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Differentiation of grassland vegetation in relation to the physicochemical properties of peat soils in the Obra River valley, western Poland

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Abstract

The aim of the study was to present the phytosociological structure of selected grassland communities on shallow peat soils undergoing the of mursh-forming (murshing) process (humification and peat mineralization). The study area was located between the North, Middle and South channels of the Obra River (Wielkopolska Lowland, western Poland). Soil surveys were conducted in May and September 2022 and phytosociological surveys in May and September 2022–2023. Soil samples for laboratory analysis were taken from the uppermost soil horizons at a depth of 0–20 cm in 20 study points. 76 phytosociological releves were taken. Five vegetation syntaxonomic units were distinguished: *Molinietum caeruleae*, com. *Poa pratensis-Festuca rubra*, *Arrhenatheretum elatioris*, *Lolio-Cynosuretum* and *Alopecuretum pratensis*. The vegetation units with the highest diversity values and number of species recorded in the releves was *Molinietum caeruleae*, while the poorest in species with lowest Shannon-Wiener index was *Lolio-Cynosuretum*. The soils were classified as Umbric Gleysols, Mollic/Umbric Gleysols, Histic Gleysols, Histic Gleysols (Murshic). The highest contents of TOC and TN were recorded for community *Poa pratensis-Festuca rubra* and the lowest for *Arrhenatheretum elatioris*. The pH values indicated slightly acidic soils in the case of the following vegetation units: *Alopecuretum pratensis, Molinietum caeruleae, Lolio-Cynosuretum, com. Poa pratensis-Festuca rubra* and slightly alkaline soils in the case of *Arrhenatheretum elatioris*. The results of the discriminant analysis demonstrated that the most important statistically significant factor for vegetation syntaxonomic units differentiation was soil pH measured both in H_2O and KCl. *Molinietum caeruleae* association was present on the soils poor in mineral components and organic matter of relatively high C:N ratio. Shannon-Wiener index was significantly negatively correlated with TOC and TN. It is advisable to continue to maintain the studied sites as grassland vegetation. Grassland communities can survive in the murshing process, provided they are correctly used (regular mowing, grazing, and fertilizing) and water relations are regulated. Grasslands, besides to enriching soils with nutrients, create the best conditions for limiting the decomposition of organic matter in accumulation and humus levels of mursh nature, which is extremely important in the face of climate change.

1. Introduction

Grasslands are important terrestrial ecosystems and integral components of the global environment, playing a crucial role in biodiversity conservation, climate change mitigation, water regulation, wildlife habitat, human livelihoods and ecosystem services (Kumar et al., 2017; Mencel et al., 2022a, 2022b; Yang et al., 2020). Despite such an important role, grasslands found in Europe are one of the most endangered ecosystems. In Poland, where the present study was conducted, they have significantly reduced their acreage, currently accounting for only 21.5% of agricultural land (GUS, 2023).

Grasslands are carbon sinks, sequestering atmospheric carbon dioxide through photosynthesis and storing it in organic matter in the soil. Grasses have shallow, horizontally distributed roots. In contrast, species of meadow communities other than grasses (so primarily dicotyledonous species) have deep root systems that can sequester carbon underground while helping to mitigate climate change by removing it from the atmosphere (Borana et al., 2023; Khalil et al., 2021; Mencel et al., 2022a, 2022b; Smith, 2014). Various factors affect the carbon content of grassland soils, these include species composition, soil structure, climate, soil type or management practices (Bengtsson et al., 2019; Lal, 2020; Liu et al., 2023; Yang et al., 2020).

Diversity of grassland communities is important because it improves the functioning of the ecosystem, makes it more stable and less vulnerable to unfavorable external factors, such as climate change. In addition, it positively affects nutrient cycling, productivity or interspecies interactions (Dumont et al., 2022; Freitag et al., 2023; Mashiane et al., 2023). The diversity of grassland communities depends on biotic and abiotic factors, among other plant species richness, land use or landscape structure (Boonman et al., 2021; Nguyen, 2022; Wilsey, 2018).

Organic soils are characterized by their susceptibility to transformation and degradation. They are mainly derived from plant residues, so this characteristic is important for agricultural areas (Glina et al., 2019a; Krüger et al., 2015; Łachacz et al., 2023; Nicia et al., 2018; Oleszczuk et al., 2022; Zając et al., 2018). Murshic soils are a soil that is a transitional type from organic soils to mineral soils. Murshic soils, often associated with wetlands, play a key role in grassland biodiversity. These soils provide unique conditions that support diverse plant and microbial communities, which in turn contribute to the overall biodiversity of grassland ecosystems (Guo et al., 2023; Plante et al., 2011). The murshic soils accompanying grasslands have a unique composition and texture (Jurasinski et al., 2020; Łachacz et al., 2023). They are characterized by a high content of decomposed plant material (e.g., rotten roots, leaves, stems), that is, a high content of soil organic matter. Among other things, this characteristic provides the described soils with structure and richness in plant nutrients, and promotes good soil aeration and drainage (Zhao et al., 2023). Decomposition of organic matter by soil microorganisms is accompanied by the release of nutrients essential for plants, such as nitrogen, phosphorus, potassium. This process promotes the occurrence of species with different nutritional requirements, which leads to the biological diversity of the ecosystem (Łachacz et al., 2023; Lisec et al., 2024; Pawluczuk et al., 2019). Due to their high organic content, organic and post-organic soils have a high capacity to retain water. This helps plants survive unfavorable environmental conditions such as drought (Deng et al., 2016). Organic soils, due to their high organic matter content, are highly productive and fertile. However, once they are drained, the circulation and storage of water is disrupted. This process leads to a situation where carbon can no longer be stored and is released, which in turn causes habitat loss (Berglund and Berglund, 2010; Dawson et al., 2010; Łachacz et al., 2023; Liu et al., 2020; Xu et al., 2018).

Responsible and sustainable grassland management is an extremely important issue, especially in the context of carbon sequestration and biodiversity. Additionally, grassland soils need to be protected and conserved, as they are important for diversity of grassland ecosystems in the face of environmental challenges such as climate change and habitat loss (Smreczak and Ukalska-Jaruga, 2021). In order to achieve these long-term goals, knowledge of the processes and properties in the topsoil layers is needed.

The aim of the study was to present the phytosociological structure of selected grassland communities on shallow peat soils undergoing the of mursh-forming (murshing) process (humification and peat mineralization). This is crucial in an era of biodiversity loss and climate change. We pose the following research hypotheses: 1. grassland vegetation syntaxonomic units are related to different properties of peat soils, 2. the diversity of grassland vegetation depends on content of organic matter and soil pH.

