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Luvisols as a habitat for larch stands: a case study from the Miechowska Upland, S Poland

Marta Kempf[1], Ewa Błońska[1], Jarosław Lasota[1]

[1] University of Agriculture in Krakow, Faculty of Forestry, Department of Ecology and Silviculture, 29 Listopada Str. 46, 31-425 Kraków, Poland

* Prof. dr hab. inż. Ewa Błońska, ewa.blonska@urk.edu.pl, ORCID iD: https://orcid.org/0000-0001-7731-1673

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Abstract

Our research aimed to present the properties of Luvisols developed from the loess of the Miechowska Upland, S Poland, as a favourable substrate shaping habitats for larch stands. Detailed characteristics covered ten research plots in mature stands, where Polish larch *(Larix decidua* var. *polonica*) was the main species. On each research plot, a soil pit was dug and the separated genetic horizons were described. The diagnosis of the habitat type was developed using the Trophic Soil Index (SIG). Samples were taken from each genetic horizon for laboratory analysis. Basic physicochemical properties (particle size distribution, pH, total organic C and total N content, available phosphorus content and sorption properties) were determined in the soil samples. As a result of the research, it was found that the Polish larch can create high-production stands in the fresh upland broadleaved forest sites (Lwyż św) with the admixture of deciduous species (common beech *Fagus sylvatica*, English oak *Quercus robur*, common hornbeam *Carpinus betulus*, common sycamore *Acer pseudoplatanus*). The investigated soils were described as Haplic Luvisols, which differed in the characteristics of humus horizons. The high share of larch (40–60%) growing on Luvisols does not negatively affect the properties of humus horizons and the degree of leaching of Luvisols created from loess. In the case of stands with a predominant share of larch (>60%), there is a tendency to deteriorate the properties of the humus accumulation horizons and the formation of the ectohumus horizon on the surface. SIG indicates that the tested soils shape the eutrophic fresh upland broadleaved forest sites. The decrease in the SIG value in two cases is the result of the deterioration of the properties of humus horizons.

1. Introduction

Polish larch *(Larix decidua* var. *polonica*) is a valuable breed of European larch, which can form tree stands together with many tree species inhabiting meso-eutrophic soils. Along with larch, there are common beech, pedunculate oak, sessile oak, common hornbeam and sycamore maple in tree stands. Most Polish larch sites cover the central and eastern regions of the Central Uplands belt, the Carpathian Foothills, and the Western Beskids (Boratyński, 1986). According to the current Forest Breeding Principles (ZHL, 2012), larch is treated as an admixture species. In the framework species compositions proposed for the habitats of fresh upland mixed broadleaved forest sites (LMwyż św) and fresh upland broadleaved forest sites (Lwyż św) in the area of Silesia and Małopolska, the share of larch with other admixture species is proposed in the amount of 10–30%. In the area of the Silesia, a slightly higher share of this species (30% together with other admixture species) is recommended for upland mixed broadleaved forest sites (LMwyż). In comparison, within upland broadleaved forest sites (Lwyż), a small admixture of larch and other species is suggested to be up to 10%. In the case of the Małopolska region, the proposed ranges of the share of larch with other admixtures are higher and account 20–30% in the LMwyż and 30% in the Lwyż (ZHL 2012). Views about the foreign nature of larch mean that in Natura 2000 areas the amount of larch introduced to managed stands is reduced (Matuszkiewicz, 2007).

The scale of Polish larch's ecological and especially soil requirements has yet to be fully discovered. It is believed that, in general, larch cultivation requires deep and sufficiently permeable soils, which enable the development of a deep root system and proper growth of this species (Boratyński, 1986). Larch has low requirements regarding soil fertility, and reacts to a greater extent to their physical properties than to the content of nutrients (Białobok, 1986). The wide tolerance of larch towards soil chemistry is evidenced by its occurrence in various conditions, from river gravel in the foothills through rendzinas to acidic silicate soils (Białobok, 1986). According to Zieliński (1970) larch can grow on Luvisols. The properties of Luvisols are strongly related to their granulation and how they are used. Luvisols made of sandy-silt formations are characterized by a smaller amount of mesopores and micropores compared to soils made of loess, and the higher number of macropores in forest soils compared to cultivated soils deserves special attention (Turski and Witkowska–Walczak, 2004). Luvisols of forest areas are characterized by a more favourable ratio of the accumulation horizons' organic carbon content to the directly adjacent horizons (Turski and Witkowska-Walczak, 2004).

