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RELATIONS BETWEEN FEATURES OF FOREST FLOOR VEGETATION AND SURFACE SOIL HORIZONS PROPERTIES IN SCOTS PINE (*PINUS SYLVESTRIS* L.) STANDS IN SOUTHWEST POLAND***

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Abstract. The paper presents the studies on relations between features of forest floor vegetation and surface soil horizons (organic and humus) properties. The research was taken in 100 pine stands located in southwest Poland. The investigated relations were different when concerning two forest floor layers. The higher values of the analysed herb layer indicators (the herb layer cover and the amount of plant species in the herb layer) are related to the higher trophy of the surface soil horizons. For the analogous moss layer indicators the relations are opposite to the herb layer relations. In the investigated pine stands the forest floor species composition was more related to organic than to humus horizon properties.

The relations between forest floor vegetation and upper soil horizons properties are double-sided. The associations of particular forest floor plant species can influence the soil properties [3, 5], but soil properties also determine forest floor plant composition. The second relation results from different plant species requirements to soil conditions [6]. The occurrence of particular plant species in forest floor is an important indicator of soil trophy and humidity that is commonly used in Poland to assess the forest site productivity for silviculture [21].

Scots pine (*Pinus sylvestris* L.) is a tree species which strongly forms soil properties that concerns mainly upper soil horizons acidification [1, 4]. In undergrowth of pine stands, species that tolerate distinct acid and poor soil

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conditions usually prevail. In southwest Poland pine was commonly planted in silviculture on sites of originally deciduous forests [12]. As a result, in pine stands, species that are typical for deciduous forests occur varying the forest floor species composition. The aim of the paper was to evaluate the relations between forest floor vegetation and surface soil horizons (organic and humus) properties in selected pine stands in southwest Poland.

MATERIALS AND METHODS

The studies were conducted in 100 pine stands in the Bolesławiec, Głogów and Oława forest division in southwest Poland. In each stand, Scots pine (*Pinus sylvestris* L.) was the dominant tree species in overstory. Study plots were located at soil pits that had been earlier analysed in the soil forest survey works for the investigated forest divisions [13-15].

In each study plot: organic horizon was sampled according to the instructions of the Polish forest survey [7]; thickness of organic and humus horizon was determined; phytosociological relevé was taken according to Braun-Blanquet method [2] – nomenclature of vascular plants follows Rutkowski [19], of mosses follows Ochyra and Szmajda [11] and of lichens follows Nowak and Tobolewski [10].

The following parameters were determined in the collected organic samples:

- total organic carbon (TOC) and total nitrogen (Nt) content by CNS Vario Max analyser Elementar (Germany),
- pH in H_2O (pH_{H2O}) and in 1M KCl (pH_{KCl}) by the potentiometric method,
- hydrolytic acidity (HA) by the Kappen method,
- content of exchange basic cations (Ca^{2+}, Mg^{2+}, Na^+, K^+) following extraction of samples in 1M CH_3COONH_4 at pH 7.0 and the AAS method,
- values of absorbance at wavelength 472 and 664 nm for separated humic acids in 0.5% NaOH and 0.5% $Na_2C_2O_4$,
- humification degree (HD) by the Springer method [20].

For each organic sample the following factors were calculated: TOC:Nt ratio; the sum of exchange basic cations (S); cation exchange capacity (CEC); base saturation (BS); values of absorbance ratio at wevelength 472 to 664 nm (A4/6). Analytical determinations (organic carbon - OC, pH_{H2O}, pH_{KCl}, HA, exchange basic cations content) and indicators (S, CEC, BS) that concern humus horizon were taken from the soil descriptions resources of the State Forests National Forest Holding [13-15]. The statistical characteristics of the investigated soil properties are shown in Table 1.

On the basis of the phytosociological relevés taken for each study plot the following indicators were calculated: amount of plant species in a herb layer (AHL); amount of moss and lichen species in a moss layer (AML). The statistical