2. Materials and methods

2.1. Study area

The study area was located between the North, Middle and South channels of the Obra River (Wielkopolska Lowland, central Poland). According to the Detailed Geological Map of Poland (Jodłowski, 2003; Krzysztofka, 1993; Szałajdewicz, 2004), all the soils studied were formed from shallow peats on alluvial materials (mainly sands, occasionally silts). The grasslands under study are located in the fully humid warm temperate climate zone with warm summers (Kottek et al., 2006). The mean annual air temperature and the mean annual precipitation in this region are 10.6°C and 414.6 mm, respectively. It is noteworthy that 2022 was 1.2°C warmer than the multi-year averages of 1991–2020, and that the average annual precipitation in that year is 77% of the norm for the area (IMGW PIB, 2022).

2.2. Phytosociological survey

The present study was conducted on semi-natural grasslands. A total of 76 phytosociological releves were taken using the Braun-Blanquet (1964) method during the period 2022–2023. The releves were made at 20 survey points, represented areas of 100 m^2 and homogeneous species composition. Phytosociological releves were entered into TURBOVEG (Hennekens and Schaminée, 2001), a specific database of phytosociological releves, and exported to the JUICE program (Tichý et al., 2011), where they were analyzed. The collected releves were assigned to the phytosociological system according to Matuszkiewicz (2023). Four plant associations and one community were distinguished: *Molinietum caeruleae* (12 releves), community (com.) *Poa pratensis-Festuca rubra* (16 releves), *Arrhenatheretum elatioris* (16 releves), *Lolio-Cynosuretum* (16 releves) and *Alopecuretum pratensis* (16 releves). Cover index (D) allows to quantify the average proportion of individual species or groups of species in different vegetation layers. D was determined as the sum of the average percentage values of the coverage of the selected taxon in all phytosociological releves in which the species occurs, multiplied by 100 and divided by the total number of releves (Pawłowski, 1977). Species richness (SR), the Shannon-Wiener index (H') (Shannon and Weaver, 1949), were used as indicators of floristic diversity. H' index was calculated at the level of phytosociological releve.

2.3. Soil survey and sampling

Phytosociological sites were sampled for soils in May and September 2022 in the area of four municipalities. Sampling sites were located in municipality of: Kościan (1, 2, 3, 4), Wielichowo (5, 6, 7, 9, 10, 13, 14, 15, 17), Przemęt (8, 11, 12, 18, 19, 20) and Wolsztyn (16) (Fig. 1).

Soil samples for laboratory analysis were taken from the uppermost soil horizons at a depth of 0–20 cm in each soil from three points at one sampling site to account for potential soil variability (ISO 10381-1:2002). The soil was collected with soil sampler – Egner's Cane. The numbers of the soil samples corresponded to the soil materials from which they were taken. Sampling locations were georeferenced in the field (Table 1).

Soil samples were collected in plastic bags and transported in a lightproof box to the laboratory for refrigeration.

Fig. 1. Location of (A) the study area and (B) sampling sites

Table 1
Location of sampling sites with phytosociological classification of grasslands

Sampling sites	Grassland units	Coordinates WGS 84 (N/E)
1.	*Molinietum caeruleae*	52°05'42"N 16°31'30"E
2.	*Molinietum caeruleae*	52°05'42"N 16°31'33"E
3.	*Molinietum caeruleae*	52°05'43"N 16°31'37"E
4.	*Molinietum caeruleae*	52°05'43"N 16°31'39"E
5.	com. *Poa pratensis-Festuca rubra*	52°06'07"N 16°22'12"E
6.	com. *Poa pratensis-Festuca rubra*	52°06'07"N 16°22'08"E
7.	com. *Poa pratensis-Festuca rubra*	52°06'04"N 16°22'03"E
8.	com. *Poa pratensis-Festuca rubra*	52°01'27"N 16°16'23"E
9.	*Arrhenatheretum elatioris*	52°06'03"N 16°22'07"E
10.	*Arrhenatheretum elatioris*	52°06'00"N 16°21'56"E
11.	*Arrhenatheretum elatioris*	52°00'49"N 16°16'52"E
12.	*Arrhenatheretum elatioris*	52°01'01"N 16°16'43"E
13.	*Lolio-Cynosuretum*	52°06'02"N 16°22'04"E
14.	*Lolio-Cynosuretum*	52°05'59"N 16°22'00"E
15.	*Lolio-Cynosuretum*	52°06'00"N 16°22'01"E
16.	*Lolio-Cynosuretum*	52°04'23"N 16°14'11"E
17.	*Alopecuretum pratensis*	52°05'58"N 16°21'57"E
18.	*Alopecuretum pratensis*	52°00'47"N 16°16'54"E
19.	*Alopecuretum pratensis*	52°00'47"N 16°16'57"E
20.	*Alopecuretum pratensis*	52°01'02"N 16°16'44"E

2.4. Chemical analyses

In the laboratory, the soil samples were air-dried, disaggregated, homogenized, and sieved through a 2 mm sieve. The chemical analyses consisted of the determination of the following parameters: total organic carbon (TOC) and total nitrogen (TN) content with a Vario-Max CNS analyzer; soil pH potentiometrically in 1 M KCl and in a suspension of distilled water at a ratio of 1:2.5; macro- and micro-nutrients were determined by the method of Sapek and Sapek (1997) using 0.5 M HCl. The macro- and micro-nutrients included: phosphorus (P) content determined by colorimetric method, potassium (K) content by flame photometry, magnesium (Mg) and manganese (Mn) content by atomic absorption spectrometry (AAS). No calcium carbonate was recorded in the studied soils.

2.5. Statistical analysis

The mean values of the Shanon-Wiener diversity index and the number of species (species richness) were compared between grassland vegetation units by one factorial analysis of variance (ANOVA I) with Tukey post hoc comparisons because both diversity index and species richness were normally distributed (Shapiro-Wilk test p>0.05). According to our second hypothesis, the relationships between species diversity (H and SR) and soil TN, TOC, pH_{H2O}, and pH_{KCl} were tested by Pearson correlations. We took 40 plots with complete species and soil data for this analysis. The mean soil properties in grassland units were compared by the Kruskal-Wallis non-parametric test with Dunn post hoc comparisons because most parameters did not demonstrate normal distribution (Shapiro-Wilk test p<0.05). For calculations, Past 3.16b software was used (Hammer et al., 2001).

