame AAS, Na and K with flame photometry. Total of exchangeable base cations (TEB), cation exchange capacity (CEC) and base saturation (BS) were calculated. Organic carbon was determined by the Tiurin method. Total nitrogen (TN) and potassium ($K_{H_2SO_4-H_2O_2}$) were determined after digestion of soil samples with sulphuric acid and hydrogen peroxide, total nitrogen was determined by the Nessler method, and potassium was measured by flame photometry. Total phosphorus was determined with ammonium metavanadate method after digestion with nitric acid and perchlorid acid mixture. The Spearman correlation analysis was done for selected soil properties, using a significance level of 5%.

RESULTS

The soils located on the slope shoulder are Luvisols, although their profiles are affected by erosion and tillage. The *luvic* horizon is eroded or incorporated into the plough horizon by tillage, while the *argic* horizon is directly beneath the plough horizon. Only soil on the slope shoulder in field 10 (profile 10a) is the Arenosol, because of the low pH and low base saturation value in the Ap horizon. Soils in the footslope are Mollic Gleysols (Colluvic) – deluvial soils, because of deep humus horizons.

On the slope shoulder Luvisols of a loamy sand texture developed. The depth of plough horizons in these soils varies from 20 to 30 cm, except the soils from field 9 (profile 9a and 9b), where the Ap horizons are 38 cm deep (Table 1). On the lower part of the slope deluvial soils of loamy sand and sandy loam occurred with humus horizon with a depth of 38 to 110 cm. The soil particle size distribution of Ap horizons in soils in both positions on the slope is similar (Table 2). The

TABLE 1. DESCRIPTION OF THE STUDIED FIELDS AND STUDIED SOILS

Study field	Slope (%)	Length (m)	Profile	Position on the slope	Horizon	Depth (cm)	Texture	Soil type
Field 12 (Łupianka Stara)	2.5	358	12a	Midslope	Ap Bt C	0-23 23-80 80-150	LS LS LS	Luvisol
			12b	Footslope	Ap A Cg G	0-30 30-47 47-70 70-150	SL SL SL SL	Mollic Gleysols (Colluvic)
Field 1 (Radule)	2.6	96	1a	Shoulder	Ap Bt BC Ck	0-20 20-45 45-74 74-150	SL SL LS LS	Luvisol
			1b	Footslope	Ap A AC C	0-20 20-40 40-50 50-150	SL SL SL SL	MollicGleysols (Colluvic)
Field 7 (Kolonia Topilec)	2.7	278	7a	Shoulder	Ap Bt C	0-30 30-49 49-150	LS LS S	Luvisol
			7b	Footslope	Ap A AC C G	0-26 26-65 65-76 76-90 90-150	LS LS LS SL S	MollicGleysols (Colluvic)
Field 10 (Jeńki Romanowo)	2.7	420	10a	Shoulder	Ap Bv C	0-25 25-60 60-150	LS LS S	Arenosol
			10b	Midslope	Ap AC C	0-50 50-60 60-150	SL LS S	MollicGleysols (Colluvic)
			10c	Footslope	Ap AC C	0-30 30-47 47-150	SL SL SL	MollicGleysols (Colluvic)
Field 9 (Kurowo)	4.1	100	9a	Shoulder	Ap Bt C	0-3838- 7474-15 0	SL LS S	Luvisol
			9b	Midslope	Ap Eet Bt C	0-38 38-53 53-89 89-150	LS LS SL LS	Luvisol

TABLE 1. CONTINUATION

Study field	Slope (%)	Length (m)	Profile	Position on the slope	Horizon	Depth (cm)	Texture	Soil type
Field 3 (Bokiny)	4.8	210	3a	Shoulder	Ap Bt BC C	0-30 30-52 52-70 70-150	SL SL SL SL	Luvisol
			3b	Footslope	Ap A1 A2 Ab Cb	0-40 40-80 80-100 100-120 120-150	SL SL SL SL SL	MollicGley sols (Colluvic)
Field 5 (Łupianka Stara)	5.1	390	5a	Shoulder	Ap Bt C	0-31 31-50 50-150	LS SL LS	Luvisol
			5b	Midslope	Ap A C	0-38 38-46 46-150	SL S S	MollicGley sols (Colluvic)
			5c	Footslope	Ap A Ab Cb	0-40 40-110 110-160 160-	LS LS LS S	MollicGley sols (Colluvic)
Field 11 (Łupianka Stara)	5.3	350	11a	Shoulder	Ap Bt C	0-30 30-60 60-150	SL SL SL	Luvisol
			11b	Midslope	Ap Bt C	0-40 40-60 60-150	LS LS LS	Luvisol

differences in the morphological features are more pronounced in soils developed on the relatively steeper slopes 4.1-5.3%. On field 3 on the footslope, deluvial soil developed with 100 cm of deposits occurring on the humus horizon of the buried soil. The deposits are of a sandy loam texture and the parent material of buried soil is of a light loam texture. Even more distinctive differences in soils were found on the slope of 5.1%. Field 5 on this steep slope stretches from the summit to the footslope. On the lower part of the field deluvial soil with 110 cm of deposits occurred. The deposits are of a loamy sand texture.

The C_{org} concentration ranges from 2.50 to 9.93 g kg^{-1}, except two samples from lower parts of the slope where the concentration of organic carbon amounts 11.01 and 17.63 g kg^{-1}. In most fields the organic C content is higher in the lower part of the slope (Table 3).

Total nitrogen in plough horizon ranges from 0.47 to 1.69 g kg^{-1} (Table 3) and is not affected by the position on the slope. The TN is strongly correlated with C_{org} and exchangeable form of calcium and magnesium, as well as with the percentage

TABLE 2. PARTICLES SIZE DISTRIBUTION OF PLOUGH HORIZONS OF STUDIED SOILS

Location of fields	Profile	Percentage of fraction with particle diameter (mm)						In total		
		1-0.1	0.1-0.05	0.05-0.02	0.02-0.005	0.005-0.002	<0.002	1-0.05	0.05-0.002	<0.002
Field 12 (Łupianka Stara)	12a	74	9	4	4	1	8	83	9	8
	12b	56	16	8	7	4	9	72	19	9
Field 1 (Radule)	1a	52	14	7	8	4	15	66	19	15
	1b	57	17	7	5	1	13	74	13	13
Field 7 (Kol. Topilec)	7a	71	9	5	4	1	10	80	10	10
	7b	73	10	5	4	0	8	83	9	8
Field 10 (Jeńki Romanowo)	10a	74	8	3	5	1	9	82	9	9
	10b	51	16	11	8	5	9	67	24	9
	10c	54	14	7	5	2	18	68	14	18
Field 9 (Kurowo)	9a	68	11	5	5	1	10	79	11	10
	9b	67	13	6	4	1	9	80	11	9
Field 3 (Bokiny)	3a	53	18	9	5	3	12	71	17	12
	3b	48	15	12	9	3	13	63	24	13
Field 5 (Łupianka Stara)	5a	78	8	3	1	2	8	86	6	8
	5b	68	12	6	3	0	11	80	9	11
	5c	65	15	5	2	3	10	80	10	10
Field 11 (Łupianka Stara)	11a	62	9	6	7	2	14	71	15	14
	11b	75	8	4	4	1	8	83	9	8

TABLE 3. Concentration of C_{ORG}, TN, TP, $K_{(H_2SO_4-H_2O_2)}$, AND C/N AND pH IN H_2O AND pH IN KCL IN PLOUGH HORIZONS OF STUDIED SOILS

Location of fields	Position on the slope	Profile	C_{org}	TN	TP	$K_{(H_2SO_4-H_2O_2)}$	C/N	pH	
					(g kg^{-1})			H_2O	KCl
Field 12 (Łupianka Stara)	Midslope	12a	6.06	1.37	0.38	0.89	4	6.90	6.61
	Footslope	12b	6.54	0.99	0.34	1.00	7	6.36	5.47
Field 1 (Radule)	Shoulder	1a	5.80	1.36	0.22	0.95	4	6.17	5.32
	Footslope	1b	5.75	0.60	0.31	1.17	10	5.73	4.62
Field 7 (Kol. Topilec)	Shoulder	7a	4.17	0.57	0.34	0.95	7	6.56	5.70
	Footslope	7b	17.63	1.69	0.29	0.82	10	6.86	5.98
Field 10 (Jeńki Romanowo)	Shoulder	10a	4.71	0.47	0.41	0.69	10	5.21	4.29
	Midslope	10b	9.93	1.65	0.39	1.05	6	6.11	5.21
	Footslope	10c	3.54	1.48	0.36	1.02	2	4.84	4.06
Field 9 (Kurowo)	Shoulder	9a	3.73	0.82	0.48	1.16	5	5.97	4.81
	Midslope	9b	3.76	0.82	0.55	0.98	5	5.14	4.26
Field 3 (Bokiny)	Shoulder	3a	7.33	1.21	0.38	1.82	6	7.35	6.66
	Footslope	3b	11.01	1.64	0.47	2.07	7	6.53	5.59
Field 5 (Łupianka Stara)	Shoulder	5a	2.50	0.63	0.29	0.87	4	7.88	7.60
	Midslope	5b	4.67	0.50	0.25	0.91	9	4.93	3.92
	Footslope	5c	3.33	0.52	0.34	0.93	6	5.07	3.89
Field 11 (Łupianka Stara)	Shoulder	11a	5.17	1.54	0.40	2.39	3	7.73	7.35
	Midslope	11b	5.25	1.05	0.37	0.98	5	7.23	7.09

of silt (Table 4). The total nitrogen concentration in lower slope soils is less than in soils on the slope shoulder in the case of field 12 and 1 located on gentle slopes as well as in the case of field 11 on the steepest slope. On the other hand, the TN concentration in the lower slope position is higher than on the slope shoulder in the case of a 2.7% slope (field 7 and 10) and in the case of a 4.8% slope (field 3). The TN concentration in Ap horizons of soils from field 9 and 5 located on the 4.1% and 5.1% slopes respectively is relatively uniformly distributed within the surface layer.