In our research, we tried to present the properties of Luvisols on which Polish larch may be the dominant or subdominant species. In addition, the paper presents the properties of humus accumulation horizons of Luvisols in stands with various shares of Polish larch in the range of 40–90%. We assume that the different share of larch in forest stands growing on Luvisols influences the properties of soils, especially surface horizons. The Trophic Soil Index was used to determine the trophism of the soils where larch grew.

2. Materials and methods

2.1. Study sites and data collection

The study included ten research plots located in the Miechowska Upland, in places where loess covers occur. The study plots were located in mature stands, in which Polish larch was the dominant species or co-creating stands with a more than 40% share. The location of the study plots and selected stand features are presented in Table 1. The criteria for selecting the study plots were the presence of Luvisols developed from loess and the share of larch in tree stand. On each study plot, a soil pit was dug in which genetic horizons were separated. Soil samples were collected from each genetic horizon for further laboratory analysis. Soil description was carried out following the Classification of Forest Soils of Poland (2000). Additionally, on each plot, habitat conditions were analyzed according to a comprehensive method developed by The Polish Forest Research Institute (IBL) (IUL part II 2012).

2.2. Laboratory analysis

Basic physicochemical properties were determined in samples collected from the profile (Ostrowska et al., 1991). Samples with disturbed structure were taken for all laboratory analyses, apart from bulk density determination. The texture was determined using laser diffraction (Analysette 22, Fritsch, Idar-Oberstein, Germany). The soil pH was determined in H_2O and KCl using the potentiometric method (1:5 ratio in organic samples; 1:2.5 ratio in mineral samples). Hydrolytic acidity (Y) was determined by the Kappen method. Organic C and total N were measured using an elemental analyzer (LECO CNS TrueMac Analyzer Leco, St. Joseph, MI, USA). The cation concentrations (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}) were determined after extraction in 1M ammonium acetate (pH=7.0) by inductively-coupled plas-

Table 1.
Characteristics of research plots

Profile	Location and Forest division	Altitude a.s.l.	Share of *Larix*	Stand age	Coordinates	Soil type
M1	Miechów Forest District; 372c	295	50%	115	50°11'53''N 20°03'50''E	Haplic Luvisol
M2	Miechów Forest District; 373c	311	50%	115	50°11'59''N 20°03'26''E	Haplic Luvisol
M3	Miechów Forest District; 374h	349	40%	90	50°11'57''N 20°02'56''E	Haplic Luvisol
M4	Miechów Forest District; 375d	348	50%	105	50°11'58''N 20°02'37''E	Haplic Luvisol
M5	Miechów Forest District; 376c	348	80%	80	50°12'00''N 20°02'29''E	Haplic Luvisol
M6	Miechów Forest District; 380c	342	40%	90	50°11'56''N 20°02'02''E	Haplic Luvisol
M7	Miechów Forest District; 362a	286	40%	75	50°13'03''N 20°04'09''E	Haplic Luvisol
M8	Miechów Forest District; 363a	287	70%	75	50°13'02''N 20°03'53''E	Haplic Luvisol
M9	Miechów Forest District; 366d	297	90%	75	50°13'02''N 20°02'43''E	Haplic Luvisol
M10	Miechów Forest District; 367f	283	60%	70	50°13'13''N 20°02'16''E	Haplic Luvisol

ma analysis (ICP-OES Thermo iCAP 6500 DUO, Thermo Fisher Scientific, Cambridge, UK). Potentially available phosphorous was determined using the Bray-Curtz method. Bulk density was determined using Kopecky cylinder in humus horizons. In other cases, the following formula was used to determine the bulk density: D = 1.3773*e–0.0547*x (x – organic carbon content) (Brożek and Zwydak, 2003). The diagnosis of forest site type was determined according to forest management principles (CILP, 2012). Moreover, the Trophic Soil Index (SIGg) was calculated (Brożek et al., 2015). The Trophic Soil Index takes into account four parameters: the total stock of fractions with a diameter below 0.02 mm (Z_{CZS}), the sum of basic cations (Z_S), the ratio of hydrolytic acidity (Z_{Hh}) to Z_{CZS}, determined in a soil column with a cross-section of 1 m^2 and a depth 1.5 m, and the N^2/C ratio in surface mineral-humus horizon.

2.3. Statistical analysis

The Spearman correlation coefficients for the soil characteristics and share of larch in forest stands were calculated. Principal component analysis (PCA) was used to interpret factors in particular data sets. The Statistica 12 software (StatSoft, 2012) was used for data analysis.