Discriminant analysis was applied to identify the most important soil properties in the differentiation of grassland vegetation syntaxonomic units. We used the ordination method – Canonical Variate Analysis (CVA) as discriminant analysis, focusing on conditional effects which exclude effects of the most correlated variables (Šmilauer and Lepš, 2014). Conditional effects summarize the partial effect of each predictor, representing the variation (and its significance) explained by a predictor after accounting for the impact of the predictors already selected (ter Braak and Šmilauer, 2012). The predictors were chosen in the order of decreasing explained variation by the forward selection procedure. Their statistical significance was assessed by Monte Carlo Permutation test. For calculations Canoco 5.0 program was applied (ter Braak and Šmilauer, 2012).

3. Results

3.1. Characteristics of grassland vegetation syntaxonomic units

The described communities are diverse within the *Molinio-Arrhenatheretea* class. They belonged to two orders: *Arrhenatheretalia* and *Molinietalia*. In the *Arrhenatheretalia* order, two association and one community were distinguished: *Arrhenatheretum elatioris, Lolio-Cynosuretum* and com. *Poa pratensis-Festuca rubra.* And in the order *Molinietalia* two associations were distinguished. *Alopecuretum pratensis* and *Molinietum caeruleae*.

Species richness of the analyzed communities is shown in Table 2. The total number of species recorded in the *Molinio-Arrhenatheretea* in 76 phytosociological releves was 102. The community with the highest number of species recorded in the releves was *Molinietum caeruleae*, while the poorest in species was *Lolio-Cynosuretum*. This is a result that could have been expected, as it is due to the characteristics of these grassland communities.

The values of the Shannon-Wiener H' index were highest for *Molinietum caeruleae* and lowest in *Lolio-Cynosuretum* (Table 2). The highest cover index was characterized by *Alopecuretum pratensis* meadows, D was 6933.

The structure of sociological (habitat) groups of the analyzed vegetation syntaxonomic units is shown in Fig. 2.

All studied grassland communities showed good ecological condition. This was indicated by the high proportion of characteristic syntax-specific species (Appendix 1.). As expected, *Alopecuretum pratensis* and *Molinietum caeruleae* were dominated by species of the *Molinietalia caeruleae* order, while com. *Poa pratensis-Festuca rubra, Arrhenatheretum elatioris, Lolio-Cynosuretum* had a significant share of species of the *Arrhenatheretalia elatioris*. In addition to the *Molinio-Arrhenatheretea* class, species from the *Phragmitetea* class had a visible share in the studied communities.

Molinietum caeruleae was characterized by the dominance of *Molinia caerulea, Festuca pratensis, Potentilla anserina* and *Ra-*

Table 2
Indicators of biodiversity of selected grassland vegetation units. H' – Shannon-Wiener diversity index, D – cover index. Statistically significant differences in biodiversity indicators between grassland vegetation syntaxonomic units are marked by different letters (p≤0.05; ANOVA I with Tukey post hoc comparisons). Differences in D were not assessed

Grassland units	Total number of species	Number of species in the releve (range and mean)		H'	D
Molinietum caeruleae	57	17–29	23 [c]	2.38 [b]	6088
Alopecuretum pratensis	44	10–22	17 [b]	1.75 [ac]	6933
Arrhenatheretum elatioris	54	14–24	19 [b]	2.03 [bc]	5930
Lolio-Cynosuretum	36	8–16	12 [a]	1.49 [a]	5193
com. *Poa pratensis-Festuca rubra*	50	12–24	19 [b]	2.18 [b]	5813

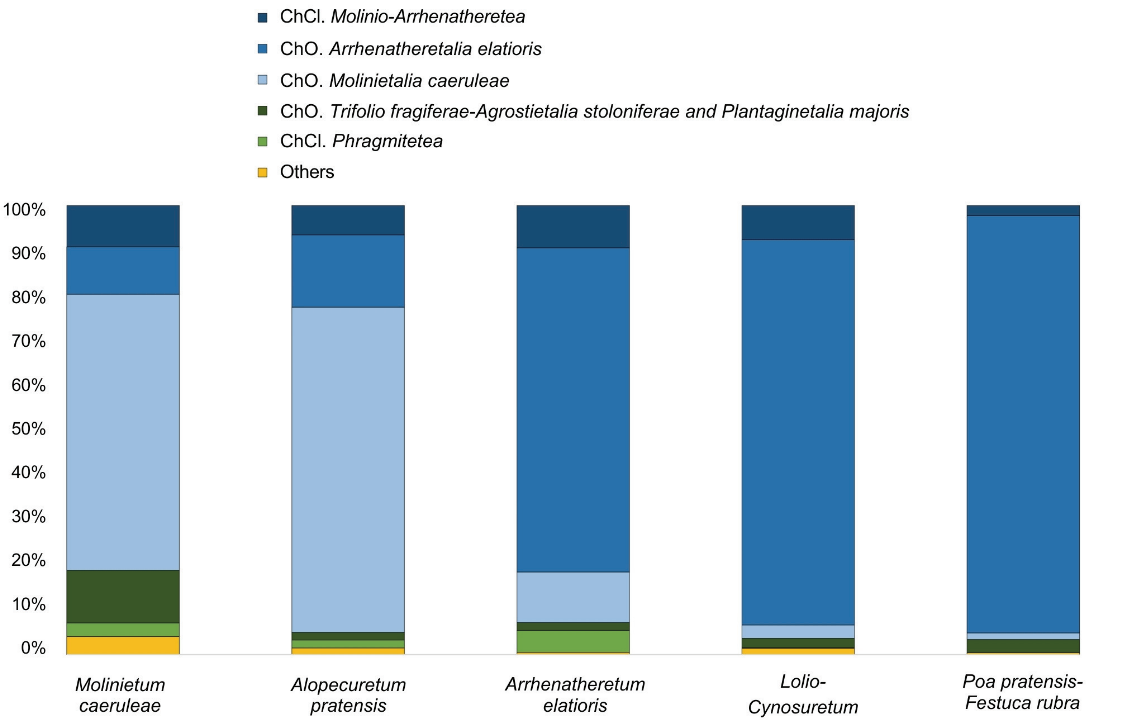

Fig. 2. Structure of sociological (habitat) groups of the analysed vegetation syntaxonomic units ChCl – species characteristic for class, ChO – species characteristic for order, others – species that occurred in very small numbers in others syntaxa

