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THE EVALUATION OF QUALITY OF SOILS OF THE CARPATHIAN LIME TREE FOREST AND BEECH FORESTS ON THE BASIS OF SOME CHEMICAL AND BIOCHEMICAL PROPERTIES

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Abstract. The aim of this study was to evaluate the quality of *endoeutric cambisols*, developed from Magura sandstones and schists of Carpathian flysch under the Carpathian lime tree forest *Tilio-Carpinetum typicum* of a fertile variant (T-C_f) and a poor variant (T-C_p), and the Carpathian beech forest of a typical variant *Dentario glandulosae-Fagetum typicum* (Dg-F_t) and a fertile variant *Dentario glandulosae-Fagetum lunarietosum* (Dg-F_l). Soil samples from humus horizons in 10 replications and one cumulative sample from each of deeper horizons were collected from soil of each plant community. Such soil properties as pH in H_2O and 1 M KCl, mechanical composition, sorption properties, org. C, total N, available P, exchangeable Ca, Mg, K, and Na, as well as the activities of dehydrogenases, phosphatases, invertase, urease, protease, and cellulases were compared. The distributions of values of investigated properties were compared by using Tukey's test. Uniformed tendency in properties of humus horizons of the investigated forest communities was not confirmed. While the decrease in abundance of available phosphorus and organic matter (per 1 ha), as well as in activity of dehydrogenases, proteases and urease (in terms of soil volume in a profile of 1 $dm^2 \times 1$ m), along with impoverishment of plant communities, were noted arranging investigated forests in the following sequence: T-C_f > Dg-F_l > T-C_p > Dg-F_t. The study results permitted to conclude that the lime tree forest has a more favourable effect on soil quality than the beech forest.

Key words: Carpathian lime tree forest, Carpathian beech forest, soil enzyme activity, soil quality

INTRODUCTION

One of the present challenges of soil science is to define the adequate index of soil quality [Leirós et al. 1999]. The evaluation of soil quality should take into account soil properties most highly associated with the level of its quality. Biological and biochemi-

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cal properties of soil, as very susceptible to stress and management treatments, should be used in soil quality estimation [Dick 1994, Nannipieri 1994, Trasar-Cepeda et al. 1998, Leirós et al. 1999, 2000, Januszek 1999, 2001]. Results of investigations of Januszek [1995, 1999, 2001] on activity of enzymes taking part in chemical change of organic compounds of carbon and nitrogen showed that the activity of dehydrogenases, proteases, and urease adequately characterizes the biological activity and quality of major forest soil types of southern Poland. For evaluation of soil quality this author proposed the enzymatic index of soils EIG_{DPU} elaborated on the basis of activity of dehydrogenases, proteases, and urease determined in a soil profile to the depth of 100 cm [Januszek 1999, 2001].

The aim of this study was to evaluate the quality of endoeutric cambisols developed from Magura sandstones and schists of Carpathian flysch, being under the influence of various plant communities of the Beskid Sądecki range, on the basis of activity of selected enzymes and some chemical properties of soils. The study concerned community of the Carpathian lime tree forest and two sub-associations of the Carpathian beech forest. The Carpathian lime tree forest, a floristic curiosity recognized in Europe (the only lime tree forest in the Carpathian Mountains), grows on the Mikowa hill near the town of Muszyna [Pawłowski 1921, Fabijanowski 1961]. The authors became interested in this forest because of the favourable effect of lime tree on soil. This tree species creates good shade conditions and favourable temperature and moisture relations of air [Obrębska-Starklowa 1967, 1970], and provides the forest with ample leaf litter susceptible to microbiological decomposition [Puchalski and Prusinkiewicz 1990]. The question, whether this tending character of lime tree toward the soil would be reflected in soil chemical and biochemical properties, was very interesting.

MATERIAL AND METHODS

Four areas representing different plant communities were chosen for the study. Two study plots were established in the "Obrożyska" lime tree reserve situated near Muszyna. They represented the fertile variant of the Carpathian lime tree forest (association *Tilio-Carpinetum typicum* – Tilia cordata with *Stelaria holostea*; T-C_f, profile 1), and the poor variant of the lime tree forest (Tilia cordata with *Polytrichum formosum*; T-C_p, profile 2) [Fabijanowski 1961]. The remaining two plots were situated in patches of well developed sub-associations of the Carpathian beech forest. The plot representing the typical sub-association of the Carpathian beech forest (*Dentario glandulosae-Fagetum typicum*; Dg-F_t, profile 3) was situated in the old beech stand in compartment 156 of the Majdan forest section, the Piwniczna forest district, while the plot in the richer sub-association of the Carpathian beech forest with *Lunaria rediviva* (*Dentario glandulosae-Fagetum lunarietosum*; Dg-F_l, profile 4) was established in the control unit 121 of the Forest Experimental Station in Krynica.

The investigated soil profiles, forming the forest site type of the mountain forest, were situated near the lower boundary of the lower mountain climatic-vegetation belt (altitude from 502 to 600 m above sea level). They slightly differed in conditions of the mesorelief. Patches of the more fertile lime tree forest (profile 1) and the more fertile beech forest (profile 4) occurred in concave parts of slopes, while patches of the poorer lime tree forest (profile 2) and the typical Carpathian beech forest (profile 3) were situated on ridges.

From the humus horizon of each of the investigated plant communities 10 samples were taken along the line, keeping the distance of 5 m between samples. From the remaining genetic horizons of each soil profile one cumulative sample was taken within a soil pit. Also from all genetic horizons of the investigated soils the soil of undisturbed structure was taken to cylinders, 250 cm^3 in volume, in order to determine the volume density. In horizons of high soil skeleton content (above 60%) the bulk density was taken into account.

In samples of natural moisture, screened through sieve of 2 mm mesh, and kept in cold store at 4°C, the activity of following enzymes was determined calorimetrically:

– dehydrogenases (AD) by Lenhard's method using procedure of Casida et al. [1964],
– urease (AU) by the method of Romejko and Malińska [Haziev 1976], modified by Čunderova, using the phosphate buffer of pH 6.7 and 5-percent urea solution as a substrate, and 24 h. incubation,
– proteases (AP) by the method of Hoffmann and Teicher [Haziev 1976],
– phosphatases (AF) by the method of Kramer and Erdea [Haziev 1976],
– invertase (AI) by the method of Ščerbakova [Haziev 1976],
– cellulases (AC) by the viscometric method [Russel 1972].

The moisture was determined by the gravimetric method.

The enzymatic activity was recalculated into the absolutely dry matter of soil, as well as the absolutely dry matter of soil in soil core of 1 dm^2 cross-section and 1 m depth. The enzymatic activity in individual genetic horizons, volume of soil skeleton, and volume density of earthy parts in respective genetic horizons were taken into consideration in these calculations.