The amount of TP in plough horizon is from 0.22 to 0.55 g kg^{-1} (Table 3). On the gentle slopes erosion has no significant effect on the phosphorus distribution in the Ap horizon and TP concentration in soils in the lower slope is less than in the upper slope position, except the soils on field 1 located on the gentle slope (2.7%). On the other hand, on the steeper slopes, erosion has a significant effect on the TP concentration in the Ap horizon, which is higher in soils located in the lower slope position. Potassium concentration ranges from 0.82 to 2.39 g kg^{-1} (Table 3). The K concentration is higher in soils located in the lower part of the field, except field 7 and 11. The TP concentration is not correlated with any other analyzed soil features, while the potassium concentration is positively correlated with exchangeable sodium (Table 4).

While the TN concentration is low in the soils in lower parts of the fields it results in a higher C/N ratio in these soils. The studied soils have a wide range of pH in KCl values, ranging from 4.29 to 7.60 and this parameter is lower (3.89-7.09) in the lower part of the field (Table 3). The pH is strongly correlated with percentage of silt, as well as with exchangeable calcium and magnesium, base saturation.

The cations exchange capacity of plough horizons ranges from 4.28 to 19.60 cmol(+) kg^{-1} (Table 5). Exchangeable calcium is the dominant cation in the sum of base cations. The soil content of Ca^{2+} ranges from 0.29 to 17.90 cmol(+) kg^{-1}. Exchangeable magnesium and potassium are next in the sequence of cations abundance in the sum of base cations, and their contents range from 0.05 to 0.99 cmol(+) kg^{-1} and from 0.03 to 0.31 cmol(+) kg^{-1} respectively. The lowest in the plough horizon is the content of exchangeable sodium ranging from 0.01 to 0.04 cmol(+) kg^{-1}. Higher exchangeable acidity corresponds with a low amount of Ca^{2+}. High variability of all exchangeable cations in the soil results in a wide range of base saturation, ranging from 4.8 to 97.7% (Table 5). The exchangeable forms of sodium and magnesium are positively correlated with the percentage of silt, while the Na^+ content is correlated with the percentage of clay. The K^+ content is correlated with exchangeable sodium content (Table 4). The content of Ca^{2+} and Mg^{2+} in the Ap horizons from upper parts of the slope is lower comparing with the lower parts of the slope, which results in higher exchangeable acidity in the soils from slope shoulder. The content of K^+ is less pronounced and only few soils in the lower field position are enriched with this cation. The amount of Na^+ is similar in soils from both positions on the field. Base saturation is higher in soils located on the slope shoulder.

TABLE 4. CORRELATION COEFFICIENT BETWEEN CHEMICAL AND PHYSICOCHEMICAL FEATURES AND TEXTURE

Parameter	Sand 0.1-0.05	Silt 0.05-0.002	Clay <0.002	C_{org}	TN	TP	$K(H_2SO_4-H_2O_2)$	pH in KCl	Ca^{2+}	Mg^{2+}	K^+	Na^+	TEB	EA	CEC	BS
Sand 0.1-0.05	1.00															
Silt 0.05-0.002	0.03	1.00														
Clay <0.002	-0.31	0.01	1.00													
C_{org}	0.41	0.45	-0.19	1.00												
TN	-0.25	**0.53***	-0.11	0.63	1.00											
TP	-0.27	0.04	0.24	0.02	0.16	1.00										
$K(H_2SO_4-H_2O_2)$	-0.21	0.23	0.41	0.23	0.38	0.43	1.00									
pH in KCl	0.04	**0.94**	-0.06	0.33	0.42	-0.01	0.10	1.00								
Ca^{2+}	0.02	**0.99**	-0.01	0.45	**0.54**	0.07	0.27	**0.92**	1.00							
Mg^{2+}	0.10	**0.78**	0.15	**0.62**	**0.57**	-0.13	0.18	0.75	0.75	1.00						
K^+	-0.31	0.01	1.00	-0.19	-0.11	0.24	0.41	-0.06	-0.01	0.15	1.00					
Na^+	0.01	0.23	**0.49**	-0.01	0.14	-0.29	0.02	0.14	0.23	0.38	**0.49**	1.00				
TEB	0.02	**0.99**	0.03	0.45	0.55	0.01	0.27	**0.90**	**0.99**	**0.79**	0.03	0.30	1.00			
EA	-0.05	**-0.74**	-0.15	-0.09	-0.06	0.40	-0.01	**-0.76**	**-0.70**	**-0.59**	-0.15	-0.33	**-0.72**	1.00		
CEC	-0.23	**0.55**	-0.21	0.21	**0.62**	0.42	0.27	0.46	**0.59**	0.29	-0.21	0.02	**0.57**	0.03	1.00	
BS	-0.03	**0.94**	0.14	0.36	0.40	-0.18	0.20	**0.90**	**0.91**	**0.81**	0.13	0.33	**0.93**	**-0.89**	0.30	1.00

TABLE 5. Sorption features of plough horizons of studied soils

Location of fields	Position on the slope	Profile	Base cations							BS^3
			Ca^{2+}	Mg^{2+}	K^+	Na^+	TEB^1	EA^2	CEC	
			$cmol(+)\ kg^{-1}$							
Field 12 (Łupianka Stara)	Midslope	12a	4.43	0.53	0.15	0.02	5.13	2.33	7.45	68.8
	Footslope	12b	3.73	0.69	0.12	0.02	4.57	3.86	8.43	54.2
Field 1 (Radule)	Shoulder	1a	4.17	0.86	0.17	0.03	5.23	2.21	7.44	70.3
	Footslope	1b	2.33	0.30	0.11	0.02	2.76	2.72	5.48	50.4
Field 7 (Kol. Topilec)	Shoulder	7a	2.34	0.35	0.15	0.02	2.85	3.04	5.89	48.4
	Footslope	7b	4.93	0.99	0.06	0.03	6.01	3.15	9.16	65.6
Field 10 (Jeńki Romanowo)	Shoulder	10a	0.74	0.10	0.06	0.01	0.91	7.35	8.26	11.0
	Midslope	10b	5.43	0.16	0.03	0.02	5.64	6.79	12.43	45.4
	Footslope	10c	0.29	0.05	0.09	0.01	0.45	8.63	9.07	4.8
Field 9 (Kurowo)	Shoulder	9a	1.74	0.23	0.23	0.03	2.22	5.40	7.62	29.2
	Midslope	9b	1.14	0.15	0.19	0.01	1.49	8.55	10.04	14.8
Field 3 (Bokiny)	Shoulder	3a	5.93	0.46	0.16	0.01	6.55	1.61	8.17	80.3
	Footslope	3b	5.93	0.79	0.21	0.03	6.95	3.53	10.47	66.3
Field 5 (Łupianka Stara)	Shoulder	5a	9.78	0.31	0.10	0.03	10.22	0.36	10.58	96.6
	Midslope	5b	0.60	0.07	0.20	0.03	0.90	3.47	4.37	20.6
	Footslope	5c	0.65	0.12	0.20	0.03	1.00	3.28	4.28	23.4
Field 11 (Łupianka Stara)	Shoulder	11a	17.90	0.91	0.31	0.04	19.15	0.45	19.60	97.7
	Midslope	11b	6.93	0.58	0.11	0.01	7.62	0.86	8.48	89.8

TEB^1 – total exchangeable bases, EA^2 – exchangable acidity, BS^3 – base saturation.