3. Results

The analysis of 10 profiles of Luvisols developed from loess indicates their great similarity in terms of morphological structure and basic properties. In the structure of the profiles, there is a humus accumulation horizon, which more often shows the features of the mineral-humus horizon (A) (Fig. 1). In three cases (study plots M5, M8, M9) on the surface, the shallow (2–5 cm) organic horizon (of fermentation) was found, characterized by a fibrous-piece structure, organic carbon content in the range of 28.5–32.5%, C/N ratio of 26.1–29.4 and significant acidification (pH in H_2O 4.2–4.5, Hh 92.4–124.7 cmol(+)$kg^{-1)}$ (Table 2 and 3). The humus-mineral horizon (A) in the examined Luvisols is thin, 6 to 14 cm thick, and has a sub-angular blocky structure. The soil consists mainly of silt fraction (73–90%) with an admixture of sand (5–17%) and clay (5–10%). The humus-mineral horizon contains a varied content of organic carbon 1.79–8.72% and nitrogen (0.075–0.51%) and the C/N ratio in this horizon is in the range of 15.9–23.9. The content of potentially available phosphorus in these horizons is 2.91–10.41 mg kg^{-1}. The reaction of the humus-mineral horizons is acidic (pH in H_2O 4.23–5.15), the hydrolytic acidity is very diverse (2.13–17.56 cmol(+) $kg^{-1)}$, the content of basic cations is 0.42–6.10 cmol(+) kg^{-1}, and the saturation of the sorption complex with these cations varies widely from 4.3 to 71.5% (Table 2, 3). The Eet eluvial horizons of the analyzed soils are well developed, characterized by a thickness in the range of 22–40 cm, silt graining (the content of sand fractions 7–13%, silt 76–88%, clay 4–11%), and clearly weaker compaction than the lower horizon of clay leaching. Eluvial horizons (Eet) are characterized by pH in H_2O in the range 4.42–4.90, carbon content in the range of 0.31–0.99%, nitrogen content in the range 0.017–0.036% and C/N ratio in the range 16.1–29.1. The eluvial horizons of the analyzed Luvisols contain 3.15–9.77 mg kg^{-1} of potentially assimilable phosphorus, 0.20–1.61 cmol(+) kg^{-1} of exchangeable basic cations, and the saturation of the sorption complex with these cations is low (2.5–20.5%) (Table 2, 3). Below the Eet horizon, in the analyzed soils, there is a strongly compact clay leaching horizon (Bt), which varies in thickness, 27–55 cm, with a darker color compared to the upper eluvial horizon. It is also characterized by a higher clay fraction content (12–20%). Bt horizons contain a negligible amount of carbon (0.13–0.31%).

Fig. 1. Examples of investigated Luvisols (study plots M1, M10).

Table 2.
Properties of the analyzed Luvisols (content of organic carbon, total nitrogen, available phosphorus and grain size)