In air dry samples, screened through sieve of 2 mm mesh, the following properties were determined [Ostrowska et al. 1991]:

– mechanical composition by the aerometric method of Casagrande modified by Prószyński,

– soil pH in H_2O and 1M KCl by the potentiometric method with ratio soil:solution 1:2.5,

– hydrolytic acidity by the Kappen's method,

– content of exchangeable forms of Ca, Mg, K, and Na by the method of extraction in 1M ammonium acetate using a spectroscope of atomic absorption, and calculating the total exchangeable bases (S) and the degree of saturation of the sorption complex with basic cations (V%),

– organic carbon by the oxidometric method of Tiurin modified by the Department of Soil Science, Agricultural University of Cracow, with calculation of organic substance, using conversion factor of 1.724,

– available phosphorus by the method of Bray-Kurtz I [Procedure... 1995].

The distributions of activity of the investigated enzymes (in 30 replications) and physicochemical properties of humus horizons of the investigated soils (in 10 replications) were compared using the Tukey's test. Also simple correlations between tested properties were calculated. Data were analysed using the STATISTICA (version 6) statistcal package.

RESULTS

The investigated soils, forming site of the mountain forest type with different plant communities, showed a certain diversification of basic physicochemical properties, in spite of being classified in one subtype of *endoeutric cambisol*. They were characterized by loamy graining. Sandy loam interbedded with very fine sandy loam occurred in profile 1 representing a richer variant of lime tree forest. Soil of the poor lime tree forest (profile 2) was deeply underlaid with clay loam. Soil of the typical Carpathian beech forest (profile 3) was characterized by a somewhat heavier graining in the transitional horizon (AB) to 40 cm, while soil of beech forest with *Lunaria rediva* (profile 4) had the heaviest graining, with graining of medium and heavy loams from depth of 40 cm and deeper, and containing the least amount of colloidal clay in the top horizon (Fig. 1, Table 1).

Table 1. Some physical and physico-chemical properties of the investigated soils
Tabela 1. Wybrane właściwości fizyczne i fizykochemiczne badanych gleb

Profile number Numer profilu	Depth Głębokość cm	Horizon Poziom	Bulk density Gęstość objętościowa $g \cdot cm^{-3}$	Frakcja – Fraction mm			pH		*Th*	*V* %
				> 2	< 0.02	< 0.002	H_2O	KCl		
1	0-10	A	1.14	0	25.8* ±1.3**	9.1 ±1.3	4.53 ±0.3	3.68 ±0,3	17.95 ±1.5	30.9 ±8.9
	10-25	ABbr	1.35	10	33	8	5.1	3.7	9.15	36.1
	25-58	Bbr	1.56	45	23	8	5.5	3.9	6.40	67.2
	58-100	BbrG	1.77	40	25	9	6.1	4.4	8.00	85.0
2	0-8	A	1.04	0	27.7 ±2.3	9.6 ±2.0	5.13 ±0.2	4.32 ±0.2	16.14 ±3.0	51.4 ±8.0
	8-58	Bbr	1.21	40	26	7	4.6	3.7	5.93	10.1
	54-85	Bbrg	1.40	60	25	8	5.0	3.6	5.95	37.0
	85-100	BbrC	1.59	65	60	33	5.3	3.3	22.68	70.6
3	2-7	A	1.07	35	29.8 ±5.5	9.9 ±2.9	4.56 ±0.2	3.59 ±0.2	18.83 ±2.4	30.7 ±10.9
	7-40	ABbr	1.24	50	36	10	4.6	3.2	13.88	13.0
	40-70	Bbr	1.49	60	24	6	5.5	3.7	10.80	69.4
	70-100	BbrC	1.50	70	26	8	5.5	3.7	18.90	78.6
4	1-14	A	0.82	20	24.4 ±2.0	6.7 ±1.1	4.65 ±0.2	3.77 ±0.2	19.58 ±2.1	37.0 ±7.3
	14-40	ABbr	0.97	40	28	9	5.0	3.8	11.80	36.4
	40-70	Bbr	1.14	60	55	23	5.8	4.6	11.18	51.0
	70-100	BbrCG	1.55	70	40	11	6.0	4.6	8.90	79.8

*Mean of 10 replications.
**Standard deviation.
Th – sorption capacity in $cmol(+)kg^{-1}$ soil.
V – degree of base saturation.
*Średnia z 10 powtórzeń.
**Odchylenie standardowe.
Th – pojemność sorpcyjna w $cmol(+)kg^{-1}$ gleby.
V – stopień wysycenia kompleksu sorpcyjnego kationami zasadowymi.

The humus horizons of the investigated soils were characterized by a strongly acid reaction (Fig. 1). It was surprising that the humus horizon of poorer lime tree forest (profile 2) showed a higher reaction (by about 0.5 of pH unit) than humus horizons of the remaining soils. Slightly different degree of leaching of surface soil layers was found in each of the investigated soils. The strongest one was found in the soil of a poorer lime tree forest (profile 2), where increase of the degree of saturation of sorption complex with basic cations above 50% occurred not shallower than the depth of 85 cm. In the remaining soils this increase occurred from the depth of 40 cm in the case of beech forest, and from 25 cm in the case of the fertile lime tree forest (Table 1).

The greatest concentration of org. C was found in humus horizon A of soil of the typical Carpathian beech forest (profile 3, Fig. 3), greater than in humus horizons of the remaining soils under investigations. Soils of beech stands were characterized by deeper, reaching down to 40 cm, humus horizons than soils of lime tree stands. But the ABbr horizon in beech forest with *Lunaria rediviva* (Dg-F_l, profile 4) contained almost twice as much of organic substance (2.24%) as the same horizon in soil of the typical beech forest.

Humus horizons of soils with communities T-C_p (profile 2), Dg-F_t (profile 3), and Dg-F_l (profile 4) significantly differed from one another in respect of concentration of total nitrogen (Fig. 1). The lowest content of total nitrogen in soil humus horizon was found in the case of a poorer lime tree forest (0.20%), while in soil humus horizon of a fertile lime tree forest (T-C_f, profile 1) it was on a medium level as found in soils of beech stands. The highest nitrogen content in humus horizon (0.34%) was found in the case of a fertile beech forest with *Lunaria rediviva* (profile 4). At the same time humus horizons of floristically richer sub-associations of beech forest (profile 4) and lime tree forest (profile 1) were characterized by a better degree of conversion of organic substance, which was indicated by significantly lower values of the index C/N in comparison with soils of the poorer lime tree forest and the typical beech forest (10.7 and 12.6 respectively; Table 2).