The mean values of selected properties and particle size distribution were compared for the plough horizons of soils from slope shoulders (profiles 1a, 3a, 5a, 7a, 9a, 10a, 11a) and deluvial soils from the footslope (profiles 1b, 3b, 5c,7b, 10c, 12b). Mean C_{org} concentration for plough horizons of soils on the slope shoulder is 4.77 g kg^{-1}, while in the plough horizons of deluvial soils in the footslope the organic carbon content is higher and amounts to 7.97 g kg^{-1} (Table 6). The mean value for TN in Ap horizons sampled from the slope shoulder is equal to 0.94 g kg^{-1} and increases on the footslope position to 1.15 g kg^{-1}. However, a comparison of soils from the same slope revealed that the amount of TN is not correlated with the slope position. The mean values of TP and $K_{H_2SO_4-H_2O_2}$ are similar in soils from both studied positions on the slope. The median of pH (in H_2O and KCl) calculated for deluvial soils is lower than that calculated for soils on the slope shoulder. The

TABLE 6. COMPARISON OF TEXTURE, CHEMICAL AND PHYSICOCHEMICAL FEATURES OF PLOUGH HORIZONS IN SOIL LOCATED ON SHOULDER AND FOOTSLOPE

Features		Soils located on slope shoulder[1]	Soils located on footslope[2]
		n=7 mean	n=6 mean
Texture	sand 1.0-0.05 (%)	76±7	73±7
	silt 0.05-0.002 (%)	12±5	15±6
	clay <0.002 (%)	11±3	12±4
C_{org} (g kg^{-1})		4.77±1.55	7.97±5.49
TN (g kg^{-1})		0.94±0.47	1.15±0.52
TP (g kg^{-1})		0.36±0.22	0.35±0.08
$K_{(H_2SO_4-H_2O_2)}$ (g kg^{-1})		1.26±0.69	1.17±0.45
C/N		5±3	7±2
pH[3]	in H_2O	6.56	6.05
	in KCl	5.70	5.05
Base cation	Ca^{2+} (cmol(+) kg^{-1})	6.09±6.03	2.98±2.28
	Mg^{2+} (cmol(+) kg^{-1})	0.46±0.31	0.49±0.39
	K^{+} (cmol(+) kg^{-1})	0.17±0.08	0.13±0.06
	Na^{+} (cmol(+) kg^{-1})	0.02±0.01	0.02±0.01
	TEB (cmol(+) kg^{-1})	6.73±6.30	3.62±2.43
	EA (cmol(+) kg^{-1})	2.92±2.41	4.20±2.66
	CEC (cmol(+) kg^{-1})	9.65±4.60	7.82±2.39
BS (%)		61.9±33.51	44.1±24.78

[1] Profiles 1a, 3a, 5a, 7a, 9a, 10a, 11a; [2] profiles 1b, 3b, 5c, 7b, 10c, 12b; [3] median.

mean concentration of Ca^{2+} in deluvial soils is 2.98 cmol(+) kg^{-1}, while the average exchangeable calcium concentration in soils from upper parts of slope is equal to 6.09 cmol(+) kg^{-1}. This results in higher mean exchangeable acidity in deluvial soils (4.20 cmol(+) kg^{-1}) than in soils located in upper slope positions (2.92 cmol(+) kg^{-1}). The mean concentration of Mg^{2+} is similar for Ap horizons of soils in the upper and lower part of the slope and is equal to 0.46 cmol(+) kg^{-1} and 0.49 cmol(+) kg^{-1}, respectively (Table 6). The mean concentration of K^+ in soils from the slope shoulder is 0.17 cmol(+) kg^{-1}, while the average K^+ concentration for deluvial soils is 0.13 K^+cmol(+) kg^{-1}. The mean base saturation in soils from the upper slope position (61.93%) is higher than the mean BS value for deluvial soils (44.12%).

DISSCUSION

The studies revealed that soils on the Narew River valley slopes ranging from 2.5 to 5.3% are eroded. The truncated profile with plough horizon underlain directly with the *argic* horizon is characteristic for eroded Luvisols [10, 14, 20]. On such gentle slopes tillage erosion prevails [10]. Deluvial deposits accumulated on the lower part of the fields suggest water and tillage erosion as factors affecting soil development. On such gentle slopes tillage erosion has a dominant impact over a larger portion of the field compared to water erosion [18]. Similar texture of soils in the upper and lower parts of the slope is one piece of evidence for tillage erosion as the main factor for soil downslope translocation on the gentle slopes. Water erosion is limited to rills created during ploughing. Similar erosion patterns have been observed in other undulating landscapes [9]. The behaviour of the water erosion process at a field boundary is complex and characterized by a high spatial and temporal variability. The fraction of the overland flow infiltrate near the field boundary and sediment is likely to be deposited here, especially in the rows tilled parallel to the field lower boundary, perpendicular to the slope [21]. Partial runoff overflows the boundary and the material is deposited on the meadows located on the toeslope next to arable land. These kinds of sediment depositional areas outside the field were observed in several places during the study period. It should be emphasized that the shallow groundwater level in the lower part of the slope also has an effect on the development and morphological features of soils located on the footslope. Features of gleyic process were found in several soils on the footslope. It should be also mentioned that in dry years, farmers tend to take to ploughing parts of their meadows located in the lower position of the slope adjacent to the lower border of the arable field. These soils were mainly affected by turf growing and shallow groundwater level and only partly by the sedimentation of eroded material.

The morphological features of plough horizons in various positions on the slope are affected by tillage erosion [9, 10] and water erosion has smaller impact [14]. The deluvial deposits thick to 110 cm on the footslopes are the main evidence for soil translocation along the slope. The chemical properties of soils located in various positions on the slope are less modified, mainly by tillage erosion. Studies of Kaźmierowski [11] revealed a small impact of tillage erosion on modification of chemical and physicochemical properties of Ap horizons. On steeper slopes the material transported downslope enriches the depositional areas in the footslope with phosphorus. The erosional soil enrichment in potassium and organic carbon in lower parts of the fields is small. The enrichment of soils in depositional areas in organic carbon was also observed by Szrejder [20] and Bieniek and Wójciak [4]. However, the differences in soils from upper slope and lower slope positions are not very pronounced due to the fact that they are mainly affected by tillage erosion. This type of erosion is important in sediment transport on gentle slopes [8]. The variability of TN, TP and $K_{H_2SO_4-H_2O_2}$ along the slope may be the effect of the differences in soil texture. This is suggested by the positive correlation between TN and percentage of silt.

The variability of pH both in upper and lower part of the slope may be related to soil texture and $CaCO_3$ content and to different calcium fertilizers rates. The correlation between pH and content of exchangeable calcium and magnesium as well as with the percentage of silt suggests big role of soil texture in pH level. Higher exchangeable acidity, lower pH values and CEC of soil in lower parts of fields is affected by the shallow groundwater level and faster movement of cations along the profile. Similar content of easily migrating elements in deluvial soils compared to soils in an upperslope position was found in the young glacial landscape [10]. Also, Gołębiowska *et al*. [6] confirmed the acidification of soils in the footslope position. The deluvial soils from the Mazurian Lake District have higher CEC in comparison to eroded soils on the slope, but their Ap horizons have lower pH values and higher exchangeable acidity which is affected by blocking the ion exchange of slightly acidic binding of carboxylic groups in sorption complex by hardly exchangeable hydrogen [3].

CONCLUSIONS

1. Soils on the gentle slopes of the Narew River valley are modified by the processes of tillage and water erosion. The dominant Luvisols in the upper part of the slope are truncated and their *luvic* horizon is incorporated into the plough horizon. On the footslopes, Mollic Gleysols soils developed with thick deluvial deposits (up to 110 cm).

2. Similar texture of soils and TN, TP and $K_{H_2SO_4-H_2O_2}$ content in both slope positions are evidence of tillage erosion as the main factor of soil downslope translocation on these gentle slopes.

3. The differences in physicochemical properties of soils located in various positions on the slope are more distinct. Higher exchangeable acidity, lower pH values and CEC of soil in lower parts of fields is affected by the shallow groundwater level and faster movement of cations along the profile.

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CECHY MORFOLOGICZNE I WŁAŚCIWOŚCI CHEMICZNE POZIOMÓW ORNOPRÓCHNICZNYCH GLEB W RÓŻNYCH POŁOŻENIACH NA ZBOCZU

Badania cech morfologicznych i chemizmu poziomów Ap gleb przeprowadzono na łagodnych zboczach doliny Narwi. W górnych częściach zboczy wykształciły się przede wszystkim gleby płowe o składzie granulometrycznym, piasków gliniastych lub glin piaszczystych, natomiast u podnóży zboczy występują gleby deluwialne czarnoziemne o podobnym składzie granulometrycznym i miąższości osadów deluwialnych do 110 cm. Skład granulometryczny poziomów ornopróchnicznych oraz ich zasobność w ogólne formy azotu, fosforu i potasu są podobne. Średnia zawartość ogólnych form azotu, fosforu i potasu wynosi w glebach położonych w górnej części zboczy odpowiednio 0,94, 0,36 i 1,26 g kg^{-1}, natomiast zawartość omawianych pierwiastków w glebach u podnóży zboczy wynosi 1,15, 0,35 i 1,17 g kg^{-1}. Poziomy ornopróchniczne gleb położonych u podnóży zboczy charakteryzują się kwaśniejszym odczynem. Gleby te są bardziej zasobne w węgiel organiczny. Średnia kwasowość hydrolityczna gleb położonych w górnej części zboczy wynosi 2,92 cmol(+) kg^{-1}, podczas gdy gleby podnóży zboczy charakteryzują się wyższą średnią wartością H_h równą 4,20 cmol(+) kg^{-1}. Duża miąższość osadów deluwialnych, podobny skład granulometryczny gleb w obu położeniach oraz niewielkie wzbogacenie poziomów Ap gleb zlokalizowanych u podnóży zboczy wskazuje na erozję uprawową jako główny czynnik przemieszczania materiału glebowego wzdłuż stoku.