nunculus repens. In addition, there were species from the *Phragmitetea class,* such as *Carex acuta* and *Mentha aquatica.* Species from the *Scheuchzerio-Caricetea nigrae* class like *Hydrocotyle vulgaris, Juncus articulatus* were present in small numbers. Community *Poa pratensis-Festuca rubra* accounted for a large share of the species composition of *Poa pratensis, Poa palustris, Trifolium repens, Plantago lanceolata* and *Festuca rubra* from class *Molinio-Arrhenatheretea* and *Phalaris arundinacea* from class *Phragmitetea.* In the *Arrhenatheretum elatioris* community, the following species had the highest cover index: *Arrhenatherum elatius, Poa pratensis, Galium mollugo, Trifolium pratense* and *Alopecurus pratensis.* Occasionally there were *Urtica dioica* and *Veronica persica. Lolium perenne, Poa pratensis, Taraxacum officinale* and *Trifolium repens* were the dominant species in *Lolio-Cynosuretum.* The community consisted mainly of species in *Molinio-Arrhenatheretea,* outside this class existed*: Polygonum persicaria, Veronica arvensis, Bromus inermis, Artemisia vulgaris, Stellaria media* as single plants. *Alopecurus pratensis, Poa pratensis, Holcus lanatus, Poa palustris* are the species with the highest cover index for the *Alopecuretum pratensis. Phalaris arundinacea* and *Carex acuta* from the *Phragmitetea* class were also present in the phytosociological releves. *Polygonum persicaria* from the *Bidentetea tripartiti* class was found singly.

3.2. Characteristics of soils

Based on morphological soil materials and some physicochemical properties, according to the Polish Soil Classification (PSC) (Kabała et al., 2019) the soil types were: postmurshic soils (1, 2, 4, 10, 13), typical semimurshic soils (3, 5, 6, 9, 12, 14, 15, 17), thin murshic soils (7, 8, 18, 19, 20), murshic gleysols (11, 16). According to the IUSS-WRB soil classification (IUSS Working Group WRB, 2022), the soils were classified as Umbric Gleysols (1, 2, 4, 10, 13), Mollic/Umbric Gleysols (3, 5, 6, 9, 12, 14, 15, 17), Histic Gleysols (7, 8, 18, 19, 20), Histic Gleysols (Murshic) (11, 16). The ground water level in the soils analyzed ranged from 0.8–1.15 meters (soil samples 1–18), while in samples 19 and 20 it was 0.6–0.8 meters.

The soils of *Molinietum caeruleae* (soil materials no. 1–4) are classified as semimurshic soils. They have arenimurshic epipedons, which contain less than 6% organic carbon in the postmurshic soils subtype and 6 to 12% organic carbon in the typical semimurshic soils subtype. They originated from entirely mursh peat formations that were covered in alluvial or fluvioglacial sand mineral formations.

Community *Poa pratensis-Festuca rubra* (soil materials no. 5–8) has developed mainly on the semimurshic soils like the previous community in association with shallow semimurshic soils, the upper horizons of which show the character of organic formations (>12% organic carbon) with murshic epipedones. Below are sandy nature gleyed substrates that of both alluvial and fluvioglacial origin.

Arrhenatheretum elatioris (soil materials no. 9,10,12) and *Lolio-Cynosuretum* (soil materials no. 13–15) soils were classified as semimurshic soils, typical semimurshic soils subtype and postmurshic soils, similar to the previously described communities. However, both *Arrhenatheretum elatioris* (soil materials no. 11) and *Lolio-Cynosuretum* (soil materials no. 16) recorded groundgley soils formed in local depressions, subtype of ground-gley murshic soils. The organic murshic epipedons are less than 30 cm thick. Under them are gleyed mineral formations that frequently exhibit prominent ground-gley properties.

The majority of shallow murshic soil subtypes on which *Alopecuretum pratensis* (soil materials no. 17–20) developed are organic murshic horizons with a maximum thickness of 50 cm. They are bedded with mineral materials of the grain size of silt and loose sands, showing gorund-gley properties. Less frequent in this area are soils with arenimurshic epipedons belonging to the typical semimurshic soils subtype.

3.3. Chemical properties of soils studied

The content of total organic carbon (TOC) in the analyzed grassland soils differed between the selected grassland vegetation syntaxonomic units (Table 3). The highest contents were recorded for in the uppermost soil material in site no. 8 which was overgrown with com. *Poa pratensis-Festuca rubra* (315 g kg^{-1}), and the lowest for soil materials no. 10 – *Arrhenatheretum elatioris* (29.5 g kg^{-1}). The situation was the same in the case of total nitrogen (TN) content (Table 3). The highest contents were recorded for com. *Poa pratensis-Festuca rubra* (25.4 g kg^{-1}), and the lowest for *Arrhenatheretum elatioris* (2.61 g kg^{-1}). Because of the high variability within vegetation syntaxonomic units, the differences between TOC and TN were not statistically significant. The calculated C:N ratio was from 9.56 to 14.5 (Table 3). The pH values indicated slightly acidic soils in the case of the following vegetation units: *Alopecuretum pratensis, Molinietum caeruleae, Lolio-Cynosuretum,* com. *Poa pratensis-Festuca rubra* and slightly alkaline soils in the case of *Arrhenatheretum elatioris* (7.69 pH in H_2O and 7.27 in KCl). The pH values were significantly higher in *Arrhenatheretum elatioris* compared to other vegetation units (Table 3). The average K content in the analyzed grassland soils ranged from 35.3 to 114 mg kg^{-1}, with the highest value recorded in the soils of the *Alopecuretum pratensis* community and the lowest in *Molinietum caeruleae* (Table 3). In the case of Mg, the analyzed soils were characterized by a very high content of this element. Both the highest and lowest Mg values were recorded under the community *Arrhenatheretum elatioris* (190 mg kg^{-1} in soil material no. 9 and 1463 mg kg^{-1} in soil material no. 12 mg kg^{-1}) (Table 3). The topsoil layers of the analyzed

Table 3
Chemical properties of soils. Statistically significant differences in soil parameters between grassland vegetation syntaxonomic units are marked by different letters (p≤0.05; Kruskal-Wallis test with Dunn post hoc comparisons)