Profile	Depth (cm)	Horizon	C	N	C/N	P	sand	silt	clay	PTG 2008
M1	0–15	A	8.72	0.51	17.1	10.4	5	88	7	pyz
	15–45	Eet	0.39	0.02	19.6	6.5	7	88	5	pyz
	45–100	Bt	0.20	0.01	16.4	35.7	7	85	12	pyz
	100–150	BC	0.07	0.01	13.6	25.5	7	84	9	pyz
M2	0–15	A	2.78	0.18	15.9	5.9	7	87	6	pyz
	15–50	Eet	0.61	0.04	16.8	9.5	7	85	8	pyz
	50–90	Bt	0.21	0.02	13.7	38.9	1	83	16	pyi
	90–150	BC	0.11	0.01	12.6	24.7	2	82	16	pyi
M3	0–7	A	2.48	0.15	16.7	4.7	17	73	10	pyg
	7–30	Eet	0.50	0.03	19.1	7.7	13	76	11	pyg
	30–80	Bt	0.31	0.02	13.0	21.4	12	71	17	pyi
	80–150	BC	0.19	0.01	20.6	24.2	15	73	12	pyg
M4	0–7	A	3.30	0.19	17.4	7.1	15	76	9	pyg
	7–35	Eet	0.62	0.03	20.0	5.6	11	82	7	pyz
	35–80	Bt	0.24	0.02	15.0	21.6	11	70	19	pyi
	80–150	BC	0.09	0.01	11.8	18.3	10	76	14	pyi
M5	0–3	Of	28.45	1.09	26.1	30.2				
	3–10	A	1.47	0.08	18.8	5.6	12	79	9	pyg
	10–50	Eet	0.31	0.02	16.6	9.8	13	78	9	pyg
	50–90	Bt	0.13	0.02	8.0	36.5	16	67	17	pyi
	90–150	BC	0.06	0.00	14.7	26.2	16	72	12	pyg
M6	0–10	A	4.60	0.21	21.6	7.4	5	90	5	pyz
	10–45	Eet	0.45	0.03	16.1	3.3	9	87	4	pyz
	45–90	Bt	0.20	0.01	14.4	24.2	9	78	13	pyi
	90–150	BC	0.03	0.00	11.3	27.6	7	81	12	pyz
M7	0–14	A	3.42	0.16	21.1	2.9	6	88	6	pyz
	14–50	Eet	0.58	0.03	18.8	4.6	8	85	7	pyz
	50–80	Bt	0.20	0.01	15.0	14.7	4	78	18	pyi
	80–150	BC	0.09	0.01	17.8	21.9	4	81	15	pyi
M8	0–2	Of	30.49	1.12	27.2	34.8				
	2–8	A	2.88	0.13	22.3	3.2	14	76	10	pyg
	8–38	Eet	0.53	0.03	18.2	3.2	13	78	9	pyg
	38–65	Bt	0.25	0.02	12.0	34.7	12	72	16	pyi
	65–150	BC	0.17	0.01	13.8	20.5	11	79	10	pyg
M9	0–5	Of	32.45	1.11	29.4	21.9				
	5–12	A	1.79	0.08	23.9	5.3	10	83	7	pyz
	12–50	Eet	0.42	0.02	24.6	7.5	9	85	6	pyz
	50–95	Bt	0.19	0.01	13.2	14.6	9	76	15	pyi
	95–150	BC	0.09	0.01	12.3	22.5	12	76	12	pyg
M10	0–8	A	3.82	0.23	16.5	6.6	15	75	10	pyg
	8–30	Eet	0.99	0.03	29.1	8.4	11	80	9	pyg
	30–70	Bt	0.26	0.02	15.3	41.6	11	69	20	pyi
	70–120	BC	0.12	0.01	13.4	22.8	13	75	12	pyg

Explanations: C – organic carbon (%), N – nitrogen content (%), P – available phosphorus content (mg kg^{-1}); sand, silt, clay content (%), PTG 2008 (Polskie Towarzystwo Gleboznawcze, 2009) – soil textural classes according to PTG 2008 (pyz – silt, pyg – silt loam, pyi – silt loam).

Table 3.
Properties of analyzed Luvisols (pH, acidity and content of basic exchangeable cations)

Profile	Depth (cm)	Horizon	pH H_2O	pH KCl	Hh	Hw	S	**V(%)**
M1	0–15	A	4.85	4.06	13.1	5.5	6.10	32
	15–45	Eet	4.50	3.57	4.9	3.6	1.11	18
	45–100	Bt	4.90	3.62	5.5	3.0	7.54	58
	100–150	BC	5.26	3.96	2.3	1.2	8.82	80
M2	0–15	A	5.10	3.94	2.1	0.7	5.33	71
	15–50	Eet	4.82	3.50	10.5	4.9	1.50	12
	50–90	Bt	4.90	3.54	5.5	3.4	6.84	55
	90–150	BC	4.97	3.82	2.8	1.5	10.20	78
M3	0–7	A	5.15	4.09	8.5	1.4	2.40	22
	7–30	Eet	4.90	3.70	5.7	3.9	1.24	18
	30–80	Bt	5.37	3.74	5.2	3.6	4.50	47
	80–150	BC	5.43	3.79	3.3	1.5	3.77	53
M4	0–7	A	4.50	3.45	12.0	6.3	0.98	8
	7–35	Eet	4.48	3.44	5.1	6.1	0.28	5
	35–80	Bt	5.15	3.89	4.1	2.4	5.84	59
	80–150	BC	5.32	4.01	1.8	0.9	7.54	81
M5	0–3	Of	4.20	3.32	92.4	35.6	7.18	7
	3–10	A	4.40	3.49	9.4	4.9	0.42	4
	10–50	Eet	4.62	3.75	5.1	4.2	0.29	5
	50–90	Bt	5.21	3.86	3.7	1.9	4.58	55
	90–150	BC	5.39	4.02	2.3	0.6	3.21	58
M6	0–10	A	4.85	4.06	10.5	5.8	3.88	20
	10–45	Eet	4.51	3.47	3.2	3.7	1.24	20
	45–90	Bt	5.05	3.57	3.9	2.0	7.20	55
	90–150	BC	5.42	4.09	2.0	0.7	9.46	85
M7	0–14	A	4.99	3.97	8.7	1.2	2.83	38
	14–50	Eet	4.75	3.48	5.2	2.7	1.61	13
	50–80	Bt	5.05	3.77	3.7	1.4	6.67	54
	80–150	BC	5.39	4.20	1.2	0.9	9.78	75
M8	0–2	Of	4.48	3.64	114.3	25.7	9.58	8
	2–8	A	4.87	3.95	6.0	1.8	3.32	35
	8–38	Eet	4.80	3.72	4.2	2.3	0.98	19
	38–65	Bt	5.20	3.85	3.7	1.9	6.94	65
	65–150	BC	5.35	3.97	2.8	0.9	9.17	76
M9	0–5	Of	4.25	3.31	124.7	38.7	5.86	4
	5–12	A	4.56	3.50	8.1	4.2	1.27	14
	12–50	Eet	4.42	3.40	4.5	4.8	0.26	5
	50–95	Bt	4.87	3.74	2.9	3.8	4.68	61
	95–150	BC	5.16	3.89	2.0	1.2	6.91	78
M10	0–8	A	4.23	3.30	17.6	7.1	1.37	7
	8–30	Eet	4.43	3.64	7.8	6.3	0.20	2
	30–70	Bt	5.40	3.79	5.0	3.4	4.64	48
	70–120	BC	5.58	4.06	2.5	0.6	3.45	58