TABLE 1. THE STATISTICAL CHARACTERISTICS OF THE SOIL PROPERTIES

Property	Organic horizon		Humus horizon	
	Mean ± SD	Range	Mean ± SD	Range
Thickness (cm)	6.5 ± 1.7	3-12	10.7 ± 5.8	2-30
(T)'OC (%)	38.6 ± 6.9	19.4-64.4	1.70 ± 1.37	0.50-9.53
Nt (%)	1.462 ± 0.344	0.805-2.615	0.079 ± 0.061	0.018-0.397
(T)'OC : Nt	27.0 ± 4.4	12.9-41.0	22.8 ± 6.5	8.3-37.7
A4/6	6.69 ± 0.84	4.73-9.64	n.d.	n.d.
HD	28.0 ± 6.4	12.7-59.6	n.d.	n.d.
pH_{H_2O}	3.8 ± 0.3	3.2-4.9	4.0 ± 0.4	3.2-5.0
pH_{KCl}	3.0 ± 0.3	2.5-4.4	3.3 ± 0.4	2.6-4.4
HA	145 ± 30	56.7-223	8.03 ± 4.39	2.63-26.05
Ca^{2+} (mmol $_{(+)}$/100 g)	8.68 ± 5.73	0.64-30.1	0.51±0.35	0.04-2.21
Mg^{2+} (mmol $_{(+)}$/100 g)	1.49 ± 0.74	0.26-3.78	0.13 ± 0.06	0.06-0.48
Na^{+} (mmol $_{(+)}$/100 g)	0.28 ± 0.11	0.07-0.74	0.09 ±0.04	0.03-0.36
K^{+} (mmol $_{(+)}$/100 g)	0.85 ± 0.30	0.22-1.74	0.07 ± 0.03	0.02-0.19
S(mmol $_{(+)}$/100 g)	11.3 ± 6.6	1.19-34.8	0.80 ± 0.37	0.25-2.68
CEC (mmol $_{(+)}$/100 g)	156 ± 28	57.9-231	8.83 ± 4.62	3.33-28.7
BS (%)	7.62 ± 5.44	1.94-30.0	10.0 ± 4.4	2.5-26.5

TOC – concerned organic horizon, OC – concerned humus horizon; n.d. – not determined.

characteristics of AHL, AML, herb layer cover (HLC) and moss layer cover (MLC) are presented in Table 2.

The correlations were analysed in STATISTICA package, the Spearman correlations were used. Relations between forest floor species composition and soil properties were investigated in CANOCO 4.5 package [22]. Because Detrended Correspondence Analysis (DCA) detected a strong unimodal structure of vegetation data, the pattern of plant distribution was analysed by the Canonical Correspondence Analysis (CCA) [9]. Species that occured only in one study plot were downweighted in the ordination analysis. Before conducting CCA Braun-Blanquet cover values of species were transformed into the ordinal scale values [23] in the following way: r→1, + →2, 1 →3, 2 →5, 3 →7, 4 →8, 5 →9. In CCA the relative importance of each environmental variable in vegetation differentiation was assessed by the Monte Carlo permutation test [22].

TABLE 2. THE STATISTICAL CHARACTERISTICS OF THE FOREST FLOOR VEGETATION PROPERTIES

Property	Mean ± SD	Range
Amount of plant species in a herb layer (AHL)	7.1 ± 3.6	1-18
Amount of plant species in a moss layer (AML)	3.1 ± 1.6	0-7
Herb layer cover (HLC) [%]	67 ± 20	5-95
Moss layer cover (MLC) [%]	44 ± 26	0-90

RESULTS AND DISCUSSION

The correlations between surface horizons properties and some quantity forest floor vegetation properties are shown in Table 3. In the studied pine stands HLC is positively correlated ($p < 0.01$) to organic horizon thickness. The relation can cause further HLC and humus horizon OC content positive correlation in the investigated plots. The higher OC content in a humus horizon effects a higher CEC in the horizon, therefore the observed HLC to the sorption properties (HA, content of particular exchange basic cations, S, CEC; Table 3) correlations are probably indirect. In CEC of forest soils' surface horizons acid cations prevail [16], thus it can be stated that HLC to pH in humus horizon relations are indirect as well. It probably also results from the original relation between HLC and OC content in a humus layer.

More favourable trophic conditions in surface soil horizons of some studied plots (higher content of basic cations and BS, lower (T)OC:Nt ratio) enable to occur, apart from plant species that are typical for acid soils, also plants that demand relatively better trophic conditions. As a result, AHL is distinctly positive correlated to pH, content of exchange basic cations (except sodium as the element is not a nutrient for plants), BS and negatively correlated to (T)OC:Nt ratio. Most of the relations concern both organic and humus horizon (Table 3).