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Soil Genesis

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FRACTIONAL COMPOSITION OF HUMUS IN SELECTED FOREST SOILS IN THE KARKONOSZE MOUNTAINS**

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Abstract. This paper describes the fractions of humus compounds present in the organic and mineral horizons of the forest soils in the area of the Karkonosze Mountains. Soil profiles that represented the mountain Podzols and Dystric Cambisol were located on the northern slope along an altitude gradient from 890 to 1255 m a.s.l. Two soils were located under the spruce forest, and one in the subalpine meadow. Soil samples were taken both from the surface organic layers (the ectohumus layer) and from the mineral horizons. Fractionation of humus compounds was made using the modified Turin method. The soils had the texture of loamy sand and sandy loam, an acidic or strongly acidic reaction, low base saturation, and the predomination of aluminum among exchangeable cations. A significant increase in the fulvic fraction (Ia) with depth in the soil profiles was observed that confirmed the high mobility of this fraction in the acid mountain soils, higher in the forest soils, and lower in the meadow soils. The content of fraction I decreased generally with depth in the soil profile; however, a secondary increase was observed in an illuvial Bh horizon of the Podzols. Fulvic acids predominated over the humic acids and this predominance increased with depth in the soil profile. The ratio of the humic to the fulvic acids in fraction I in the ectohumus horizons was influenced by the composition of a biomass inflow. The C_{HA}:C_{FA} ratio had the highest values under a spruce forest compared to a mixed stand and a subalpine meadow. In the surface horizons of the forest soils, a predominance of humic over fulvic acids was always observed, while in the subalpine meadow soils, the fulvic acids predominated over the humic acids in all soil horizons. Based on this study, it can be stated that the vegetation type and the dominant soil-forming process rather than simply climate factors influence the fractional composition of humus in the mountain soils of the Karkonosze Mountains.

In the Karkonosze, environmental condition and local habitats change clearly with an increasing altitude above sea level due to a change in the climate that results both in forest and soil zonal occurrence [3]. However, an altitudinal

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zonation of the vegetation in the Karkonosze Mountains is somewhat different than that in other European mountains, due to the influence of two environmental factors: north-oceanic air masses advecting to the Karkonosze and small massif upheaval [25].

The lower zone of the mountain spruce forest ranges in altitude from 500 to 1000 m a.s.l. At these altitudes, the natural vegetation, including an acidic mountain beech forest, was replaced by humans with spruce monocultures due to the faster timber production [10]. Currently, 'artificial' spruce stands predominate on the habitats of the poor ('acid') mountain beech forest. As a result of spruce propagation, a fundamental alteration in the floristic composition of the communities took place. The species typical in the deciduous forests were superseded, and coniferous forests or species not connected to forest ecosystems occurred in their place [3]. From the altitude of about 1 000 to 1 250 m a.s.l. the upper zone of the mountain spruce forest occurs in the Karkonosze. These communities are in the Sudeten Mountains relatively little transformed and probably are mostly of natural origin. According to the floristic issues, it is classified to poorer communities; only the vegetation of the forest floor is quite differentiated. The forest is declining gradually by tree dwarfing, and thus a 150 m -broad transition zone (ecotone) occurs above the altitude of about 1200 m a.s.l. The ecotone zone is gradually transformed into a dwarf mountain pine zone [10].

The composition of humus in the soils of the Sudeten Mountains has been the subject of numerous studies, particularly in the period of the forest decline [6], while currently only a few papers have been published concerning mainly relations between the environmental factors and the fractional composition of humus in the mountain soils.

The subject of the present study was a quantitative analysis of the humus in the soils of the Karkonosze Mountains, located at various altitudes above sea level and under different vegetation, based on the physical-chemical soil properties and the fractionation of the humus compounds.

RESEARCH AREA AND METHODS

The study included 3 soil profiles located in the eastern part of the Karkonosze, in the Karpacz region, at various altitudes and in differentiated habitat conditions. Two profiles were located under spruce forests, while one, for comparison, on a mountain meadow.

Profile No. 1 – altitude 1255 m a.s.l.: former pasture with compact cover of a moderate height turf vegetation (*Deschampsia caespitosa, Agrostis capillaries, Festuca rubra, Polygonum bistorta, Homogyne alpina, Vaccinium myrtillus*); bedrock: granite; rain- and meltwaters stagnate seasonally in the upper part of the soil profile; soil classification [12]: Folic Cambisol (Humic, Dystric, Oxyaquic, Endoskeletic).

Profile No. 2 – altitude 1 200 m a.s.l.; upper zone of the mountain spruce forest; numerous windthrows; mosaic vegetation of the forest floor (patches of *Vaccinium myrtillus*, *Calamagrostis villosa*, clumps of *Deschampsia flexuosa*, *Homogyne alpina*, *Trientalis europaea*, *Galium anisophyllon*, ferns); bedrock: granite; soil classification [12]: Histic Albic Podzol (Oxyaquic, Endoskeletic).

Profile No. 3 – altitude 890 m a.s.l.; lower zone of the mountain spruce forest; birch and larch admixture in the stand; vegetation on the forest floor covers the entire surface (clumps of *Vaccinium myrtillus*, *Deschampsia caespitosa*, *Deschampsia flexuosa* accompanied by *Calamagrostis villosa*, *Luzula luzuloides*, *Melampyrum sylvaticum*, *Polytrichum commune*); bedrock: granite; soil classification [12]: Haplic Podzol (Endoskeletic).

The following determinations were made in the collected soil samples (in the fine earth fraction <2 mm): particle-size distribution using the sieve-hydrometer method, organic carbon content (TOC) – by the dry combustion method (using automated Strőhlein CS – MAT 5500 apparatus), pH in distilled water and 1M KCl - by the potentiometric method, total nitrogen (Nt) - by the Kjeldahl method using a Büchi analyser; exchangeable acidity (Kw) and exchangeable aluminium (Al^{+3}) - using the Sokołow method, exchangeable base cations (Ca^{+2}, Mg^{+2}, K^{+}, and Na^{+}) - by spectrophotometric method after sample extraction with ammonium acetate at pH 7. Fractionation of the humus was made using a modified Tiurin method [9] by separating the following operationally defined fractions of the humic substances:

- fraction Ia (fulvic) – humic substances extracted with 0.05 M H_2SO_4,
- fraction I – humic substances extracted by multiple soil treatment with 0.1 M NaOH,
- fraction II – humic substances extracted by an alternating soil treatment with 0.1 M H_2SO_4 and 0.1 M NaOH. This fraction was determined only in mineral horizons,
- nonhydrolyzing carbon (C_{nh}) – post-extraction residue composed of the non-humified organic materials in the ectohumus layer, and mainly of the humins and ulmins in the mineral horizons. This fraction was calculated as the difference:

$$C_{nh} = 100\% - (\%\ C_{fraction\ Ia} + \%\ C_{fraction\ I} + \%\ C_{fraction\ II})\ [\%]$$

The results of the study were elaborated statistically using STATISTICA 9 software. Pearson correlation coefficients were calculated for a normal distribution and their significance was determined at the level of $p=0.05$ with $n=14$.