Hh – hydrolytic acidity (cmol kg^{-1}); Hw – exchangeable acidity (cmol kg^{-1}); S – sum of base cations (cmol kg^{-1})

Furthermore, nitrogen content and the C/N ratio in this horizon is 0.012–0.024% and 8.0–16.4 respectively. Bt horizons are characterized by the pH in H_2O in the range 4.87–5.40 and Hh in the range 2.95–5.53 cmol(+) kg^{-1}. The content of exchangeable basic cations (4.50–7.54 cmol(+) kg^{-1}) and the saturation of the sorption complex by these cations (46.6–65.1%) increases. The content of potentially assimilable phosphorus is also the highest (14.56–41.58 mg kg^{-1} (Table 2, 3)). The deepest horizon (BC) that is distinguished in the structure of the analyzed soils is the transition horizon to the bedrock, characterized by a slight decrease in compactness and clay fraction content (9–16%). The deepest horizon of the studied Luvisols is characterized by a relatively higher pH in H_2O (4.97–5.58), low acidity (Hh 1.24–3.34 cmol(+) kg^{-1}), an increase in the content of exchangeable basic cations (3.21–10.20 cmol(+) kg^{-1}) and saturation of the sorption complex by these cations (53.0–85.4%) (Table 2, 3).

The trophic soil index and its components were calculated for the tested soils. The total stock of fraction < 0.02 (Z_{CZS}) in a pedon with a cross-section of 1 m^2 and a depth of 150 cm in the analyzed Luvisols is 817.8–1104.7 kg 1.5 m^{-3}. The stock of basic cations (Z_S) in the same soil pedone is 50.6–138.6 mol 1.5 m^{-3}. The third parameter – total acidity (Z_{Hh}) is in the range of 65.8–106.1 mol 1.5 m^{-3}. Total acidity stock related to the stock of fraction < 0.02 (Z_{Hh}/Z_{CZS}) in the analyzed Luvisols is described by the parameter Yp which is 0.0607–0.1008. The last component of the SIG index is the N^2/C parameter determined in the first mineral-humus horizon (in the case of the discussed soils, in the A horizon). In the analyzed Luvisols it is very diverse and amounts to 0.0031–0.0298; average 0.0105. It should be noted that in the case of areas with the highest share of larch (over 60%) (M5, M8, M9), N^2/C index turned out to have the lowest values (0.0031–0.0058). In other cases, when the share of larch in the stand did not exceed 60%, the N^2/C parameter assumed higher values (0.0077–0.0298) (Table 4).

The statistical analysis carried out indicates the existence of a correlation between the share of larch in tree stands and selected properties of the humus (A) and eluvial (Eet) horizons of the studied Luvisols. The increase in the share of larch reduces the pH of humus horizons. In the eluvial horizons, only a significant decrease in the content of exchangeable base cations was recorded with an increase in the share of larch on the tested plots (Table 5). The PCA analysis confirms the relationship between the share of larch in the examined stands and the properties of Luvisols. Factors 1 and 2 explain over 77% of the variability of the studied features. With the increase in the share of larch (above 60%), the properties of the tested soils deteriorate. With a large share of larch, lower values of the SIG were recorded. As a result of the dominance of larch, the N^2/C parameter, which expresses the quality of humus, will deteriorate (Fig. 2).