The relations between surface soil parameters and moss layer properties are relatively strong and enable unequivocal interpretation. In the investigated pine stands both analysed moss layer indicators (MLC and AML) are negatively correlated to increasing soil trophic conditions. It can be deduced from the indicators negative correlations to Nt, pH, content of particular exchange basic cations, S and positive correlation of the moss indicators to the (T)OC:Nt ratio. The above dependences concern both investigated soil horizons, but mostly are more distinct when the organic horizon properties are concerned (Table 3). On the basis of phytosociological relevés taken it can be stated that AML versus soil parameters relations result primarily from more frequent lichens occurrence (mainly of the *Cladonia* genus) within plots marked by poor trophic conditions in the investigated soil horizons. Similar results Fałtynowicz obtained in fertilization experiments [8].

TABLE 3. THE CORRELATIONS BETWEEN THE SOIL PROPERTIES AND THE FOREST FLOOR VEGETATION PROPERTIES

	Thickness (cm)	(T)'OC (%)	Nt [%]	(T)'OC : Nt	A4/6	HD	pH_{H_2O}	pH_{KCl}	HA	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	S	CEC	BS (%)
Organic horizon																
HLC (%)	0.274**	0.047	0.208*	-0.164	-0.305**	0.122	-0.096	-0.116	0.124	0.006	0.081	0.055	0.029	0.012	0.149	0.001
MLC (%)	0.196	0.012	-0.348**	0.379**	0.113	0.255*	-0.502**	-0.536**	0.249*	-0.509**	-0.560**	-0.016	-0.264**	-0.512**	0.168	-0.490**
AHL	-0.149	-0.178	0.190	-0.390**	-0.159	-0.407**	0.383**	0.358**	-0.467**	0.496**	0.521**	-0.042	0.145	0.495**	-0.408**	0.549**
AML	0.251**	0.053	-0.205*	0.285**	0.226*	0.164	-0.324**	-0.280**	0.285**	-0.376**	-0.380**	-0.024	-0.175	-0.377**	0.238*	-0.382**
Humus horizon																
HLC (%)	0.029	0.339**	0.335**	-0.014	n.d.	n.d.	-0.366**	-0.381**	0.359**	0.224*	0.249*	-0.136	0.224*	0.260**	0.365**	-0.132
MLC (%)	-0.010	-0.156	-0.284**	0.190	n.d.	n.d.	-0.039	-0.169	-0.250*	-0.101	-0.342**	-0.160	-0.317**	-0.192	-0.259**	0.102
AHL	-0.031	0.215*	0.457**	-0.494**	n.d.	n.d.	-0.160	-0.052	0.385**	0.237*	0.371**	-0.076	0.340**	0.336**	0.394**	-0.088
AML	-0.108	-0.058	-0.221*	0.296**	n.d.	n.d.	-0.010	-0.082	-0.147	-0.067	-0.247*	0.045	-0.211*	-0.116	-0.151	0.074

**p<0.01; * $0.01 < p < 0.05$. Explanations as in Table 1.

The author concluded that after fertilization, vascular plants and mosses portions in forest floor vegetation of pine stands increased, while the lichens portion after the treatment decreased.

The obtained results confirmed the conception of Prusinkiewicz and Kowalkowski [18] that the amount of vascular plant species occurring in a forest parcel [17] can be an indirect indicator of the soil trophy. On the basis of the presented results, it can be also assumed that an index that concerns both herb layer and moss layer properties could be a good indirect indicator of the surface soil trophy. It could be caused by often opposite correlations between properties of these two layers and soil parameters (Table 3). The results suggest also that the index could concern not only species amount in forest floor layers but also cover degree of the layers.

In the species-organic horizon properties relations, the forward selection and the Monte Carlo permutation test detected Ca^{2+}, Mg^{2+} and K^{+} cations content, HA, pH_{KCl} and TOC:Nt ratio as the significant ($p < 0.05$) variables in the pattern of a species distribution (Fig. 1). The forward selection of explanatory variables demonstrated that the Ca^{2+} concentration had the largest contribution to the total variance of the floristic data. It explains 7.6% of the species distribution variance in the CCA ordination diagram. The next explanation values of statistically important soil properties in the species pattern of Fig. 1 are: 3.1% (TOC:Nt), 2.5 (pH_{KCl}), 2.3% (Mg^{2+} content), 1.5% (K^{+} content) and 1.3% (HA). All the properties of organic parameters that were considered in the ordination diagram presented in Fig. 1 explained 22,2% of the total variance in the species data set. The statistically unimportance in the species distribution of BS can result from a strong correlation between this indicator and analysed basic cations contents, as it can be seen in Fig. 1. Other properties of organic horizon such as the humification degree and the A4/6 ratio proved to be of no significant importance in the CCA. These two perameters were not taken into consideration in the presented ordination diagram in Fig. 1.