RESULTS AND DISCUSSION

The examined soils had the texture of loamy sand and sandy loam with a considerable fine skeleton content (Table 1). Whole profiles were strongly acidic: the pH measured in 1 M KCl ranged from 2.7 to 4.0, and the lowest pH values were observed in the ectohumus layers. Irrespective of the location and soil

TABLE 1. PARTICLE-SIZE DISTRIBUTION ACCORDING TO THE CLASSIFICATION OF PTG [24] AND IUSS [12]

Mineral soil horizon	Depth (cm)	Particle size (mm) distribution (%)										Sum of fine earth fractions (%)			Texture class
		>2.0	2.0-1.0	1.0-0.5	0.5-0.25	0.25-0.1	0.1-0.05	0.05-0.02	0.02-0.005	0.005-0.002	<0.002	2.0-0.05	0.05-0.002	<0.002	
Profile 1 – Folic Cambisol, subalpine meadow, 1 255 m a.s.l.															
ABg	0-13	31	18	13	17	11	14	18	5	3	1	73	26	1	LS
Bwg	13-26	32	15	11	11	10	12	25	12	3	1	59	40	1	SL
Bw	26-63	36	13	10	10	10	12	25	15	4	1	55	44	1	SL
Profile 2 - Histic Albic Podzol, spruce forest, 1 200 m a.s.l.															
AEg	0-8	15	14	15	15	16	13	13	8	5	1	73	26	1	LS
Esg	8-16	10	16	18	18	17	12	8	5	5	1	81	18	1	LS
Bhsg	16-24	18	17	19	21	15	9	5	6	7	1	81	18	1	LS
Bsg	24-35	26	12	14	20	17	13	11	6	6	1	76	23	1	LS
Bs	35-55	25	15	12	21	20	11	10	6	4	1	79	20	1	LS
Profile 3 – Haplic Podzol, mixed spruce forest, 890 m a.s.l.															
AE	0-6	12	14	18	15	5	11	20	11	4	2	63	35	2	SL
Bs	6-30	19	20	12	12	8	12	21	10	3	2	64	34	2	SL
Bws	30-60	38	25	15	12	9	12	13	8	4	1	73	25	2	LS

type, an increase in the pH with depth was observed in the profiles. Such a strong acidic reaction of the soils in the Karkonosze Mountains is their natural feature conditioned by environmental conditions, as confirmed by Adamczyk *et al*. [1].

The exchangeable acidity in the soils was clearly dependent on the content of organic matter (Table 2) which was also confirmed in other mountain soils by Drozd *et al*. [6]. The acidity decreased uniformly down the soil profile (in profiles Nos 1 and 3), while in profile No. 2 the highest acidity was observed in the illuvial horizon Bhsg, above and below which the acidity was lower. The characteristic feature of the examined soils was a low cation exchange capacity and predominance of aluminum among the exchangeable cations. The sum of the exchangeable base cations in mineral horizons did not exceed 1.25 cmol (+) kg^{-1}, while the degree of base saturation was within the range of 8.7 to 27.1%, and generally increased with the depth and soil pH (except profile No. 2).

The combination of biotic and abiotic factors in the Karkonosze favours the formation of ectohumus in forest soils and the enrichment of the mineral horizons in the humus. The high content of the organic substances in the whole profile is presented in numerous papers devoted to forest soils as a feature characteristic for these soils [7, 13]. The examined ectohumus horizons contained similar amounts of organic carbon, ranging from 23.8% (profile No. 1) to 27.0% (profile No. 3). In mineral horizons, the content of organic carbon decreased gradually with depth (in profiles 1 and 3), or (as in profile No. 2) reached a minimum in the eluvial level - 0.92%, and then increased in the illuvial horizon to 3.87%. A relatively high content of organic carbon was also observed in the deepest horizons of the soil profiles – ranging from 0.84 to 1.25%. Similar amounts and a vertical distribution were noted by Laskowski [18] and Kowaliński *et al*. [17]. Maciaszek *et al*. [21] and Gonet *et al*. 11] noted that ectohumus, where the predominant plant residues are spruce and pine needles, usually has an acid reaction, high content of organic carbon, low content of organic nitrogen and wide C/N range reaching even the values of 50 or more. In the analyzed profiles, the ratio of C/N in ectohumus ranged from 16 to 28 and was wider in the mineral horizons, where values from 24 to 36 were calculated.

The contribution of the particular fractions of humic substances was analyzed separately in the ectohumus and in the mineral horizons. When analyzing the fractional composition of humus it may be noticed that a small contribution was represented by fraction Ia representing low-molecular organic compounds of the highest solubility and mobility (Table 3). The contribution of the Ia fraction in organic horizons was within the range of 1.3 to 7.0 % TOC, while in mineral horizons it was in the range of 3.5 to 45.3 % TOC, and in all analyzed profiles increased with the depth. This demonstrates the very high mobility of fraction Ia in the whole profile, irrespective of the kind of soil and the plant cover. The contribution of fraction Ia increased in the soil profile with a pH increase (r=0.77)

TABLE 2. PHYSICO-CHEMICAL PROPERTIES OF SOILS UNDER INVESTIGATION

Soil horizon	Depth (cm)	pH		TOC	Nt	TOC:Nt	Kw	Al^{3+}	Ca^{2+}	Mg^{2+}	K^+	Na^+	S	ECEC	BS (%)
		H_2O	KCl	(%)			cmol(+) kg^{-1}								
Profile 1 – Folic Cambisol, subalpine meadow, 1 255 m a.s.l.															
M	12-0	4.5	3.8	23.80	1.48	16	6.36	6.17	0.80	0.38	0.19	0.09	1.46	7.82	18.7
ABg	0-13	4.7	3.9	3.46	0.14	24	3.35	3.28	0.72	0.25	0.09	0.08	1.14	4.49	25.4
Bwg	13-26	4.7	3.9	1.37	n.d.	n.d.	2.79	2.68	0.64	0.24	0.08	0.07	1.03	3.82	27.0
Bw	26-63	4.7	4.0	0.84	n.d.	n.d.	2.31	2.25	0.56	0.23	0.04	0.03	0.86	3.17	27.1
Profile 2 - Histic Albic Podzol, spruce forest, 1 200 m a.s.l.															
Oh	10-0	3.7	3.1	27.00	1.65	16	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
AEg	0-8	4.1	3.4	2.97	0.12	26	4.48	4.40	0.80	0.25	0.04	0.07	1.16	5.64	20.6
Esg	8-16	4.1	3.4	0.92	n.d.	n.d.	3.36	3.29	0.80	0.23	0.03	0.06	1.12	4.48	25.0
Bhsg	16-24	3.5	3.2	3.87	n.d.	n.d.	11.22	11.06	0.72	0.24	0.06	0.05	1.07	12.29	8.7
Bsg	24-35	4.3	3.7	2.45	n.d.	n.d.	6.06	6.01	0.70	0.22	0.04	0.06	1.02	7.08	14.4
Bs	35-55	4.4	3.9	1.03	n.d.	n.d.	2.34	2.30	0.56	0.22	0.03	0.06	0.85	3.19	26.6
Profile 3 – Haplic Podzol, mixed spruce forest, 890 m a.s.l															
Oh	2-0	3.5	2.7	26.80	0.969	28	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
AE	0-6	3.5	2.8	7.09	0.210	35	11.23	10.59	0.66	0.32	0.18	0.09	1.25	12.48	10.0
Bs	6-30	4.1	3.7	2.67	n.d.	n.d.	5.74	5.69	0.56	0.26	0.08	0.07	0.97	6.71	14.5
Bws	30-60	4.5	3.9	1.25	n.d.	n.d.	2.62	2.58	0.46	0.23	0.04	0.05	0.78	3.40	22.9

TOC – total organic carbon, Nt – total nitrogen, Kw - exchangeable acidity, S – sum of exchangeable cations, ECEC – effective cation exchangeable capacity (ECEC=Kw+S), BS – base saturation, n.d. – not determined.

TABLE 3. FRACTIONAL COMPOSITION OF HUMUS. ALL FRACTIONS WERE SHOWN IN PERCENT OF THE TOTAL ORGANIC CARBON (TOC)

Soil horizon	Fraction Ia	Fraction I				Fraction II				CHA I+II	CFA I+II	CHA/CFA I+II	Cnh
		C-extracted	CHA	CFA	CHA: CFA	C-extracted	CHA	CFA	CHA: CFA				
	(% TOC)					(% TOC)				(% TOC)			
Profile 1 – Folic Cambisol, subalpine meadow, 1 255 m a.s.l.													
M	7.0	48.0	23.8	24.2	0.98	n.d.	n.d.	n.d.	n.d.	23.8	24.2	0.98	45.0
ABg	18.0	36.0	17.4	18.7	0.93	1.9	1.0	0.9	1.11	18.4	19.6	0.94	44.1
Bwg	33.2	28.9	11.6	17.3	0.67	3.9	3.0	0.9	3.33	14.6	18.2	0.80	34.0
Bw	37.7	20.6	7.7	12.9	0.60	5.2	1.8	3.4	0.53	9.5	16.3	0.58	36.5
Profile 2 - Histic Albic Podzol, spruce forest, 1 200 m a.s.l.													
Oh	1.3	46.6	31.4	15.2	2.06	n.d.	n.d.	n.d.	n.d.	31.4	15.2	2.07	52.1
AEg	4.3	38.6	26.2	12.3	2.13	2.4	1.6	0.8	2.00	27.8	13.1	2.12	54.7
Esg	9.6	44.7	25.7	19.0	1.35	1.9	1.5	0.4	3.75	27.2	19.4	1.40	43.8
Bhsg	12.7	48.9	28.3	20.2	1.40	4.8	3.2	1.6	2.00	31.5	21.8	1.44	33.6
Bsg	29.4	28.3	10.9	17.4	0.63	1.5	0.8	0.7	1.14	11.7	18.1	0.65	40.8
Bs	45.3	15.7	6.4	9.3	0.69	1.9	0.9	1.0	0.90	7.3	10.3	0.71	37.1
Profile 3 – Haplic Podzol, mixed spruce forest, 890 m a.s.l													
Oh	1.5	51.7	27.3	24.4	1.12	n.d.	n.d.	n.d.	n.d.	27.3	24.4	1.12	46.8
AE	3.5	41.6	26.7	14.9	1.80	3.1	2.2	0.9	2.44	28.9	15.8	1.83	51.8
Bs	17.3	44.1	19.9	24.1	0.83	4.5	3.1	1.4	2.21	23.0	25.5	0.90	34.1
Bws	42.3	22.0	8.9	13.1	0.68	3.5	2.6	0.9	2.88	11.5	14.0	0.82	32.2