Moreover, a slightly higher concentration of available phosphorus was found in soil humus horizon of the richer beech forest Dg-F_l (profile 4; Fig. 1).

From among the physical, physicochemical, and chemical properties investigated in humus horizons the greatest variation was found in the case of available phosphorus (Fig. 1). The coefficient of variation for this feature ranged from 11% (T-C_f) to 63% (Dg-F_l). The smallest variation was observed in the case of pH.

There were significant differences in activity of investigated enzymes in soil humus horizons of the investigated plant associations. The activity of invertase was the most variable one (Fig. 2). In humus horizons of the fertile lime tree forest (T-C_f, profile 1) and the beech forest with *Lunaria rediviva* the activity of invertase was similar, but it was on a higher level than in humus horizons of the remaining soils. The lowest activity of invertase was found in humus horizon of the Dg-F_t community (profile 3).

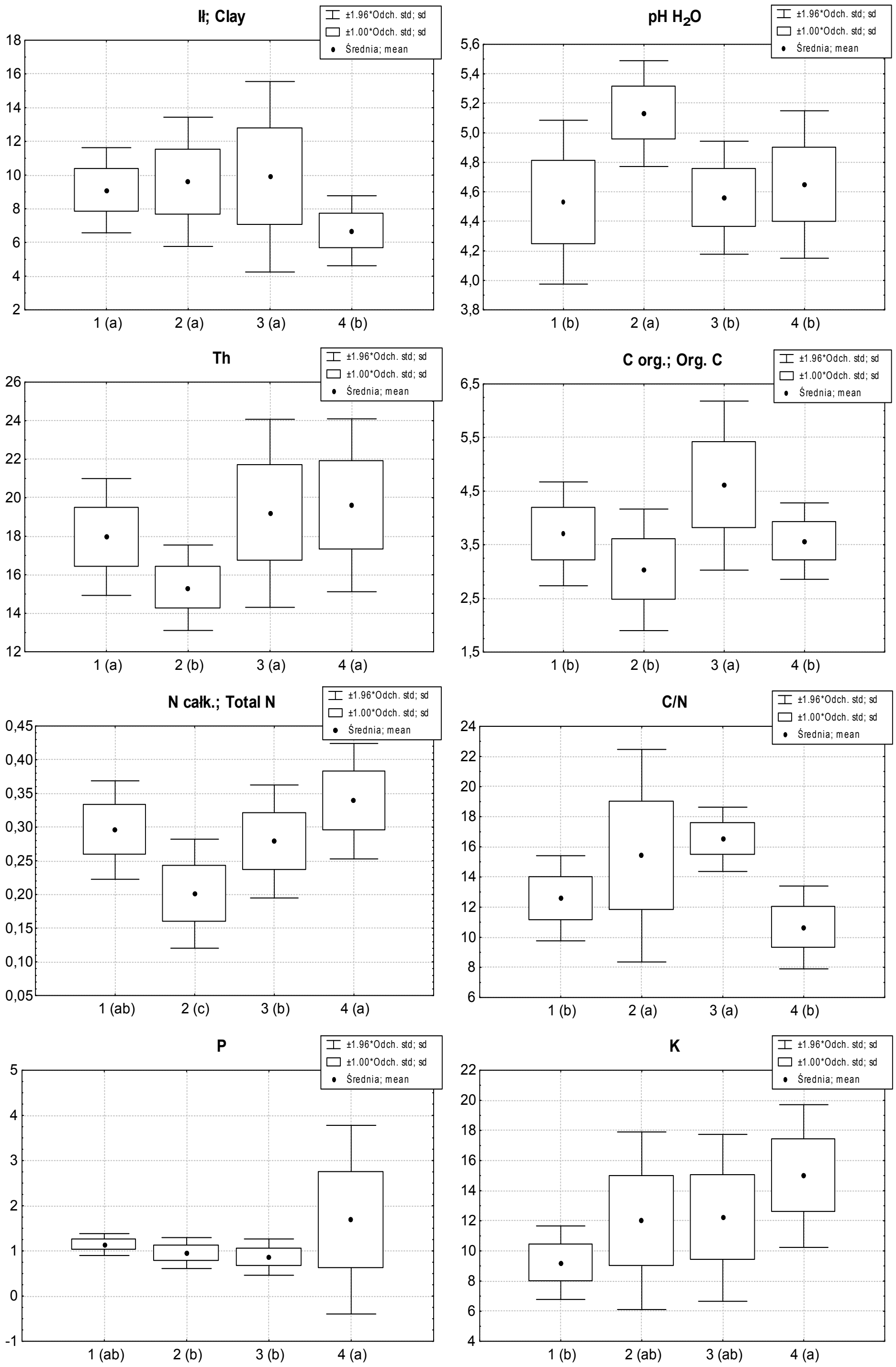
Ił; Clay
±1.96*Odch. std; sd
±1.00*Odch. std; sd
Średnia; mean
1 (a) 2 (a) 3 (a) 4 (b)
pH H_2O
1 (b) 2 (a) 3 (b) 4 (b)
Th
1 (a) 2 (b) 3 (a) 4 (a)
C org.; Org. C
1 (b) 2 (b) 3 (a) 4 (b)
N całk.; Total N
1 (ab) 2 (c) 3 (b) 4 (a)
C/N
1 (b) 2 (a) 3 (a) 4 (b)
P
1 (ab) 2 (b) 3 (b) 4 (a)
K
1 (b) 2 (ab) 3 (ab) 4 (a)

Table 2. Some chemical and biochemical properties of the investigated soils
Tabela 2. Niektóre właściwości chemiczne i biochemiczne badanych gleb