Table 4.
Trophic Soil Index (SIG) calculated for the tested Luvisols

Profile	Zczs	Z_S	Z_Y	Yp	N^2/C	SIG
M1	1021.9	129.3	93.5	0.091	0.0298	39
M2	1104.7	137.5	106.1	0.096	0.0110	37
M3	1008.5	72.3	91.4	0.091	0.0089	36
M4	1045.9	109.9	70.6	0.068	0.0109	37
M5	974.8	54.1	84.0	0.086	0.0042	33
M6	1028.8	132.2	66.3	0.064	0.0099	36
M7	1083.2	133.4	65.8	0.061	0.0077	35
M8	991.5	138.6	73.6	0.074	0.0058	34
M9	992.6	83.9	77.3	0.078	0.0031	32
M10	817.8	50.6	82.4	0.101	0.0141	35

Zczs – Stock of fraction < 0.02 (kg 1.5 m^{-3}); Z_S – stock of the sum of basic exchangeable cations (mol 1.5 m^{-3}); Z_Y – stock of acid ions (mol 1.5 m^{-3}); Yp – converted acidity – the amount of acid ions per kg of fraction <0.02 in the soil pedon with a thickness of 1.5 m^3; N^2/C – organic matter quality parameter in the first humus accumulation mineral horizon

Table 5.
Correlations between the share of larch and the properties of soil horizons (A, Eet) in the studied Luvisols

		pH H_2O	pH KCl	S	Hw	V	C/N
Larix share	A	–0,58*	–0,65*	–0,45	0,18	–0,44	0,29
	Eet	–0,33	–0,28	–0,69*	0,12	–0,52	0,32

S – sum of base cations, Hw – exchangeable acidity, V – base cation saturation, * p<0.05

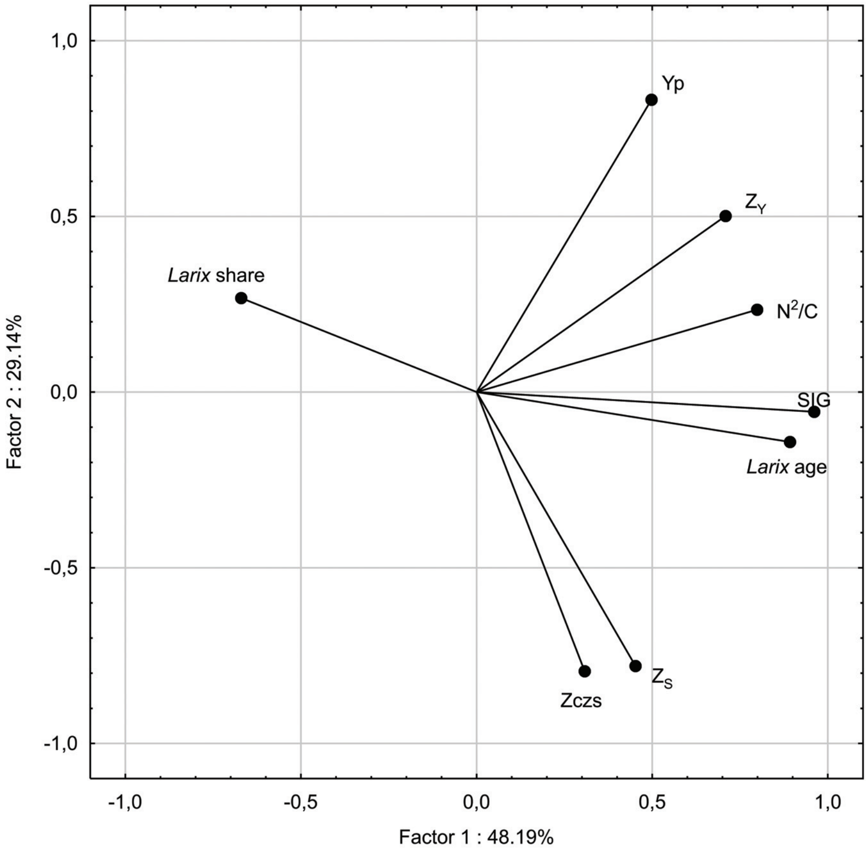

Fig. 2. The projection of variables on a plane of the first and second PCA factor; Zczs – Stock of fraction < 0.02 (kg 1.5 m^{-3}); Z_S – stock of the sum of basic exchangeable cations (mol 1.5 m^{-3}); Z_Y – stock of acid ions (mol 1.5 m^{-3}); N^2/C – organic matter quality parameter in the first humus accumulation mineral horizon; Yp – converted acidity – the amount of acid ions per kg of fraction <0.02 in the soil pedon with a thickness of 1.5 m^3.