CHA – carbon of humic acids, CFA – carbon of fulvic acids, Cnh - nonhydrolizing carbon, n.d. – not determined.

and base saturation (r=0.66), and inversely to a decrease in total organic carbon content (r=-0.62) and total nitrogen (r= -0.57) (Table 4). The contribution of fraction Ia in deeper soil horizons under spruce forests in the Karkonosze has also been observed by Kowaliński *et al*. [17], Drozd [5], Drozd *et al*. [4, 6, 7], as well as by Niemyska-Łukaszuk [22], and Niemyska-Łukaszuk and Miechówka [23] in forest and meadow soils of the Tatra Mountains, which suggests a dependence on the climate. Based on the present study and the results of the mentioned authors, it may be concluded that the high contribution of fraction Ia was connected to the strongly acidic reaction of the soils and presence, at least periodically, of an excessive humidity in the upper layers of the soil profile. Both factors favour mobilization and relocation of the low-molecular humic substances. Attention should also be paid to the fact that differentiation in the contribution of fraction Ia in profiles Nos 2 and 3 is similar – from about 4% to over 40% of TOC, which confirms the podzolization in both profiles. Another possible explanation of both the overall tendency and a gradual change in the contribution of fraction Ia in the central section of the profiles is the polygenetic character of numerous mountain soils, which was suggested by Kabała *et al*. [15, 16]. In a subalpine Cambisol (profile No. 1), the vertical differentiation of the contribution of fraction Ia is slightly lower than in other profiles (from 7.0 to 37.7% of TOC), similar to minimal pH differentiation in the whole profile. This is accompanied by the lack of podzolization features, despite the location in the most humid and cool altitude zone.

The most important group among the humus compounds was fraction I, defined classically as the organic compounds easily bonding with calcium and with the non-silicate forms of sesquioxides. However, in the analyzed mountain soils, strongly acidic and poor in calcium, fraction I should be defined

TABLE 4. COEFFICIENTS OF CORRELATION BETWEEN THE HUMUS FRACTIONS AND SOIL PROPERTIES

Variable	Depth	pH	TOC	Nt	S
Fraction Ia	0.98*	0.77*	-0.62*	-0.57*	0.12
Fraction I - C extr.	-0.85*	-0.70*	0.62*	0.54*	-0.13
Fraction I - CHA	-0.86*	-0.80*	0.59*	0.54*	-0.17
Fraction II - C extr.	0.53	0.33	-0.74*	-0.75*	0.35
Fraction II - CHA	0.33	0.19	-0.69*	-0.71*	0.37
CHA I+II	-0.83*	-0.79*	0.50	0.45	-0.13
CFA I+II	-0.41	-0.19	0.35	0.25	0.04
C- non-extracted	-0.74*	-0.60*	0.51	0.52	0.13

*Statistically significant at $p<0.05$, n = 14. Other symbols explained in Tables 2 and 3.

operationally, *i.e*. as a fraction extracted with a specified reagent in the given conditions. Such an understood fraction includes the group of low-molecular humic acids easily extracted with the weak alkaline solution. The contribution of this fraction reflects the current direction and intensity of the soil forming processes. In the ectohumus horizons, the contribution of fraction I was within the range of 46.6-51.7% of TOC, while in mineral horizons it has usually been lower, in the range of 15.7 to 48.9% of TOC (Table 3). In a soil without any morphological symptoms of podzolization, as in profile No. 1, the contribution of fraction I decreased gradually down the soil profile. In the podzolized soils (as in profiles Nos 2 and 3), the contribution of that fraction was clearly lower in mineral surface horizons, and the maximum was reached in the illuvial Bhsg horizon. A decrease in the contribution of fraction I was always accompanied by a very low contribution of fraction Ia – below 5%, which demonstrated the occurrence of an eluvial process. The contribution of fraction Ia was significantly negatively related to soil pH ($r = -0.70$) and significantly positively related to the organic carbon ($r = 0.62$). This is the typical distribution of fraction I in the forest soils formed from granite, as observed already by Laskowski [18] in the Sudetes Mountains, Niemyska-Łukaszuk [22] in the Tatra Mountains, and Drozd *et al*. [4, 6, 7], Licznar *et al*. [19, 20] in the Karkonosze Mountains. The ratio of the humic to fulvic acids (C_{HA}/C_{FA}) extracted in fraction I changed significantly in the soil profiles with depth. In the soil profile No. 1 (Cambisol), the ratio of C_{HA}/C_{FA} decreased from 0.98 to 0.60, and in profile No. 2 (Podzol) of from 2.06 to 0.69, pointing to the essential inversion of fractions ratio within the profile. The relative increase in the fulvic acids contribution with depth reflects the vertical segregation in the soil profiles caused by the stronger binding of the humic acids in surface layers and fulvic fraction movement to the underlying horizons. The relative increase in the contribution of the fulvic acids of fraction I with depth was clearly correlated with a similar increase in the contribution of the fulvic acids of fraction Ia. A relative balance between the humic and fulvic fraction was observed in ectohumus horizons, both on the pasture in a subalpine zone, and under a mixed stand in the lower forest zone, whereas a predominance of the humic fractions was found in ectohumus under the spruce forest. Profile No. 2 featured the considerable predominance of spruce needles as an ectohumus building material, while in profile No. 1 it was grass material, and in profile No. 3 - shrub-grassy with an addition of birch leaves and spruce needles. The high predominance of the humic above fulvic acids in an ectohumus of soil under the spruce forests has already been noticed by other authors, *e.g*. Drozd *et al*. [6]. There is, however, lack of a convincing explanation in the literature as to why a higher amount of high-molecular connections is formed in an ectohumus formed of spruce needles, when compared to the material of a mixed composition. 'Needle' ectohumus in profile No. 2 is characterized by the highest content of nitrogen (Table 2), which may be the key to explaining the results of the microbiological transformations of residual organic matter. Dziadowiec [8] reveals that in 'deciduous' beddings, humification is characterized rather by a predominance of the formation of fulvic acids, while in 'coniferous' beddings a relative balance between C_{HA} and C_{FA} is usually created.

The contribution of fraction II, defined as a stable connection with silicates, was small and did not exceed 5.2% of TOC. Such a low content of this fraction probably resulted from the scant amount of clay (1-2%) with which the fraction forms stable mineral-organic complexes [6, 20]. The percentage of fraction II was variable in the examined profiles. In the subalpine Cambisol (profile No. 1) the contribution of fraction II – in contrast to the fraction I – increased clearly with depth, mainly due to an increase in fulvic fraction contribution. However, due to the small contribution of fraction II, the sum of C_{HA} I + II and the sum of C_{FA} I + II decreased uniformly in the profile and this was also accompanied by a gradual loss in the contribution of non-hydrolysing carbon (Table 3). Such an arrangement is very typical for the brown earths (Cambisols), where weathering processes are accompanied by an *in situ* stabilization in the surface and subsurface horizons. The only distinguishing feature of the analyzed mountain soils is the very low C_{HA}/C_{FA} I + II index, reaching a value of 0.58, which indicates the large mobility of the fulvic acids in the strongly acidic soils. In forest soils (profiles Nos 2 and 3), the contribution of fraction II was the highest in subsurface horizons B due to an accumulation of the humic fraction. In both profiles of forest soils, the sum of humic acids (CHA I + II) and fulvic acids (CFA I + II) decreased down the profile, however, with distinct fluctuations in surface and subsurface mineral horizons, pointing to the less or more advanced podzolization of these soils.

The very high contribution of nonhydrolysing carbon, not only in ectohumus layers, but also in surface mineral horizons, reaching even 54.7% of TOC, indicated a slow rate of humification in these soils and the high percentage of non-decomposed organic debris, besides the already formed humins and ulmins [29]. A rapid increase in the amount of non-hydrolysing carbon in lower parts of profile no. 2 (up to 40.8% of TOC) can be explained by the bi-partial structure of the slope covers and also, as mentioned above, the polygenetic character of the Podzols in the upper zone of the Karkonosze Mountains.

CONCLUSIONS

1. The contribution of the low-molecular humus compounds (fraction Ia) increases in the soil profile with depth, which confirms their high mobility in acid mountain soils, higher in the forest soils, and lower in the meadow soils.