Profile number Numer profilu	Horizon Poziom	Organic C C_{org}	Total N $N_{całk}$	C/N	Available P P_{przysw} mg/kg	*AD*	*AI*	*AF*	*AU*	*AP*	*AC*
		%									
1	A	3.7*	0.30	12.59	1.14	34.63	3.34	13.97	3.37	148.82	78.3
		±0.47**	±0.04	±1.39	±0.12	±10.65	±0.85	±2.72	±1.31	±18.96	±13.3
	ABbr	0.90	0.11	8.2	0.34	5.28	0.24	2.50	0.82	63.10	0.0
	Bbr	0.22	0.02	11.0	0.64	0.26	0.01	0.68	0.06	16.03	21.6
	BbrG	0.20	0.02	10.0	0.35	0.16	0.07	0.00	0.06	0.00	0.0
2	A	3.03	0.20	15.41	0.95	34.98	2.30	11.49	3.54	119.81	57.1
		±0.55	±0.04	±3.40	±0.17	±6.53	±0.59	±1.57	±2.20	±22.12	±8.0
	Bbr	0.43	0.04	10.8	0.21	1.22	0.26	1.57	0.21	6.70	0.0
	Bbrg	0.19	0.02	9.5	0.20	0.44	0.17	0.87	0.08	5.01	11.5
	BbrC	0.31			0.13	0.01	0.04	0.19	0.00	0.00	8.8
3	A	4.60	0.28	16.38	0.86	39.50	1.60	16.85	2.37	118.53	72.0
		±0.77	±0.04	±1.14	±0.19	±8.89	±0.57	±3.84	±1.10	±17.72	±8.2
	ABbr	0.71	0.06	11.8	0.07	6.45	0.53	1.61	0.55	15.84	18.1
	Bbr	0.28	0.03	9.3	0.04	1.01	0.10	0.53	0.11	1.94	16.7
	BbrC	0.26			0.05	0.08	0.05	0.45	0.00	5.76	10.7
4	A	3.57	0.34	10.66	1.69	39.36	3.49	14.73	3.61	209.59	81.0
		±0.34	±0.04	±1.32	±1.01	±10.85	±1.21	±7.15	±0.50	±75.47	±14.0
	ABbr	1.23	0.12	10.3	1.00	3.85	0.14	1.88	0.80	53.26	17.1
	Bbr	0.49	0.06	8.2	0.35	0.64	0.01	1.08	0.48	21.23	13.8
	BbrCG	0.27			0.17	0.15	0.00	0.15	0.03	9.98	10.3

*Mean of 10 replications. **Standard deviation.

AD – dehydrogenase activity (mg TPF · 100 g^{-1} soil · 24 h^{-1}), *AI* – invertase activity (mg glucose · 1 g^{-1} soil · 1 h^{-1}), *AF* – phosphatase activity (mg phenol · 5 g^{-1} soil · 2 h^{-1}), *AU* – urease activity (mg $N\text{-}NH_4$ · 1 g^{-1} soil · 24 h^{-1}), *AP* – protease activity (mg $N\text{-}NH_2$ · 100 g^{-1} soil · 20 h^{-1}), *AC* – cellulase activity (percentage of viscisity decrease of 0.9% methylocellulose solution).

*Średnia z 10 powtórzeń. **Odchylenie standardowe.

AD – aktywność dehydrogenaz (mg TFF · 100 g^{-1} gleby · 24 h^{-1}), *AI* – aktywność inwertazy (mg glukozy · 1 g^{-1} gleby · 1 h^{-1}), *AF* – aktywność fosfatazy (mg fenolu · 5 g^{-1} gleby · 2 h^{-1}), *AU* – aktywność ureazy (mg $N\text{-}NH_4$ · 1 g^{-1} gleby · 24 h^{-1}), *AP* – aktywność proteaz (mg $N\text{-}NH_2$ · 100 g^{-1} gleby · 20 h^{-1}), *AC* – aktywność celulaz (procent spadku lepkości 0,9-procentowego roztworu metylocelulozy).

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Fig. 1. Mean values (10 replications) and distribution of clay content (%), pH in H_2O, sorption capacity (cmol(+)kg^{-1} of soil), org. C and total nitrogen concentration (%), C:N ratio, available phosphorus (P; mg·100 g^{-1} of soil) and exchangeable potasium (K; mg·100 g^{-1} of soil) in humus horizons of soil in the investigated plant communities: 1 – *Tilio-Carpinetum* fertile variant, 2 – *Tilio-Carpinetum* poor variant, 3 – *Dentario glandulosae-Fagetum typicum*, 4 – *Dentario glandulosae-Fagetum lunarietosum*. Different small letters in brackets close to profile number on the *x* axis, denote distributions significantly differring with 95% probability or greater

Rys. 1. Wartości średnie (10 powtórzeń) oraz rozkłady zawartości iłu (%), pH w H_2O, pojemności sorpcyjnej (cmol(+)kg^{-1} gleby), koncentracji $C_{org.}$ (%), $N_{całk.}$ (%), stosunku C:N, $P_{przys.}$ (mg·100 g^{-1} gleby) oraz $K_{wym.}$ (mg·100 g^{-1} gleby) w poziomach próchnicznych gleb badanych zbiorowisk roślinnych: 1 – *Tilio-Carpinetum* wariant żyzny, 2 – *Tilio-Carpinetrum* wariant ubogi, 3 – *Dentario glandulosae-Fagetum typicum*, 4 – *Dentario glandulosae-Fagetum lunarietosum*. Małe litery w nawiasach, obok numeru profilu glebowego na osiach *x*, oznaczają rozkłady różniące się statystycznie istotnie z prawdopodobieństwem 95-procentowym lub większym