Grassland units	*Molinietum caeruleae*	*Alopecuretum pratensis*	*Arrhenatheretum elatioris*	*Lolio-Cynosuretum*	com. *Poa pratensis-Festuca rubra*
Site no.	1–4	17–20	9–12	13–16	5–8
	min–max mean	min–max mean	min–max mean	min–max mean	min–max mean
pH H_2O	5.97–6.66 6.44 [a]	5.97–6.55 6.26 [a]	7.45–7.91 7.69 [b]	6.13–7.43 6.59 [a]	6.20–6.89 6.64 [ab]
pH KCl	5.31–6.25 6.00 [a]	5.71–6.26 5.98 [a]	7.07–7.49 7.27 [b]	5.63–7.17 6.12 [a]	5.96–6.61 6.33 [ab]
	g kg^{-1} D.M. of soil				
TOC [1]	37.5–81.6 61.6 [a]	72.0–256 169 [a]	29.5–168 82.9 [a]	43.1–147 96.5 [a]	34.1–315 127 [a]
TN [2]	3.07–7.46 5.06 [a]	6.35–21.0 13.9 [a]	2.61–13.8 7.14 [a]	4.25–12.3 8.39 [a]	3.20–25.4 11.0 [a]
C:N [3]	10.9–14.1 12.3 [a]	11.2–14.4 12.1 [a]	10.1–14.5 11.5 [a]	10.2–12.2 11.4 [a]	9.56–12.4 11.1 [a]
	mg kg^{-1} D.M. of soil				
K [4]	31.5–38.8 35.3 [a]	84.6–180 114 [b]	43.8–163 84.5 [ab]	48.0–81.9 62.6 [ab]	40.3–71.6 55.9 [a]
Mg [5]	201–336 270 [a]	360–657 560 [a]	190–1463 637 [a]	272–625 373 [a]	219–831 410 [a]
Mn [6]	37.1–69.3 46.1 [a]	117–233 176 [b]	56.5–315 221 [b]	68.1–195 115 [ab]	121–470 271 [b]
P [7]	16.8–69.1 43.4 [a]	283–490 365 [b]	123–803 275 [b]	101–591 455 [b]	150–466 317 [b]

[1] total organic carbon, [2] total nitrogen, [3] total organic carbon to total nitrogen ratio, [4] plant available potassium, [5] plant available magnesium, [6] plant available manganese, [7] plant available phosphorus

Table 4
Conditional term effects of discriminant analysis (CVA) of soil parameters and vegetation syntaxonomic units (n=4). Statistically significant factors are marked in bold ($p \le 0.05$). Conditional term effects exclude the effect of the most correlated variables

Variable	% variation explained	pseudo-F	p
pH_{H2O}	**19**	**4.2**	**0.002**
pH_{KCl}	**12.4**	**3.1**	**0.028**
K	9.2	2.5	0.058
Mn	7.6	2.2	0.096
C:N	6.4	2	0.136
P	6.2	2	0.126
C	3.6	1.2	0.348
N	2	0.7	0.572
Mg	1.2	0.4	0.794

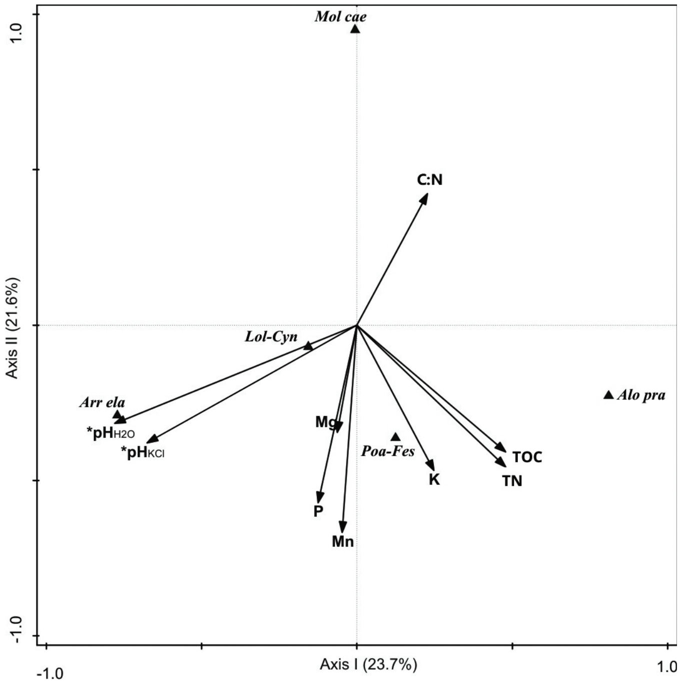

Fig. 3. Results of discriminant Canonical Variate Analysis (CVA) of soil parameters and grassland units. Abbreviations of vegetation syntaxonomic units: Alo pra – *Alopecuretum pratensis*, Arr ela – *Arrhenatheretum elatioris*, Lol-Cyn – *Lolio-Cynusoretum*, Mol cae – *Molinietum caeruleae*, Poa-Fes – com. *Poa pratensis-Festuca rubra*. Significant factors in the model are marked by stars * ($p \le 0.05$)

grasslands were characterized by low (37.1 mg kg^{-1}) to high (470 mg kg^{-1}) Mn content in *Molinietum caeruleae* and com. *Poa pratensis-Festuca rubra*, respectively (Table 3). Mn and P contents were significantly lower in *Molinietum caeruleae* compared to other vegetation units. In summary, the lowest average contents of all analyzed elements were found in *Molinietum caeruleae*, and the highest mainly in *Alopecuretum pratensis* and *Arrhenatheretum elatioris*. The results of the discriminant analysis demonstrated that the most important statistically significant factor for grassland vegetation syntaxonomic units differentiation was soil pH measured both in H_2O and KCl (Table 4). This variable explained 19% and 12.4% respectively of the variability between vegetation units. The rest of the variables were not statistically significant in the model.

The highest values of pH, both in H_2O and KCl, were noted in *the Arrhenatherum elatioris* association while the lowest was in *Alopecuretum pratensis* (Fig. 3). *Molinietum caeruleae* association was present on the soils poor in mineral components of relatively high C:N ratio. The differences in soil parameters between other vegetation units were not so clearly expressed.

3.4. Relationship between species diversity and soil parameters

Results of correlation analysis between diversity indicators and organic matter content and soil pH revealed that H' was significantly negatively correlated with TOC and TN (Fig. 4). The correlation coefficient was equal in both cases