2. The contribution of fraction I decreases generally from the surface down the soil profile, but in soils subjected to podzolization it increases in illuvial Bh horizons. The relative predominance of the fulvic over humic acids in that fraction increases with depth.

3. The composition of a biomass inflow influences the ratio of the humic and fulvic acids of fraction I in ectohumus horizons. The ratio of C_{HA}/C_{FA} reaches the highest values under a monoculture spruce forest.

4. In the surface horizons of the forest soils, a predominance of humic over fulvic acids is always observed, while in the subalpine meadow soils, fulvic acids predominate over humic acids in all horizons of the soil profile.

5. Vegetation type and the dominant soil-forming process rather than simply climate factors influence the fractional composition of humus in the mountain soils of the Karkonosze Mountains.

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SKŁAD FRAKCYJNY PRÓCHNICY WYBRANYCH GLEB LEŚNYCH KARKONOSZY

Celem przedstawionej pracy była ocena ilościowa próchnicy górskich gleb Karkonoszy zróżnicowanych pod względem położenia nad poziom morza i występującej szaty roślinnej w oparciu o właściwości fizykochemiczne gleb i skład frakcyjny związków próchnicznych. Badaniami objęto 3 profile glebowe zlokalizowane we wschodniej części Karkonoszy, w rejonie Karpacza, na różnych wysokościach oraz w zróżnicowanych warunkach siedliskowych. Dwa profile zlokalizowane zostały w ekosystemach leśnych, natomiast jeden dla porównania, w strefie ekotonowej, w ekosystemie łąkowym. W pobranych próbkach gleb oznaczono: skład granulometryczny, zawartość węgla organicznego, pH, zawartość azotu ogółem, kwasowość wymienną oraz glin wymienny, wymienne kationy zasadowe oraz skład frakcyjny związków próchnicznych zmodyfikowaną metodą Tiurina. Na podstawie przeprowadzonych badań stwierdzono, że udział niskocząsteczkowych połączeń próchnicznych (frakcja Ia) zdecydowanie rośnie w profilu glebowym wraz z głębokością, co potwierdza ich dużą mobilność w kwaśnych glebach górskich, większą w glebach leśnych, a mniejszą w glebach łąkowych. Udział frakcji I (wolnej), zmniejsza się w głąb profili, ale w glebach podlegających bielicowaniu wzrasta w poziomach wzbogacenia Bh. Wraz z głębokością rośnie względna przewaga kwasów fulwowych nad huminowymi tej frakcji. Skład dopływającej biomasy wpływa na proporcję kwasów huminowych i fulwowych frakcji I w poziomach ektopróchnicy. Proporcja C_{HA}:C_{FA} przyjmuje najwyższe wartości pod monokulturowym borem świerkowym. W powierzchniowych poziomach gleb leśnych zawsze występuje przewaga kwasów huminowych nad fulwowymi, natomiast w glebie brunatnej pod murawą subalpejską kwasy fulwowe dominują nad huminowymi we wszystkich poziomach genetycznych profilu glebowego. Nie tyle strefowość klimatyczna, co charakter zbiorowiska roślinnego oraz dominujący proces glebotwórczy wpływają na skład frakcyjny związków próchniczny w profilach górskich gleb Karkonoszy.

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Soil Fertilization

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INFLUENCE OF LONG-TERM FERTILIZATION AND CROP ROTATION IN DIFFERENT SYSTEMS OF PLANTS CULTIVATION ON THE CONTENT OF DISSOLVED ORGANIC CARBON IN SOIL

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Abstract. The aim of study was to assess the influence of cultivated plant species (potato and rye) in monoculture and in crop rotation as well as the impact of the applied fertilizers on the content of soil organic carbon which was extracted by a 0.004 M $CaCl_2$ solution (EOC). Soil samples were taken from a long-term static fertilization experiment carried out in Skierniewice, Poland. The content of TOC in the soil of the plots fertilized with manure was higher than in objects with mineral fertilization. In monoculture, the higher mean content of EOC was found in soil organic matter under the rye and in crop rotation system in soil under potato. Regardless to cultivated plant species as well as regardless to type of fertilization higher contribution of EOC was determined in crop rotation system than in monoculture. Regardless to cultivated plant species, EOC contribution in organic carbon (TOC) in both cultivation systems depended on fertilizer and was highest in the soil fertilized with NPK.

The soil organic matter has a differentiated and complex composition depending on the initial substrates, as well as bioecological conditions of its decomposition. In the soil material, beyond a group of humus compounds which are difficult to dissolve, there is a fraction of humus that is water soluble – SOM (Soluble Organic Matter) – considered the most mobile organic fraction of the soil. SOM may be composed of carbohydrates, protein, fat, hydrocarbons and their derivatives, low-particle fractions of humic acids, as well as many other simple organic compounds. The formed soluble and mobile SOM bindings with mineral components of the soil may be washed deeper into the soil profile and further into the ground waters [14]. The SOM content in cultivated soils changes depending on the means of fertilization or the species of cultivated plants, among other factors [1, 8, 10, 13]. The addition of the fresh organic matter to the soil increases the content of SOM [2],

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while soil cultivation may cause its decrease [9]. Cultivation of plants that increase the humus content in the soil also increases the SOM content [5]. Quantitative research on SOM in soils are based on measuring the content of organic carbon as a fraction extracted with water and/or weak solutions of neutral salts.

The aim of this paper was to evaluate the content of organic carbon and its soluble form in the soils from the rye and potato cultivation. The research was based on investigating the soil samples from a multi-year cultivation of these plants in monoculture and crop rotation with differentiated organic-mineral fertilization.

MATERIAL AND METHODS

The test soils were taken from a plot of the multi-year static fertilization experiment at the Research Station in Skierniewice, Poland. The original plot descriptions related to this experiment were used after Mercik [12]. The experimental plot is located on silt, pseudo-stagnic soils according to the WRB (2006) 'Stagnic Luvisols'. Soil samples were taken from the arable horizon (0-25 cm) of the plots after potato and rye cultivation in monoculture (plots D_5 and D_6) and five-field crop rotation (plots E_{1A} and E_{1E}) with the selected fertilization combinations. In the selected experimental variant, the first factor was the species of the cultivated plant – potato or winter rye, while the second factor was the fertilization method.

The soils from the plots with previous monoculture potato (D_5) and rye (D_6) cultivation were taken from the following fertilization combinations: Ca (control); NPK; CaNPK and Ca + manure (20 t $ha^{-1}year^{-1}$); and CaNPK + manure (30 t ha^{-1}every 4 years – starting in 1989). The samples from the fields with the five-field crop rotation (potato – 30 t ha^{-1} manure, spring barley, red clover, wheat, rye) were taken from under the potato cultivation E_{1A} and rye cultivation E_{1E} from the following objects: Ca (control); NPK; and CaNPK. In the bulk samples of the soil material (mean of 5 measurements), the content of organic carbon (C_{org}) was measured in g kg^{-1} soil – using the CHN analyzer (Model 1106, manufactured by Carlo-Erba Strumentazione, France). The extraction of the soluble organic matter was carried out using a 0.004M solution of $CaCl_2$. In the above solutions, the content of extracted compounds of organic carbon was assessed in mg C kg^{-1} d.m. soil sample – using the analyzer O-I-Analytical Model 1010 Wet Oxidation Total Organic Carbon (France). Tables 1-3 contain the calculated percentage content of the extracted organic carbon (EOC) in C_{org} (% in C_{org}). The extraction was carried out on air-dry soil samples in 1 h. The ratio of soil to the extractant was 1:10 [6].

RESULTS AND DISCUSSION

In the monoculture cultivation of potato (D5) and rye (D6), the mineral fertilization caused a decrease in the content of organic carbon (C_{org}) in relation to the control (Table 1). There was an increase in the content of the EOC fraction and

TABLE 1. EOC CONTENT (mg kg^{-1}), EOC CONTRIBUTION (%) IN SOIL ORGANIC CARBON POOL (% TOC) AND pH IN SOIL UNDER POTATO AND RYE CULTIVATED IN MONOCULTURE AND CROP ROTATION

Plants	Fertilization*	TOC** (g kg^{-1})	EOC (mg kg^{-1})	EOC % TOC	pH_{KCl}
Potato, field D_5	Ca/control	7.6	49.14	0.65	6.08
	NPK	5.4	61.02	1.13	5.07
	Ca NPK	5.5	69.93	1.27	5.09
	Ca + manure	8.6	72.63	0.84	6.07
	CaNPK + manure	8.5	65.75	0.77	5.82
Rye, field D_6	Ca/control	9.7	62.24	0.64	6.36
	NPK	8.8	95.99	1.09	4.79
	Ca NPK	9.9	67.50	0.68	6.10
	Ca + manure	16.2	81.00	0.50	6.10
	CaNPK + manure	12.4	102.47	0.83	5.87
Potato, field E_{1A}	Ca/control	9.7	102.87	1.06	5.83
	NPK	9.9	137.57	1.39	5.22
	Ca NPK	10.1	115.97	1.15	5.86
Rye, field E_{1E}	Ca/control	8.6	98.15	1.14	5.69
	NPK	9.7	130.55	1.35	4.25
	Ca NPK	9.9	72.36	0.73	6.11