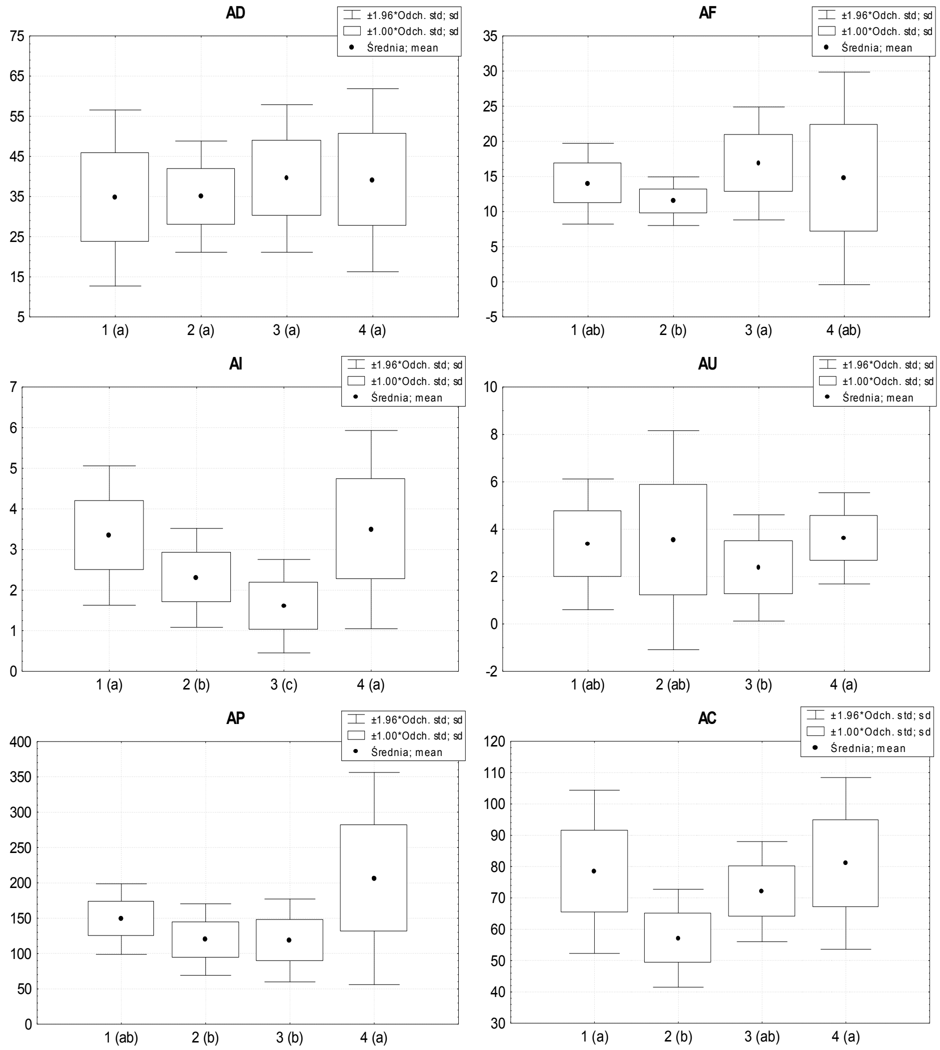

Fig. 2. Mean values (30 replications) and distribution of dehydrogenase activities (*AD*; mg TPF · 100^{-1} g of soil · 24 h^{-1}), phosphatase activities (*AF*; mg of phenol · 5 g^{-1} of soil · 2 h^{-1}), invertase activities (*AI*; mg of glucose · 1 g^{-1} of soil · 1 h^{-1}), urease activities (*AU*; mg N-NH_4 · 1 g^{-1} of soil · 24 h^{-1}), protease activities (*AP*; mg N-NH_2 · 100 g^{-1} of soil · 20 h^{-1}) and cellulase activities (*AC*; % of viscosity decline of 0.9% methyl cellulose solution in McIlvaine buffer (pH 5.5) in humus horizons of soil in the investigated plant communities (for designations see Figure 1)

Rys. 2. Wartości średnie (30 powtórzeń) oraz rozkłady aktywności dehydrogenaz (mg TFF · 100 g^{-1} gleby · 24 h^{-1}), fosfataz (*AF*; mg fenolu · 5 g^{-1} gleby · 2 h^{-1}), inwertazy (*AI*; mg glukozy · 1 g^{-1} gleby · 1 h^{-1}), ureazy (*AU*; mg N-NH_4 · 1 g^{-1} gleby · 24 h^{-1}), proteaz (*AP*; mg N-NH_2 · 100 g^{-1} gleby · 20 h^{-1}) oraz celulaz (*AC*; % spadku lepkości 0,9-procentowego roztworu metylcelulozy w buforze McIlvaine (pH 5,5) w poziomach próchnicznych gleb badanych zbiorowisk roślinnych (oznaczenia jak na rysunku 1)

A smaller degree of variation was found in activity of phosphatases, proteases, urease, and cellulases (Fig. 2). The activity of phosphatases, the enzymes taking part in transformation of organic compounds of phosphorus into non-organic phosphates, in humus horizon of the typical beech forest (Dg-F_t, profile 3) was higher than that in humus horizon of the poorer lime tree forest (T-C_p, profile 2). In humus horizons of the remaining two associations the activity of phosphatases was at the medium level, without any significant difference (Fig. 2). While the activity of proteases, enzymes taking part in degradation of proteins, in humus horizon of the beech forest with *Lunaria rediviva* (Dg-F_l, profile 4) was higher than that in humus horizon of the poorer lime tree forest (T-C_p, profile 2) and the typical Carpathian beech forest (Dg-F_t, profile 3). In soil humus horizon under the community of fertile lime tree forest (T-C_f) the activity of proteases was at the medium level without any significant differences between this activity and the activity of these enzymes in humus horizons of the remaining soils investigated (Fig. 2). The activity of urease, which catalyzes hydrolysis of urea, in humus horizon of beech forest with *Lunaria rediviva* (Dg-F_l) was higher than the activity of this enzyme in humus horizon of the typical Carpathian beech forest (Dg-F_t). In soil humus horizons under lime tree forest (profiles 1 and 2) the activity of urease was on the medium level, and did not differ from activity of this enzyme in soils of beech forests (profiles 3 and 4). The activity of cellulases, very important enzymes taking part in decomposition of cellulose, in humus horizons of soils of floristically richer sub-associations of beech forest (Dg-F_l) and lime tree forest (T-C_f) was on similar level, but it was higher than activity of these enzymes in humus horizon of the poorer lime tree forest (T-C_p). In soil of the typical Carpathian beech forest (Dg-F_t) the activity of cellulases was not significantly different from activity of these enzymes in humus horizons of the remaining soils under investigations, assuming a medium level (Fig. 2). There were no significant differences in activity of dehydrogenases in humus horizons of soils of the investigated plant associations, which may be recognized as the index of similarity between microbiological activity of the investigated soils.

The greatest variation in enzyme activity in humus horizons of the investigated soils was found in the case of urease (Fig. 2). The coefficient of variation ranged from 15% (Dg-F_l) to 66% (T-C_p). The smallest one was noted in activity of dehydrogenases, where this coefficient varied from 20% (T-C_p) to 32% (T-C_f).

For a better comparison of enzymatic activities of soils of the investigated plant communities, the activities of identified enzymes was recalculated into the absolutely dry matter of soil in soil core of 1 dm^2 cross-section and 1 m depth (Table 4). For each of the investigated enzymes a similar sequence of soils and plant communities according to total activity calculated in a soil core was obtained: T-C_f > Dg-F_l > T-C_p > Dg-F_t. However, the activity of ivertases and phosphatases played the smallest role in community diversification. The investigated soils were arranged according to the values of the enzymatic soil index (EIG_{DPU}) calculated on the basis of activities of dehydrogenases, proteases, and urease in agreement with the formula proposed by Januszek [1999]:

$$EIG_{DPU} = 0.01 \cdot ADh + AP + AU$$

where:

- ADh – activity of dehydrogenases in mg TFF/absolutely dry soil matter in soil core of 1 $dm^2 \times 1$ m/24 h,
- AP – activity of proteases in g N-NH_2/absolutely dry soil matter in soil core of 1 $dm^2 \times 1$ m/20 h,

AU – activity of urease in g N-NH_4/absolutely dry soil matter in soil core of 1 $dm^2 \times 1$ m/24 h.

The calculated values of EIG_{DPU} distinctly differentiated the investigated soils, similarly as abundance of available phosphorus and abundance of organic substance per 1 ha, illustrated in absolute units (Fig. 3, Table 5), as well as in percent in relation to maximum values of the investigated properties in soil of the fertile lime tree forest (Fig. 4). All of these parameters reached the highest values in the fertile lime tree forest (T-C_f), and were decreasing subsequently in the beech forest with *Lunaria rediviva* (Dg-F_l), poorer lime tree forest (T-C_p), and typical Carpathian beech forest (Dg-F_t) with the lowest values.