4. Discussion

Our research shows that larch stands with a varied share of this species significantly impact the properties of Luvisols. This is in line with the previously conducted research, which found that Luvisols, depending on the method of management, are characterized by different physicochemical properties (Kaczmarek et al., 2006). Cultivated Luvisols differed in their properties compared to Luvisols with mid-field shelterbelts, and mid-field shelterbelts may be part of a targeted agrotechnical system, especially in areas exposed to erosion. Our research proved species composition's importance in shaping Luvisols' surface horizons properties. Different types of humus were noted depending on the species composition of the stand. Research by Błońska and Lasota (2013) indicates a varied influence of vegetation on the properties of Luvisols, especially their surface horizons. The authors of the above study noted the differentiation of the enzymatic activity of the upper horizons of Luvisols depending on the vegetation. During our research, we indicated the variation in the N^2/C parameter, which is used to calculate the Trophic Soil Index and indicates the quality of soil organic matter. In stands with a higher proportion of larch (>60%), the lowest N^2/C ratio was recorded, which confirms the poorer quality of soil organic matter. The N^2/C parameter was successfully used to assess soil organic matter quality in previous studies (Lasota and Błońska, 2022). A small admixture of deciduous species in coniferous stands leads to an improvement in the properties of the upper soil horizons (Błońska et al., 2016). The litter of deciduous species undergoes a faster decomposition process, releasing more components into the soil (Błońska et al., 2021). Forest stands affect soil properties not only through litter fall and the components released by it, but also through root systems. Previously conducted studies indicate that mixed stands compared to monoculture stands, especially coniferous stands, are characterized by higher above-ground biomass and higher underground biomass (Błońska et al., 2018). Our observations regarding the influence of forest stands on shaping the surface properties of Luvisols horizons are consistent with the results of previous studies. According to Jonczak (2013), the type of land use strongly impacted soil organic matter properties, and forest soils and soils never used for agriculture contained a much higher amount of TOC compared to arable soils.

The research indicates no negative impact of larch in mixed stands, where this species coexists with beech, oak and an admixture of hornbeam and sycamore. In the case of the larch share of up to 60%, there are no disturbances in the circulation of nutrients in the analyzed Luvisols, as evidenced by the lack of ectohumus and the formation of mull humus. This type of humus is appropriate for eutrophic fresh upland broadleaved forest sites, which are developed on the studied haplic Luvisols (Lasota and Błońska, 2013). There are many reports in the scientific literature on the impact of mixed stands of complex composition and structure on the characteristics of the soil environment. First of all, such stands, compared to single-species stands, show better use and more intense overgrowth of the underground space by root systems, which translates into an increased supply of exudates and dead acidity stocks roots to the soil environment. This enhances the microbiological activity of the soil and increases the content of the stable fraction of soil organic matter, strongly bound with the colloidal substance of the soil (Błońska et al., 2017; Błońska et al., 2018). In addition, there are reports of a high abundance of mycorrhizal fungi inhabiting the roots of larch (Leski and Rudawska, 2014), which determines the high biochemical activity in the root zone formed by this species (Staszel-Szlachta et al., 2023). Because of the facts cited, there should be no concern about the negative impact of larch on the soil environment when mixed stands are cultivated. However, there is a desire to determine the target species composition of stands concerning the assemblages of potential natural vegetation. Matuszkiewicz (2007) proposed the composition of such forest stand. For the region where our research areas are located (region number 18), Matuszkiewicz (2007) proposes a beech stand type in which larch is not included For our region, Matuszkiewcz (2007) does not propose a tree species composition that corresponds to multi-species deciduous forests. A multi-species deciduous forest in addition to beech forests is a suitable for fresh upland broadleaved forest sites. Subordinating the species composition of stands to proposals that consider only potential plant associations will undoubtedly have an impact on abandoning the cultivation of Polish larch in eutrophic habitats developed from Luvisols described in this paper. It should be noted that during the fieldwork devoted to the analysis of the presented soils, it was observed that excellent growth characteristics and good health characterize the Polish larch occurring in mixed stands.