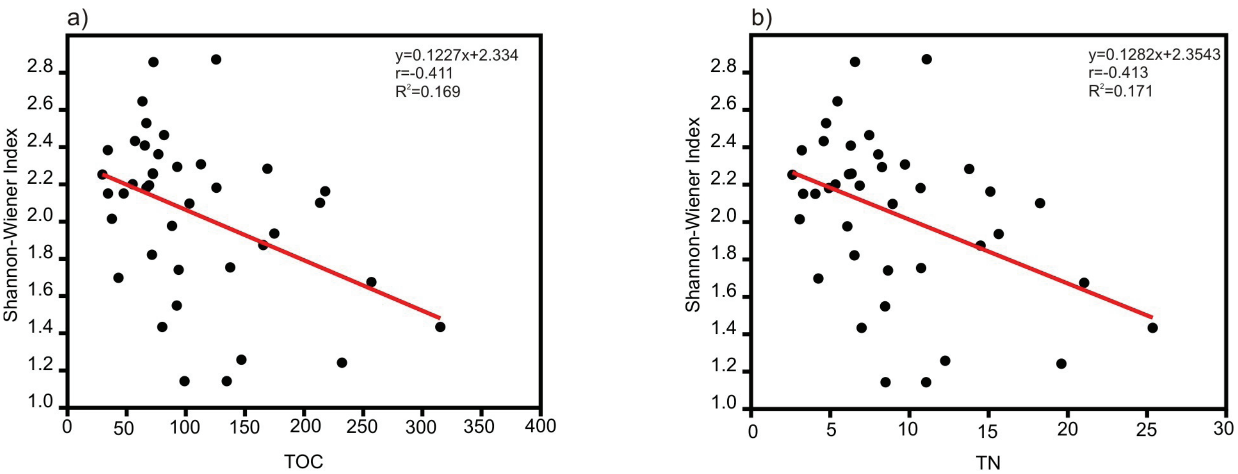

Fig. 4. Results of correlation analysis between species diversity index and a) total organic carbon and b) total nitrogen. Regression equations are given on the graphs, r – Pearson correlation coefficient ($p<0.05$), R^2 – determination coefficient

to r=–0.41 and p=0.008. However, the variance in the diversity index explained by the relation between TOC and TN was not high and amounted to 17%. Other relationships were not significant. We did not find a correlation between diversity indicators and soil pH.

4. Discussion

The soils analyzed belonged to shallow peat soils in the past, which gradually underwent. This resulted, among other things, in the decession of organic matter causing a change in the taxonomic affiliations of these soils. The course of decession of organic formations has been undertaken in many scientific studies and is well recognized (Glina et al., 2019b, 2013; Łachacz et al., 2023). A characteristic feature of organic soils is the high dynamics of morphological changes, which are a response to changes in water conditions and, consequently, bio-ecological conditions (Mitsch et al., 2013; Sykuła, 2020; Withey and Van Kooten, 2011). Bieniek et al. (2005) noted that the mursh-forming (murshing) process occurs more intensively on soils used as arable land than on meadows or forests. Turbiak (2013), on the other hand, points to the intensive process of organic matter decay occurring in grasslands developed on murshic soils. According to his study, the annual loss of organic matter was more than 3%, which, in the case of the soils he studied, would indicate that in 40 years this murshic soil would convert to mineral soil. At present, they mostly belong to different subtypes of murshic soils (soil materials no. 1–10, 12–15, 17–20) (IUSS Working Group WRB, 2022; Kabała et al., 2019; Świtoniak et al., 2016). This is a distinctive arrangement and is found in many river valleys (Łachacz et al., 2023; Pawluczuk et al., 2019). In the lowest areas, clear gleyic features are outlined, hence they were classified as ground-gley murshic soils (soil materials no. 11, 16).

In the present study, five grassland vegetation syntaxonomic units were distinguished and differentiated within *Molinio-Arrhenatheretea* class. The mentioned communities belonged to *Arrhenatheretalia* and *Molinietalia* orders. *Molinietalia* order includes moist hay meadows of meso- and eutrophic character, periodically waterlogged due to their occurrence along rivers. The species composition and dynamics of this order depend on the type and intensity of the economic treatments (Matuszkiewicz, 2023; Suder, 2007). The habitat is found on soils of varying pH, both acidic, neutral and slightly alkaline, both mineral-poor and very fertile. In addition, *Molinietalia* is characterized by its occurrence on the boggy soils, fluvial muds, as well as podzolic soils (except extremely poor) and saline soils (Trąba and Wolański, 2012). In the present study, two communities were distinguished within the *Molinietalia* order: *Alopecuretum pratensis* and *Molinietum caeruleae*. *Molinietum caeruleae* was clearly distinguished from the other communities studied. These meadows had the highest biodiversity index (H'=2.38). This is confirmed in the literature. *Molinia* meadows are considered one of the most important communities in terms of species richness and biological diversity. They provide habitat for rare and endangered plant species (Chmolowska et al., 2023; Kącki and Michalska-Hejduk, 2010; Marciniuk et al., 2016; Trąba and Wolański, 2012; Wójcik et al., 2022; Wójcik and Janicka, 2016). *Molinietum caeruleae* are defined as the most valuable communities in Poland and Europe. Meadows of the *Molinion* alliance are protected in the European Union by the Habitats Directive with code 6410 (Council Directive, 1992). These grassland communities related to the variable wetness of habitats are in danger of extinction. This is due to the draining of organic soils, the changing nature of river valleys which is associated with the intensification of fertilization and use or its abandonment, and climatic mentions, such as rainfall deficits. As meadows of low fodder value, they were excluded from cultivation at the earliest (mowing once a year or less often) (Chmolowska et al., 2023; Trąba and Wolański, 2012; Wójcik et al., 2022). However, despite their great natural value, *Molinietum caeruleae* analyzed in this study are characterized by soils that are the poorest in analyzed macro- and micronutrients. Low levels of nutrients in *Molinia* meadows were also noted by the Zelnik and Čarni (2008) and Kozłowski et al. (2012). Also Swacha et al. (2018) describe in their study a low nutrient status in *Molinion* meadows soils. Unlike *Molinietum caeruleae*, *Alopecuretum pratensis* are a very productive community, the most productive of the communities found in *Molinietalia* order. These phytocenoses occur in fertile riparian habitats in river valleys. They are intensively cultivated (they are mowed up to four times a year) and tilled (Matuszkiewicz, 2023). According to Suder (2007), *Alopecurus pratensis*, which is the dominant species in these grassland communities, is an indicator of phosphorus-rich soils. However, this correlation was not noted in our study. Due to the dominance of a single species in this community, the species diversity index (H') is relatively low. The second order noted in this research is *Arrhenatheretalia. Arrhenatheretalia* groups communities of fertile meadows and pastures occurring on soils with more optimal moisture content than *Molinietalia* (Matuszkiewicz, 2023; Velev, 2018). These grassland communities occur in mesic habitats from moderately wet to slightly dry soils, with a wide pH range (slightly acidic to alkaline). It occurs on mineral, less often organic soils. These meadows are not flooded and are referred to as fresh (Brągiel et al., 2016; Matuszkiewicz, 2023; Pruchniewicz et al., 2024). The studied grassland communities belonging to *Arrhenatheretalia* was represented by the: *Arrhenatheretum elatioris, Lolio-Cynosuretum* and com. *Poa pratensis-Festuca rubra.* Fresh meadows are also a threatened type of natural habitats in Poland (Acic et al., 2013; Janišová et al., 2010; A. A. Klarzyńska and Kryszak, 2015; Rozbrojová et al., 2010). *Arrhenatheretum elatioris* belongs to agriculturally valuable grasslands. The typical form of the complex is mostly rich in dicotyledonous species (Brągiel et al., 2016; Matuszkiewicz, 2023). According to Trąba et al. (2008) *Lolio-Cynosuretum*, occupying the most acidic and P-, K- and N-poor sites, showed the greatest floristic diversity. In our study, this community occupied neutral to slightly alkaline soils and had relatively high K and N contents, especially P (the highest average value among all communities) and the lowest floristic diversity as determined by H'=1.49. A characteristic feature of the com. *Poa pratensis-Festuca rubra* habitat is the close relationship with the form and intensity of meadow management. Com. *Poa pratensis-Festuca rubra* is primarily an indicator of drying soils (usually murshic soils) and the abandonment of proper grassland management.