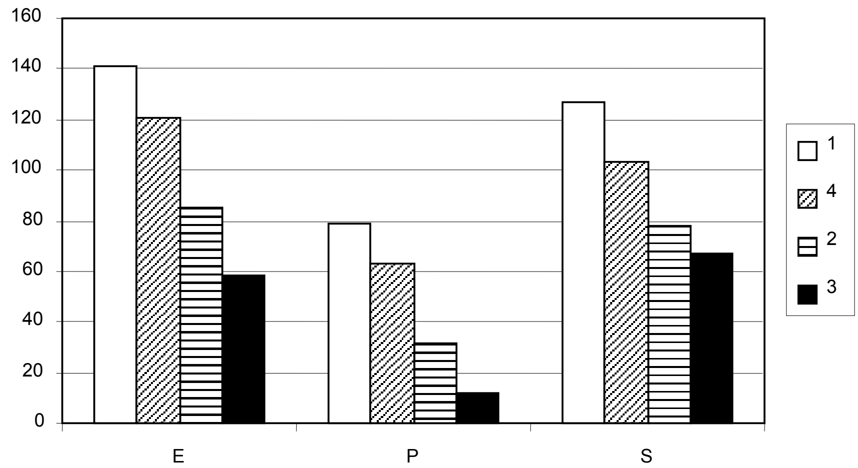

Fig. 3. Soil enzyme index EIG_{DPU} ($E = EIG_{DPU} \cdot 10$), aboundance of available phosphorus (P; kg/ha) and soil organic matter aboundance (S; Mg·ha^{-1}) in soil of the investigated plant communities (for designations see Figure 1)
Rys. 3. Enzymatyczny indeks glebowy EIG_{DPU} ($E = EIG_{DPU} \cdot 10$), zasobność fosforu przyswajalnego (P; kg·ha^{-1}) oraz zasobność substancji organicznej (S; Mg·ha^{-1}) w glebach badanych zbiorowisk roślinnych (oznaczenia jak na rysunku 1)

Simple correlations between individual enzymes and the remaining properties of humus horizons of the investigated soils are shown in Table 3. Very high positive correlations between the activities of proteases, invertase, and phosphotases and the concentration of total nitrogen, a high correlation between the activity of phosphatases and the volume of the sorption complex, as well as the negative correlations between the activities of phosphatases and cellulases and the values of soil pH in H_2O, may be recognized as more important relationships. High correlations between the activity of proteases and the contents of exchangeable potassium and available phosphorus may be recognized as interesting.

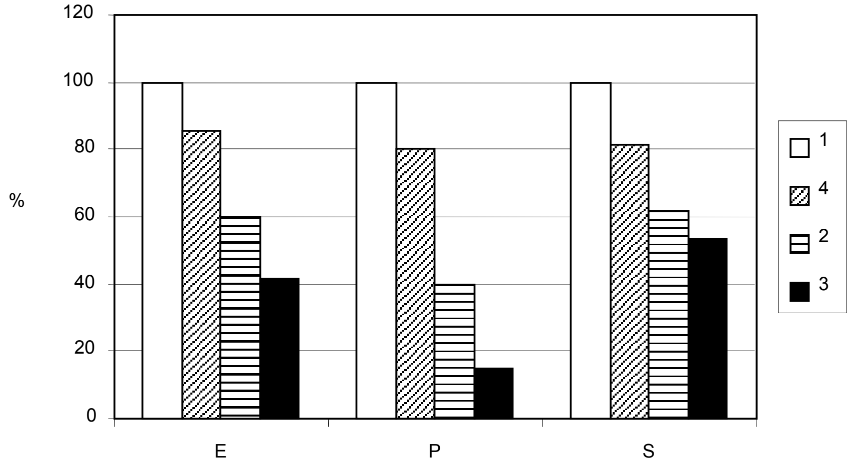

Fig. 4. Soil enzyme index EIG_{DPU} (E), abundance of available phosphorus (P) and soil organic matter abundance (S) expressed in percentage, in relation to maximum values in soil of the investigated plant communities (for designations see Figure 1)
Rys. 4. Enzymatyczny indeks glebowy EIG_{DPU} (E), zasobność fosforu przyswajalnego (P) oraz zasobność substancji organicznej (S) wyrażone w procentach w odniesieniu do maksymalnych wartości w glebach badanych zbiorowisk roślinnych (oznaczenia jak na rysunku 1)

Table 3. Correlations between activities of the investigated enzymes and other soil properties in the mineral-humus horizons in the investigated forest communities ($N = 40$)
Tabela 3. Korelacje proste między aktywnością badanych enzymów a właściwościami fizyczno-chemicznymi gleby w poziomie próchnicznym badanych zbiorowisk leśnych ($N = 40$)

Properties Właściwości	*AD*	*AP*	*AU*	*AI*	*AF*	*AC*
1	2	3	4	5	6	7
pH_{H_2O}	–0.3872*				–0.6286***	–0.5650***
pH_{KCl}					–0.4474*	–0.4960**
$C_{org.}$					0.4144*	0.4091**
$N_{og.}$	0.5255**	0.7014***		0.5842***	0.6029***	0.7805***
C/N		–0.6886***		0.6903***		–0.4099**
Y	0.3852*				0.6873***	0.6254***
S						
T_H	0.4744*	0.4903**		0.3894*	0.6864***	0.6661***
V%					–0.4856**	–0.4772**
$Cz._{spł.}$		–0.4829*		–0.4424*		
$Ił_{kol.}$		–0.4889**	–0.3897*	–0.5556**		
P		0.6605***				0.4853**

Table 3 – cont.

1	2	3	4	5	6	7
K		0.6057***	0.5145**	0.6825***		
Ca						
Mg						–0.4605**
Na				0.4193*		
AD		0.5293**			0.7645***	
AP	0.5293**			0.6241***	0.3845*	0.5551***
AU				0.5235**		
AI		0.6241***	0.5235**			
AF	0.7645***	0.3845*				0.3485*
AC	0.4847**				0.5536**	

Level of statistical significance: *99% ≥ P ≥ 95%, **99.9% ≥ P ≥ 99%, ***P ≥ 99.9%.
AD, *AP*, *AU*, *AI*, *AF*, *AC* – see Table 2.
Poziom prawdopodobieństwa korelacji: *99% ≥ P ≥ 95%, **99,9% ≥ P ≥ 99%, ***P ≥ 99,9%.
AD, *AP*, *AU*, *AI*, *AF*, *AC* – zobacz tabela 2.