The pattern of species distribution shown in Fig. 1 determines the first CCA ordination axis as the axis represented trophic gradient that increased to the right part of the diagram - in the left part the species of very poor soils are located (i.g. lichens, *Vaccinium vitis-idaea*, *Dicranum undulatum*) while in the right part, species of much higher site trophy preferences prevail (i.g. *Alliaria petiolata, Dactylis aschersoniana, Brachypodium sylvaticum, Hedera helix*). Most of the species that are located in the right part of the diagram in Fig. 1 are more typical for deciduous than for pine forests. The occurrence of these species in a part of the investigated plots is an important reason for the stated positive correlation between AHL and soil properties that determine soil trophy (Table 3).

The second ordination axis in Fig. 1 represents soil humidity gradient that increases to the upper diagram part. It can be stated from plants typical for humid sites (*Vaccinium oxycoccos, Erica tetralix, Sphagnum sp., Calamagrostis canescens*) location in the upper part of the ordination diagram.

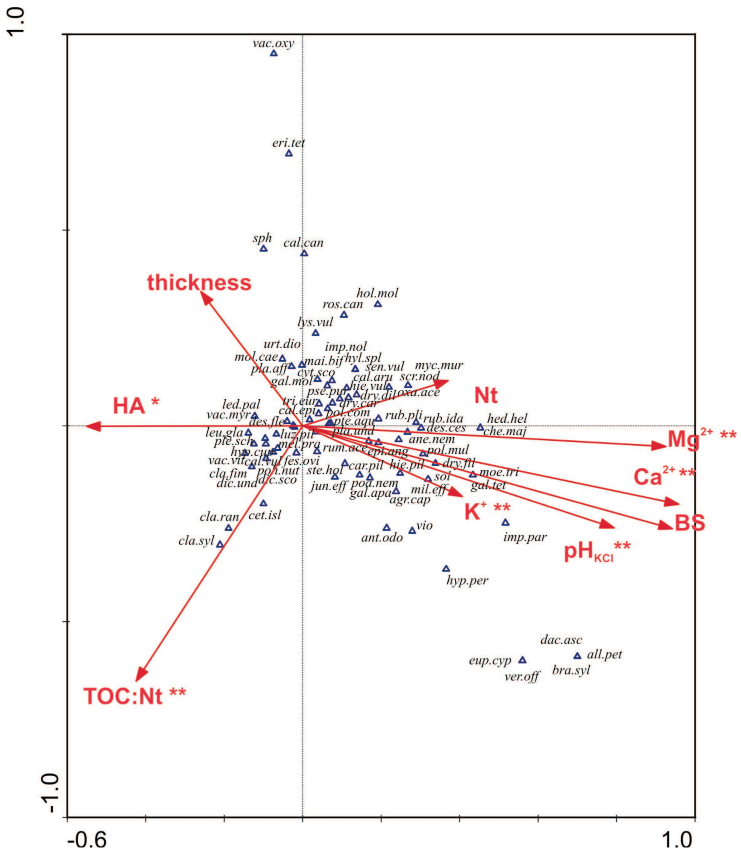

Fig. 1. CCA ordination diagram showing correlation between species composition and organic horizon properties. Significance levels of soil variables are noted by symbols: ** $p < 0.01$, * $0.01 < p < 0.05$. Species abbreviations: *agr.cap – Agrostis capillaris, all.pet – Alliaria petiolata, ane.nem – Anemone nemorosa, ant.odo – Anthoxanthum odoratum, bra.syl – Brachypodium sylvaticum, cal.aru – Calamagrostis arundinacea, cal.can – Calamagrostis canescens, cal.epi – Calamagrostis epigejos, cal.vul – Calluna vulgaris, car.pil – Carex pilulifera, cet.isl – Cetraria islandica, che.maj – Chelidonium majus, cla.fim – Cladonia fimbriata, cla.ran – Cladonia rangiferina, cla.syl – Cladonia silvatica, cyt.sco – Cytisus scoparius, dac.asc Dasctylis aschersoniana, des.ces – Deschampsia cespitosa, des.fle – Deschampsia flexuosa, dic.sco – Dicranum scoparium, dic.und - Dicranum undulatum, dry.car – Dryopteris carthusiana, dry.dil – Dryopteris dilatata, dry.fil – Dryopteris filix-mas, epi.ang – Epilobium angustifolium, eri.tet – Erica tetralix, eup.cyp – Euphorbia cyparissias, fes.ovi – Festuca ovina, gal.apa – Galium aparine, gal.mol – Galium mollugo, gal.tet – Galeopsis tetrahit, hed.hel – Hedera helix, hie.pil – Hieracium pilosella, hie.vul – Hieracium vulgatum, hol.mol – Holcus mollis, hyl.spl – Hylocomium splendens, hyp.cup – Hypnum cupressiforme, hyp.per – Hypericum perforatum, imp.par – Impatiens parviflora, imp.nol – Impatiens noli-tangere, jun.eff – Juncus effusus, led.pal – Ledum palustre, leu.gla – Leucobryum glaucum, luz.pil – Luzula pilosa, lys.vul – Lysimachia vulgaris, mai.bif – Maianthemum bifolium, mel.pra – Melampyrum pratense, mil.eff – Millium effusum, moe.tri – Moehringia trinervia, mol.cae – Molinia caerulea, myc.mur – Mycelis muralis, oxa.ace – Oxalis acetosella, pla.aff – Plagiomnium affine, pla.und – Plagiomnium undulatum, ple.sch – Pleurozium schreberi, poh.nut – Pohlia nutans, pol.mul – Polygonatum multiflorum, pol.com – Polytrichum commune, pse.pur – Pseudoscleropodium purum, pte.aqu – Pteridium aquilinum, ros.can – Rosa canina, rub.ida – Rubus idaeus, rub.pli – Rubus plicatus, rum.ace – Rumex acetosella, scr.nod – Scrophularia nodosa, sen.vul - Senecio vulgaris, sol – Solidago sp., sph – Sphagnum sp., ste.hol – Stellaria holostea, tri.eur – Trientalis europaea, urt.dio – Urtica dioica, vac.oxy – Vaccinium oxycoccos, vac.myr – Vaccinium myrtillus, vac.vit – Vaccinium vitis-idaea, ver.off – Veronica officinalis, vio – Viola sp.*

In the species-humus horizon properties relations, the forward selection and the Monte Carlo permutation test detected following variables as statistically important in the pattern of species distribution: Mg^{2+} content (4.1% of species distribution variance explanation), Ca^{2+} content (2.8%), pH_{KCl} (2.8%), OC:Nt (2.8%), thickness of the humus horizon (2.0%) and Nt content (1.8%). All parameters of the humus horizon properties that were considered in the ordination diagram presented in Fig. 2 explained 19.2% of the total variance in the species data set.

The diagnoses of the gradients represented by diagram axes in Fig. 2 are not as clear as in Fig. 1. The vectors of most soil parameters that define soil trophy are pointed to the right part of the diagram, but the pH_{KCl} vector is pointed to its upper part. Neither the pattern of species distribution is clear to interpret. The plants of higher soil trophy condition requirements are located in both, right and upper part