*Doses since 1976: field D: Ca – 1.6 t ha^{-1} CaO every 4 years; field E: 2 t ha^{-1} CaO every 5 years , N – 90 kg ha^{-1}, P – 26 kg ha^{-1}, K – 91 kg ha^{-1} ; EOC – extractable organic carbon, C_{org}; TOC – total organic carbon; ** results of Author studies [3, 4].

its content in C_{org}. The highest content of EOC in the soil of the D5 plot was noted in the CaNPK object (69.93 mg kg^{-1} and 1.27% in C_{org}), while in the D6 plot, the highest EOC content was observed in the NPK object (95.99 mg kg^{-1} and 1.09% in C_{org}). The introduction of manure into the potato and rye cultivation systems caused an increase in the accumulation of organic carbon. The growth of the C_{org} content in the soil of the D5 plot (8.6 g kg^{-1}) was accompanied by the increase in the content of EOC from 72.63 mg kg^{-1} (47.8% in relation to the control). In the case of rye D6 (12.4 g kg^{-1}C_{org}), the highest content of EOC – 102.47 mg kg^{-1} (a 65% increase in relation to the control) was also noted in the object with manure, but in combination with CaNPK. The EOC content expressed in % of C_{org} content on these objects ((D5 (Ca+manure 20 t ha^{-1} year^{-1}) and D_6 (CaNPK+manure 30 t ha^{-1} every 4 years)) was comparable (0.84 and 0.83), which corresponds to an approx. 30% increase in relation to the control object (Table 1). The obtained results

TABLE 2. VARIATION ANALYSIS FOR EOC CONTENT (mg kg^{-1}), EOC CONTRIBUTION (%) IN SOIL ORGANIC CARBON POOL (% TOC) AND pH IN SOIL UNDER POTATO AND RYE CULTIVATED IN MONOCULTURE

Experimental factors		EOC (mg kg^{-1})		EOC (% TOC)		TOC* (g kg^{-1})		pH_{KCl}	
I: plant	potato field D5	63.7	LSD 0.28	0.90	LSD 0.004	7.10	LSD 0.54	5.63	LSD 0.004
	rye field D6	81.9		0.72		11.4		5.84	
II: fertilization	Ca/control	55.6	LSD 0.64	0.64	LSD 0.009	8.7	LSD 0.54	6.22	LSD 0.010
	NPK	78.6		1.11		7.1		4.93	
	Ca NPK	68.7		0.89		7.7		5.59	
	Ca + manure	76.8		0.62		12.4		6.09	
	CaNPK + manure	84.1		0.80		10.5		5.84	

*Results of Author studies [3, 4].

(Tables 1 and 2) indicate, similar to the research of Gonet *et al*. [6] and Zsolnay and Gorlitz [15], that the use of fertilization with manure also caused an increase in the EOC content. The statistical analysis (Table 2) of the results obtained from the soil samples of the potato and rye monoculture indicated that the factor that had a significant impact on the EOC fraction was the species of the cultivated plant, as well as fertilization. Higher (by about 30%) content of EOC was found in the organic matter from rye cultivation D6 as compared to the potato cultivation D5 (81.9 and 63.7 mg kg^{-1}, respectively). Regardless of the species of the cultivated plant, the average content of EOC in C_{org} ranged from 0.62 to 1.11% and was found to be the highest in the object with NPK.

In the 5-field crop rotation (Table 3), no significant difference in the content of C_{org} was stated in the soil from the objects of potato (E1A) and rye (E1E) cultivation at the investigated fertilization combinations. The content of C_{org} was between 8.6 and 10.1 g kg^{-1} (Table 1). The factors that significantly differentiated the content of the EOC fraction in the soil were (similar to the monoculture) the species of the cultivated plant and the fertilization method (Table 3). Higher (by about 20%) content of EOC was found in the organic matter of the soil from potato cultivation (118.8 mg kg^{-1}) as compared to rye (100.3 mg kg^{-1}) – opposite to the case of monoculture. The lower content of EOC in the humus of the rye soil E1E could be a consequence of the order in which rye is cultivated in the crop-rotation. On the E1E plot, rye is cultivated in the last (5th) year after manure (the activity of the manure is weakened) and the second year after papilionaceous plants. The soil samples from the potato cultivation E1A were taken from the plots fertilized with manure in the fall of the previous year. The results confirm the prediction that the content of water-soluble organic matter in cultivated soils depends on the organic matter introduced into the soil and on the agrotechnical measures [6]. The

TABLE 3. VARIATION ANALYSIS FOR EOC CONTENT (mg kg^{-1}), EOC CONTRIBUTION (%) IN SOIL ORGANIC CARBON POOL (% TOC) AND pH IN SOIL UNDER POTATO AND RYE CULTIVATED IN CROP ROTATION

Experimental factors		EOC (mg kg^{-1})		EOC (% TOC)		TOC* (g kg^{-1})		pH$_{KCl}$	
I: plant	potato field D5	118.8	LSD 1.19	1.20	LSD 0.016	9.9	LSD n.s.	5.64	LSD 0.028
	rye field D6	100.3		1.07		9.4		5.35	
II: fertilization	Ca/control	100.6	LSD 1.82	1.10	LSD 0.025	9.7	LSD n.s.	5.76	LSD 0.349
	NPK	134.1		1.36		9.9		4.74	
	Ca NPK	94.2		0.93		10.1		5.99	

n.s. – not significant differences, *results of Author studies [3, 4].

post-harvest residue of the plants contains various amounts of material extracted using water solutions, such as wheat straw 8.9-19% [8, 13] and red clover, corn or vetch 31-35% [10].

Regardless of the species of the cultivated plant, the mean content of EOC in C_{org} ranged from 0.93 to 1.36% and was the highest in the object fertilized only with NPK (Table 3). The contents of EOC (Table 1) in the potato cultivation soil (137.57 mg kg^{-1}) and rye cultivation soil (130.55 g kg^{-1}) in crop rotation were also the highest in the objects with NPK (by 33.7 and 33.01% in relation to the control). The content expressed in % of C_{org} was respectively 1.39 and 1.35%, which corresponds to the growth by 31.13% and 18.42% as compared to the control sample. Higher contents of EOC were observed in the soil fertilized with NPK (pH 4.93 and 4.74) as compared to the objects with other fertilization combinations with liming (Tables 1-3). This confirms the research by Schuman [11], who stated that the presence of calcium ions in the soil may have a stabilizing effect on the structure of organic matter and can decrease the freeing of the mobile organic matter. Therefore, indirectly this process depends on the soil reaction, which may have a stimulating effect on the freeing of the mobile organic matter [8], at least as a result of liming or acid rainfall. The naturally acid soils, such as forest soils, contain more mobile organic matter [7]. In the described experiment on limed soils with various fertilization variations, the content of soluble carbon in the total carbon was lower than in the soil fertilized with NPK. This indicates sequestration and thus prevents the washing and losses of soluble carbon, as also observed by Zsolnay [16].

CONCLUSIONS

1. In the monoculture cultivation, a higher mean content of extracted organic carbon (EOC) was found in the organic matter of the soil from rye cultivation, while in the crop-rotation cultivation, the higher EOC content was observed in the soil organic matter from potato cultivation.

2. The highest content, as well as the highest content of EOC in the total carbon, regardless of the species of the cultivated plants, was found in the soils from the objects fertilized with NPK, both in monoculture and in crop-rotation cultivation.

3. The use of liming in the multi-year mineral, organic and mineral-organic fertilization resulted in a decrease in the content and the EOC content in the total carbon, which may indicate the increased sequestration of carbon in the soil.

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WPŁYW WIELOLETNIEGO NAWOŻENIA W RÓŻNYCH SYSTEMACH UPRAWY ROŚLIN NA ZAWARTOŚĆ ROZPUSZCZALNEGO WĘGLA ORGANICZNEGO W GLEBIE

Celem badań była ocena zawartości węgla organicznego i jego rozpuszczalnej formy w glebie pod uprawą żyta i ziemniaka. Próbki glebowe pochodziły z wieloletniego doświadczenia w Skierniewicach, z uprawy tych roślin w monokulturze i zmianowaniu, przy zróżnicowanym nawożeniu organiczno-mineralnym. Udział EWO w węglu organicznym w obu systemach uprawy, niezależnie od uprawianej rośliny, istotnie zależał od rodzaju nawożenia i był najwyższy w glebie nawożonej NPK. Zastosowanie wapnowania w wieloletnim nawożeniu mineralnym, organicznym i mineralno-organicznym powodowało zmniejszenie zawartości jak również udziału EWO w puli węgla organicznego, co może wskazywać na sprzyjanie sekwestracji węgla w glebie.