Table 4. Total (complete) enzymatic activity in soil core of 1 dm^2 cross-section and 1.0 m depth in the distinguished plant communities
Tabela 4. Aktywność enzymatyczna badanych gleb w przeliczeniu na absolutnie suchą masę w słupie gleby o przekroju 1 dm^2 i głębokości 1 m

Plot number Numer powierzchni	Plant community Zbiorowisko roślinne	*AD*	*AP*	*AU*	*AF*	*AI*
1	T-C fertile – T-C żyzn.	505.6	3 300.4	5 777.2	4 480.8	4 589.0
2	T-C poor – T-C ub.	339.5	1 307.5	3 785.5	3 294.4	3 110.4
3	Dg-F typ.	288.7	816.0	2 145.1	2 142.1	1 888.5
4	Dg-F lunar.	404.8	3 023.0	4 987.7	3 418.7	3 201.8

AD, *AP*, *AU*, *AI*, *AF* – see Table 2.
T-C fertile – *Tilio-Carpinetum typicum*, upland form, fertile variant.
T-C poor – *Tilio-Carpinetum typicum*, upland form, poor variant.
Dg-F typ. – *Dentario glandulosae-Fagetum typicum.*
Dg-F lunar. – *Dentario glandulosae-Fagetum lunarietosum.*
AD, *AP*, *AU*, *AI*, *AF*, *AC* – zobacz tabela 2.
T-C żyzn. – *Tilio-Carpinetum typicum*, forma wyżynna, wariant żyzny.
T-C ub. – *Tilio-Carpinetum typicum*, forma wyżynna, wariant ubogi.
Dg-F typ. – *Dentario glandulosae-Fagetum typicum.*
Dg-F lunar. – *Dentario glandulosae-Fagetum lunarietosum.*

Table 5. Index of enzymatic activity (EIG_{DPU}), available phosphorus and organic matter in the investigated soils
Tabela 5. Enzymatyczny indeks glebowy EIG_{DPU}, zawartość fosforu przyswajalnego oraz substancji organicznej w glebach badanych zbiorowisk leśnych

Plot number Numer powierzchni	Plant community Zbiorowisko roślinne	EIG_{DPU}	P $kg \cdot ha^{-1}$	Orgaqnic matter Substancja organiczna $t \cdot ha^{-1}$
1	T-C fertile – TC żyzn.	14.13	78.8	126.8
4	Dg-F lunar.	12.06	63.1	102.9
2	T-C poor – TC ub.	8.49	31.4	78.2
3	Dg-F typ.	5.85	11.5	67.2

$EIG_{DPU} = 0.01 \cdot ADh + AP + AU$, where: *ADh* – dehydrogenase activity (mg TPF in soil core of 1 dm^2 cross-section and 1.0 m depth/24 h), *AP* – protease activity (g $N\text{-}NH_2$ in soil core of 1 dm^2 cross-section and 1.0 m depth/20 h), *AU* – urease activity (g $N\text{-}NH_4$ in soil core of 1 dm^2 cross-section and 1.0 m depth/24 h).

$EIG_{DPU} = 0.01 \cdot ADh + AP + AU$, gdzie: *ADh* – aktywność dehydrogenaz (mg TFF w słupie gleby o przekroju 1 $dm^2 \cdot 1$ m/24 h, *AP* – aktywność proteaz (g $N\text{-}NH_2$ w słupie gleby o przekroju 1 $dm^2 \cdot 1$ m/20 h, *AU* – aktywność ureazy (g $N\text{-}NH_4$ w słupie gleby o przekroju 1 $dm^2 \cdot 1$ m/24 h).

DISCUSSION

According to the recommended criteria of the classification of forest soils [Klasyfikacja... 2000] the soils investigated during this study should be included in one subtype of *endoeutric cambisol* developed from Magura sandstones and schists of Carpathian flysch. These soils slightly differed in graining, and had approximately similar degree of saturation with cations of a basic character. The activity of the investigated enzymes was higher in the profile of soil with the community of lime tree forest in comparison with the activity of enzymes of soils with beech forest. This concerned profiles situated on concave slopes (profiles 1 and 4) as well as on ridges (profiles 2 and 3). The enzymatic activity, converted to soil volume in a profile to 1 m in depth, increased as the abundance of organic substance and available phosphorus increased. The greater abundance of available phosphorus and humus, as well as a higher enzymatic activity in soils of lime tree forest in comparison with soils of beech forest, at similar pH and properties of the parent rock on slopes as well as on ridges, may be the evidence of a more favourable effect of the lime tree stand on biochemical properties of soil than of the beech stand. The coincidence between occurrence of higher enzymatic activity and higher abundance of organic substance and available phosphorus in soils of lime tree forests suggests a more favourable effect of the lime tree stand on biological activity and quality of soil in comparison with the beech stand. However, the effect of a favourable influence of a mild microclimate of surroundings of the town of Muszyna (lime tree forest, profiles 1 and 2), and a more severe microclimate of surroundings of the town of Krynica (fertile beech forest, profile 4) [Fabijanowski 1961], as well as a possible effect of a higher elevation of the investigated beech stands (593 and 600 m above sea level) in comparison with the investigated lime tree stands (502 and 517 m), on results of this study cannot be excluded. In authors' opinion the effect of climatic conditions should not be considered as a factor deciding about diversification of the investigated chemical and biochemical properties. It should be pointed out that humus horizons of the investigated soils did not differ in activity of dehydrogenases, the enzymes reflecting a general microbiological activity of soils, which under different climatic conditions should be diversified. The authors are rather of the opinion that the differences in the chemical and physical properties of beech stands and the lime tree stand resulted from the species composition of these stands and not from climatic conditions. The authors consciously abandoned the possibility of choosing beech stands in a direct neighbourhood of lime tree stands, because there was probably a high percentage of lime tree in former forest stands growing in places of today's beech stands surrounding the reserve of Obrożyska, as is mentioned in historical records [Pawłowski 1921, Fabijanowski 1961]. The effect of former lime tree stands, occurring in areas of today's beech stands, on the present biological activity and chemical properties of soils cannot be excluded.

A lack of clear differences in activity of dehydrogenases, and a simultaneous diversification of other enzymes studied in humus horizons of soils of the investigated forest communities, may indicate a lack of differences in a general microbiological activity, at a certain diversification of numbers and activity of respective physiological groups of microorganisms in humus horizons of soils of these forests. A significant diversification of activity of invertase in humus horizons of the investigated plant communities may depend upon the plant species composition. Many authors are of the opinion that soil invertase is mainly of plant origin [Freytag 1965, Kuprevič and Ščerbakova 1966, Kobus et al. 1987].