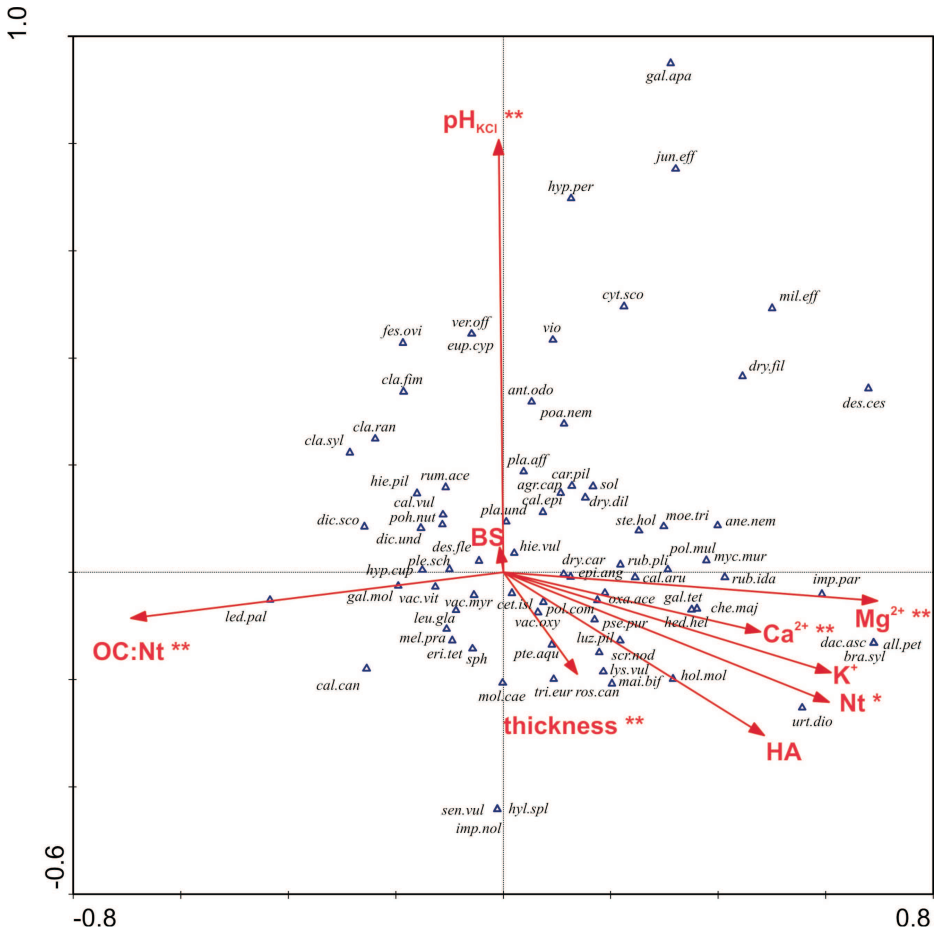

Fig. 2. CCA ordination diagram showing correlation between species composition and humus horizon properties. Abbreviations as in Fig. 1.

of the analysed diagram. The first axis in Fig. 2 represents probably content of organic matter and fine particle size fractions – the agents of CEC values in humus horizon. It can be deduced from the vectors direct of all analysed sorption parameters that is pointed in the right part of the diagram. The gradient of the second ordination axis represents pH_{KCl} (Fig. 2).

Taking into account the same soil properties set considered in both analysed ordination diagrams (Figs 1, 2) it can be assumed that in the investigated plots the relations between forest floor species composition and soil properties are more distinct for organic than for humus horizon. It can be supported by the results obtained by Dziadowiec *et al*. [5] who investigated a differentiation of organic and humus properties in plant associations of pine-oak mixed forest. The authors concluded that forest floor species composition play more important role for properties of organic than for properties of humus horizon.

CONCLUSIONS

1. The relations between forest floor vegetation and surface soil horizons properties are different when two forest layers are concerned. The higher values of the analysed herb layer indicators (AHL and HLC) are concerned to the higher trophy of the surface soil horizons. For the investigated moss layer indicators (AML and MLC) the relations are opposite to the herb layer relations.

2. It can be advisable to carry out the floristic, indirect indicator of forest soil trophy not only based on the amount of vascular plant species [18], but also concerning species of moss layer (especially lichens) occurring in a forest parcel.

3. The forest floor species composition is more related to organic than to humus horizon properties.

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RELACJE MIĘDZY CECHAMI RUNA A WŁAŚCIWOŚCIAMI POWIERZCHNIOWYCH POZIOMÓW GLEBY W DRZEWOSTANACH SOSNOWYCH POŁUDNIOWO-ZACHODNIEJ POLSKI

Badania przeprowadzono na 100 powierzchniach badawczych położonych w drzewostanach sosnowych na terenie Nadleśnictwa Bolesławiec, Głogów i Oława w południowo-zachodniej Polsce. Za pomocą analizy korelacji wykazano, że na badanych powierzchniach analizowane zależności są różne dla poszczególnych warstw runa. Wartości analizowanych wskaźników dotyczących warstwy zielnej runa (stopień pokrycia warstwy i liczba gatunków roślin w warstwie) są pozytywnie skorelowane z trofizmem poziomu organicznego i próchnicznego gleby. Zależności dla analogicznych wskaźników wyliczonych dla warstwy przyziemnej runa (mchów i porostów) okazały się przeciwne do tych uzyskanych dla warstwy zielnej. Na podstawie przeprowadzonej analizy porządkowania w pakiecie CANOCO stwierdzono, że skład gatunkowy runa jest na analizowanych powierzchniach badawczych silniej zależny od właściwości poziomu organicznego niż próchnicznego gleby.