It is distinguished by the dominance of *Poa pratensis* and *Festuca rubra* (Matuszkiewicz, 2023; Stamirowska-Krzaczek, 2015). Abandonment of use leads to the simplification of the *Arrhenatheretum elatioris* species and the formation of phytocenoses with a dominance of *Poa pratensis* and *Festuca rubra.* Analysis of the floristic composition of the sward of this community may indicate a low level of grassland management, compared with patches of the *Arrhenatheretum elatioris* (Stamirowska-Krzaczek, 2015; Warda and Stamirowska-Krzaczek, 2010).

Variability of grassland communities is strongly linked to the influence of locally occurring environmental factors (Diviaková et al., 2021; Wellstein et al., 2007; Wróbel, 2012). Our study showed that the most significant factor in communities differentiation is soil pH. This indicates the relevance of soil pH to the formation of a particular plant community on a given soil. This confirms in part our hypothesis that vegetation units are related to different soil properties. Soil reaction is a very important soil property that controls the species richness of plants in grassland communities (Diviaková et al., 2021; Palpurina et al., 2017; Riesch et al., 2018; Zelnik and Čarni, 2008). In addition, it significantly affects the development of the root system, the solubility and availability of many nutrient elements and their uptake by plants and soil-forming processes (Grzywna, 2014). At low pH values, the availability of macronutrients such as Mg, K, P and N decreases, while the availability of micronutrients such as Mn increases – even to a toxic level (Gonet et al., 2015). The pH_{H2O} values, in the soils analyzed, ranged from 5.97 to 7.91, and pH_{KCl} from 5.31 to 7.49. A similar range of soil pH and the relationship between grassland community variability and soil reaction, was recorded by Diviaková et al. (2021) and Chytrý et al. (2007). However, we did not find direct relationship between plot species diversity indicators and soil pH.

Organic and post-organic soils are characterized by a high variability of properties. These properties depend, among other things, on the origin of the soils, plant composition or admixtures of mineral material (Łachacz et al., 2023; Wallor and Zeitz, 2016). Undoubtedly an important soil property is the organic matter content, however, in our study the trait did not prove to be significantly different between vegetation units. On the other hand, our results demonstrated a direct, significantly negative relationship between species diversity index and TOC and TN. This is corroborated by studies that say the negative effects of nitrogen generally reduced plant species richness of grassland communities (Roth et al., 2013; Soons et al., 2017; Tian and et al., 2016). Averaging, in our study, *Alopecuretum pratensis* had the highest organic matter content, which is associated with its high utility value but significantly lower species diversity, e.g. compare to *Molinietum caeruleae* of the lowest TOC and TN. One feature that distinguishes the mursh-forming process is the intensive humification of organic matter (Becher et al., 2013). The C:N ratio in the studied soils ranged from 9.56 to 14.4, indicating a significant degree of organic matter processing through mineralization and humification processes and high soil biological activity. The mursh-forming process leads to a narrowing of these ratio (Sammel and Niedźwiecki, 2006). Also Wójciak and Bieniak (2005) confirm that murshic levels are characterized by a narrow C:N ratio (9.3–12), which indicates high transformation of organic matter and biological activity. It is worth noting that the C:N ratio is an important indicator of the rate of mineralization of horny matter in the soil. A wide C:N ratio means that the rate of mineralization decreases and the nitrogen available to plants is used by microorganisms. However, a narrow ratio (below 20) accelerates the rate of mineralization of organic matter and provides plants with available nitrogen. Sometimes even plants cannot use it (Becher et al., 2022; Czyż et al., 2013; Okruszko, 1993). The content of some micro- and macroelements in the tested soils also show significantly lower K, Mn and P in *Molinietum caeruleae* association. The role of phosphorus in green soils is worth emphasizing. Phosphorus is a microelement considered very important for species wealth and the diversity of meadows, however, grasslands in Europe are characterized by a low content of this element (Diviaková et al., 2021; Kopeć et al., 2010; Merunková and Chytrý, 2012).

It is important to remember that the drainage of peat soils leads to the initiation of the process of murshing. And this process, in turn, can lead to the complete disappearance of organic layers. The rate of loss of peat mass is significantly higher (10–20 times) than the rate of its growth (Łachacz et al., 2023; Oleszczuk et al., 2017; Smreczak et al., 2020). According to Ilnicki and Szajdak (2016), a 1 m peat layer takes about a thousand years to form. Studies indicate that the increased mineralization of organic layers is the main reason for changes in the use of peat soils. Arable land is being created from grassland. It leads to further loss of organic matter – which is the result of mixing organic layers with subsoil through plowing (Bieniek and Łachacz, 2012).

It should be noted that the murshing up of the surface layers of peat causes irreversible degradation of phytocenoses, which are inhabited by rare plant species. The botanical composition of the plants changes, and 100–250 kg/ha of nitrogen per year is released in the process of soil murshing. The nitrogen released and not utilized by plants enters ground and surface water, and partially enters the atmosphere. This is extremely important because properly managed grasslands are biogeochemical barriers that limit the migration of various chemicals or materials from agricultural fields to surface and deep waters (Jankowska-Huflejt, 2007).

There is a systematic increase in organic matter content in soils under grasslands. Soils characterized by a higher amount of organic matter have a greater ability to retain water than poor soils. It is necessary to take advantage of this aspect in developing practices that protect against climate change. So, an increase the resistance of ecosystems to degradation occurs as a result of the regeneration of humus reserves. The humus accumulation occurs simultaneously with the turf process. Organic matter content is a key parameter shaping soil quality, structure and hydrological properties (Jankowska-Huflejt, 2007; Pikuła, 2019).