No relationship between the activity of the investigated enzymes (dehydrogenases, proteases, urease, and invertase) and the organic content was found in humus horizons of the investigated soils, while there was the correlation between the activity of enzymes (with exception of urease) and the capacity of sorption complex and concentration of total nitrogen. It may be assumed that in the investigated soils, developed from the same geological substrate, the mineral colloids had a similar character, while the humus horizons differed in quality of organic colloids, which was indicated by differences in C:N ratio. In humus horizons of soils of the poor lime tree forest (profile 2) and the typical Carpathian beech forest (profile 3), developed on ridges, there was a significantly higher C:N ratio in comparison with humus horizons of floristically richer forest communities (profiles 1 and 4), indicating a worse quality of humus of these soils. It could be the result of a greater fraction of fulvic acids or a worse quality of humic acids, which is associated with smaller sorption capacity and smaller concentration of total nitrogen in humus horizons of these soils.

This study confirmed the necessity of taking into account the soil profile, and not only the humus horizon, in evaluation of biological activity and quality of soil, as it was already earlier noticed by Januszek [1999]. Because no uniform tendencies were observed during comparison of enzymatic activity in humus horizons of soils of the investigated forest communities, while the comparison of activity of the investigated enzymes, converted into volume of a soil core, in soil profiles of the investigated communities, always resulted in their similar sequence.

The correct choice of the criteria useful for the evaluation of quality of the investigated *endoeutric cambisols*, and soils in general, may be discussed. This study showed that such properties as the activity of dehydrogenases, proteases, and urease (in conversion to soil mass per volume unit to the depth of 1 m), as well as abundance of available phosphorus or organic substance (humus) in soil per 1 ha, may be useful for the estimation of quality of *cambisols*. The evaluation of soil quality using the abundance of available phosphorus seems to be convincing. The available forms of phosphorus occur in soils of weakly acid reaction, which favours development of bacteria and fungi, creating favourable conditions for increased biological activity. Under strongly acid reaction, as well as alkaline reaction, the phosphorus forms, difficultly available by plants, dominate. In organic soils the occurrence of available phosphorus is decided by quality of organic substances, as well as the activity of phosphatases. Thus the factor of biotic origin is the decisive one. A significant importance of available phosphorus for fertility of tropical forest soils was stressed by Saker et al. [1999].

The evaluation of cambisols on the basis of abundance of organic substance (humus) also seems to be a helpful criterion. The depth of humus horizon is one of the commonly used criteria in quality estimation of mineral soils. The content of organic substance in organic soils cannot be a good method of evaluation of soil fertility. For example peat soils of high moors have abundant organic substance, but their quality is low. At the present moment there is no simple and inexpensive method permitting to separate humus from organic substance in soil, and this makes impossible a quick determination of humus content in organic horizons or soils where specific humus compounds incrust unhumified plant and animal tissues.

The activity of dehydrogenases, proteases, and urease in the investigated brown soils, in recalculation to volume of soil to the depth of 1 m, as well as the soil index (EIG_{DPU}) elaborated on the basis of many subtypes of forest soils, and calculated on the basis of activity of dehydrogenases, proteases, and urease [Januszek 1999], provides a proper evaluation of quality of forest soils in southern Poland [Januszek 1999].

Out of three properties mentioned above, the widest range of abundance in the investigated soils has available phosphorus (Fig. 3). The soil least abundant with available phosphorus contains 14.5% of available phosphorus present in the most abundant soil. The narrowest range was found in the case of abundance of organic substance. The soil with least amount of organic substance contains 53.4% of this substance present in the most abundant soil (Fig. 4). The least expensive is the evaluation of available phosphorus abundance per 1 ha, and the most expensive is the determination of biochemical properties. However, the evaluation of soil quality on the basis of biochemical properties renders the recognition of an early phase of distortion or disturbances occurring in soils due to improper treatments in soils of the same type of humus, or in soils of similar depth of humus horizon.

CONCLUSIONS

1. The enzymatic soil index EIG_{DPU}, calculated on the basis of activity of dehydrogenases, proteases, and urease in a volume unit to the depth of 1 m, may be useful in evaluation of quality of forest soils.
2. Abundance of available phosphorus, beside the activity of enzymes mentioned above, may be the additional criterion in estimating fertility of forest soils and quality of forest sites.
3. Lime tree in Carpathian forests of lower elevations of the lower mountain climatic-vegetation belt favourably affects the soil properties.

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OCENA ŻYZNOŚCI GLEB KARPACKIEGO GRĄDU LIPOWEGO I BUCZYN KARPACKICH NA PODSTAWIE BADANYCH WŁAŚCIWOŚCI CHEMICZNYCH I BIOCHEMICZNYCH

Streszczenie. Celem badań była ocena żyzności gleb brunatnych wyługowanych, wykształconych z piaskowców i łupków warstw magurskich fliszu karpackiego, pod zbiorowiskami karpackiego grądu lipowego *Tilio-Carpinetum typicum*, wariantu żyznego (T-$C_ż$) i ubogiego (T-C_{ub}), oraz buczyny karpackiej, wariantu typowego *Dentario glandulosae-Fagetum typicum* (Dg-F_t) oraz wariantu żyznego *Dentario glandulosae-Fagetum lunarietosum* (Dg-F_l). Z poziomu próchnicznego mineralnego gleb badanych zespołów roślinnych pobierano po 10 prób, z pozostałych poziomów glebowych zebrano próby zbiorcze w obrębie profilu glebowego. Porównano następujące właściwości gleb: odczyn mierzony w H_2O i 1 M KCl, skład mechaniczny, właściwości sorpcyjne, zawartość: $C_{org.}$, $N_{całk.}$, $P_{przys.}$, wymiennych form Ca, Mg, K i Na, a także aktywności dehydrogenaz, fosfataz, inwertazy, ureazy, proteaz i cellulaz. Rozkłady wartości badanych cech porównano testem Tukeya. Nie stwierdzono jednolitej tendencji w różnicowaniu się właściwości poziomów próchnicznych badanych zbiorowisk leśnych. Stwierdzono natomiast spadek zasobności w przyswajalny fosfor i substancję organiczną (w przeliczeniu na 1 ha), jak również spadek aktywności dehydrogenaz, ureazy i proteaz (w pedonie gleby o głębokości 1 m) wraz z ubożeniem zbiorowisk roślinnych w następującej kolejności: T-$C_ż$ > Dg-F_l > T-C_{ub} > Dg-F_t. Na podstawie uzyskanych wyników można wnioskować, że las lipowy wpływa korzystniej na żyzność gleby niż las bukowy.

Słowa kluczowe: karpacki grąd lipowy, buczyna karpacka, aktywność enzymatyczna gleby, żyzność gleby

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