The presented study analysed Luvisols based on the trophic soil index. In the case of eight profiles, the SIG value >33 was determined, which is characteristic of eutrophic habitats (in our case, fresh upland broadleaved forest sites) (Brożek et al., 2015). Only in two cases (M5 and M9 areas) the SIG index was lower than 33, which is considered typical for mesotrophic habitats. The lower values of the index result from reduced values of the N^2/C parameter on plots where larch was the dominant species with a share of >60%. The obtained results indicate the possibility of using the SIG indicator also to determine the current state of the habitat. Among the parameters taken into account in the construction of the indicator, the N^2/C parameter takes into account the properties of the surface humus horizons, where the impact of the vegetation cover is concentrated. This parameter can be regarded as the most sensitive indicator of soil and habitat deformation processes. Studies conducted in larch stands on Luvisols indicate a decrease in enzymatic activity, resulting from the impact of larch monocultures (Januszek, 2011).

Luvisols in loess areas are exposed to erosion processes (Paluszek, 1994; Paluszek and Żembrowski, 2008). In Luvisols, horizon E is eroded relatively quickly, due to the lower content of organic matter concerning the surrounding horizons (Kalarus, 2009). In the conditions of the uplands, water erosion plays the primary role, and wind erosion occurs to a small extent. In the case of the profiles with larch stands described by us, no signs of erosion processes were noted. Forest vegetation improves soil properties and effectively protects Luvisols against erosive processes. Depending on the intensity of erosion processes in eroded areas, the grassy forest landscape is fully justified, as it limits soil erosion (Lipski and Kostuch, 2005).

5. Conclusions

1. The studied Luvisols developed from loess in the Miechowska Upland are a suitable substrate for the growth of mixed stands with a large share of larch.
2. In order to maintain the proper properties of Luvisols, it is beneficial to introduce multi-species stands, in which the share of larch should be at most 60%. Larch forms mixed stands on Luvisols with beech, oak, hornbeam and sycamore.
3. In the case of the dominance of larch (share >60%), a deterioration of the surface properties of the horizons is noted, which is connected with the formation of acid ectohumus and the reduction of the N2/C ratio.
4. The Trophic Soil Index classified the Luvisols in the Miechowska Upland as eutrophic soils characteristic for upland fresh broadleaved forest sites.

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Gleby płowe Wyżyny Miechowskiej jako siedlisko drzewostanów modrzewiowych

Słowa kluczowe

Ekosystem leśny
Lasy wyżynne
Właściwości gleb
Siedliskowy Indeks Glebowy

Streszczenie

Badania miały na celu przedstawienie właściwości gleb płowych Wyżyny Miechowskiej wykształconych z lessów jako korzystnego podłoża kształtującego siedliska przydatne dla drzewostanów modrzewiowych. Szczegółową charakterystyką objęto dziesięć powierzchni badawczych w dojrzałych drzewostanach, gdzie głównym (dominującym) gatunkiem jest modrzew polski (*Larix decidua* var. *polonica*). Na każdej powierzchni badawczej wykopano odkrywkę glebową i opisano wydzielone poziomy genetyczne. Diagnozę typu siedliskowego lasu określono wykorzystując Siedliskowy Indeks Glebowy. Z każdego poziomu genetycznego pobrano próbki do analiz laboratoryjnych. W próbkach oznaczono podstawowe właściwości fizykochemiczne (uziarnienie, pH, zawartość C i N, zawartość fosforu przyswajalnego oraz właściwości sorpcyjne). W efekcie badań stwierdzono, że modrzew polski może tworzyć drzewostany wysokoprodukcyjne na siedliskach lasu wyżynnego świeżego z domieszką gatunków liściastych (buk zwyczajny *Fagus sylvatica*, dąb szypułkowy *Quercus robur*, grab pospolity *Carpinus betulus*, jawor pospolity *Acer pseudoplatanus*). Opisywane gleby oznaczono jako gleby płowe właściwe, które różniły się cechami poziomów próchnicznych. Wysoki udział modrzewia (40–60%) rosnącego na glebach płowych nie wpływa negatywnie na właściwości poziomów próchnicznych i stopień wyługowania gleb płowych utworzonych z lessu. W przypadku drzewostanów z przewagą modrzewia występuje tendencja do pogarszania się właściwości poziomów akumulacji próchnicy i tworzenia się na powierzchni poziomu ektopróchnicy. Siedliskowy Indeks Glebowy wskazuje, że badane gleby kształtują eutroficzne siedliska lasu wyżynnego świeżego (Lwyż św). Obniżenie wartości SIG w dwóch przypadkach to efekt pogorszenia właściwości poziomów próchnicznych.