It is difficult to say unequivocally which of the communities in question is more likely to survive in the face of the following environmental changes, including the processes of murshing. It all depends on the use (including fertilization and the number of mowings) and water relations (Kun et al., 2021; Scholtz and Twidwell, 2022). Vegetation syntaxonomic units that are more intensively used – *Arrhenatheretum elatioris, Lolio-Cynosuretum and Alopecuretum pratensis* – are more likely to survive.

If the process of murshing up continues and use is abandoned, these communities will use the biogenes in the soil for some time (several years) before they begin to degrade, because they have a high stock of organic matter (Ameer et al., 2022). With extensive use and further problems with water relations, these communities will begin to simplify, and common, cosmopolitan species will take the place of characteristic species. However, with regular mowing (2–3 times a year) or mowing and grazing in the case of *Lolio-Cynosuretum*, fertilization and regulation of water relations the previously mentioned communities have the best chance. On the other hand, in the case of *Molinietum caeruleae*, which is used extensively by design, the process of murshing may lead to their transformation into meadows with a dominance of *Deschampsia cespitosa*, a significantly poorer community (Burczyk et al., 2018; Klarzyńska and Kryszak, 2015; Kryszak et al., 2009; Wróbel et al., 2015). The basis for the protection of valuable meadow and pasture habitats is, therefore, their proper use, which will preserve the proper structure of the sward vegetation. In conclusion, in order to preserve valuable grassland habitats and inhibit the process of murshing, it is necessary to regulate water relations, as well as to regulate the amount of mowing and provide nutrients in the form of fertilizers tailored to the specific requirements of the community (Wróbel et al., 2021).

The results presented here should be treated as a contribution to the ongoing discussion about the mursh-forming (murshing) process in soil and a variety of valuable vegetation units on semi-natural grasslands. It is reasonable to believe that grasslands, especially those used more extensively, can become an important consumer of carbon dioxide from the atmosphere and can therefore greatly reduce the effects of the greenhouse effect (Borana et al., 2023; Burczyk et al., 2018; Grzegorczyk, 2016; Pikuła, 2019; Stypiński et al., 2005). The causes of the degrading changes in the floristic composition of the communities should be seen mainly in terms of the drying of peat soils, their variability of the pH, reduced nitrogen content, and the progressive reduction in their use in recent years (Kryszak et al., 2005). Monitoring and expanding knowledge of the condition of organic soils is key to implementing rational and sustainable land use and environmental protection. The priority should be to support the maintenance of extensive forms of agricultural production, especially on grasslands in the context of preserving natural habitats such as meadows, peatlands, forests, which act as a carbon sink (Borek, 2020).

5. Conclusions

1. The floristic diversity of grassland units decreases as the amount of organic matter in the soil increases.
2. Our research has shown that the pH of analyzed soils is a key element determining the occurrence of specific vegetation units.
3. *Molinia* meadows are characterized by soils that are the poorest in selected macro- and micronutrients. Although they do not have much economic value, they present high species diversity and thus high natural values.
4. Plant associations that are more intensively used – *Arrhenatheretum elatioris, Lolio-Cynosuretum* and *Alopecuretum pratensis* – have a better chance of surviving in the murshing process, provided the correct use and regulation of water relations.
5. For ecological and economic reasons and the proposal for a soil protection directive presented by the EC on July 5, 2023, it is advisable to continue to maintain the studied sites as grasslands. Grasslands, besides enriching soils with nutrients, create the best conditions for reducing organic matter decay in the accumulation and humus murshic horizons.

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Zróżnicowanie jednostek syntaksonomicznych roślinności użytków zielonych w zależności od właściwości fizykochemicznych gleb torfowych w dolinie rzeki Obry

Słowa kluczowe

Gleby murszowe
Zróżnicowanie florystyczne
Zbiorowiska roślinne
Molinio-Arrhenatheretea

Streszczenie

Celem pracy było przedstawienie struktury fitosocjologicznej wybranych zbiorowisk trawiastych na płytkich glebach torfowych podlegających procesowi murszenia (humifikacji i mineralizacji torfu). Obszar badań zlokalizowany był pomiędzy północnym, środkowym i południowym kanałem rzeki Obry (Nizina Wielkopolska, centralna Polska). Badania glebowe przeprowadzono w maju i wrześniu 2022 roku, a badania fitosocjologiczne w maju i wrześniu 2022–2023 roku. Próbki gleby do analiz laboratoryjnych pobrano z najwyższych poziomów glebowych na głębokości 0–20 cm w 20 punktach badawczych. Wykonano 76 zdjęć fitosocjologicznych. Wyróżniono pięć jednostek syntaksonomicznych roślinności: *Molinietum caeruleae*, zbiorowisko z *Poa pratensis-Festuca rubra, Arrhenatheretum elatioris, Lolio-Cynosuretum i Alopecuretum pratensis*. Jednostką syntaksonomiczną o najwyższych wartościach wskaźnika różnorodności i liczbie gatunków odnotowanych w zdjęciach fitosocjologicznych było *Molinietum caeruleae*, podczas gdy najuboższym w gatunki z najniższym wskaźnikiem było *Lolio-Cynosuretum*. Gleby zostały sklasyfikowane jako Umbric Gleysols, Mollic/Umbric Gleysols, Histic Gleysols, Histic Gleysols (Murshic). Najwyższe zawartości TOC i TN odnotowano dla zbiorowiska *Poa pratensis-Festuca rubra*, a najniższą dla *Arrhenatheretum elatioris*. Wartości pH wskazywały na gleby lekko kwaśne w przypadku następujących jednostek syntaksonomicznych: *Alopecuretum pratensis, Molinietum caeruleae, Lolio-Cynosuretum*, zb. *Poa pratensis-Festuca rubra* oraz gleby lekko zasadowe w przypadku *Arrhenatheretum elatioris*. Wyniki analizy dyskryminacyjnej wykazały, że najważniejszym statystycznie istotnym czynnikiem różnicującym zbiorowiska roślinne było pH gleby mierzone zarówno w H_2O, jak i w KCl. *Molinietum caeruleae* występowało na glebach ubogich w składniki mineralne o stosunkowo wysokim stosunku C:N. Wskaźnik różnorodności Shannona-Wienera był istotnie ujemnie skorelowany z TOC i TN. Wskazane jest dalsze utrzymywanie badanych stanowisk jako roślinności łąkowej. Zbiorowiska użytków zielonych mają szanse na przetrwanie w procesie murszenia, pod warunkiem prawidłowego użytkowania (regularnego koszenia lub wypasania i nawożenia) i regulacji stosunków wodnych. Użytki zielone, oprócz wzbogacania gleb w składniki pokarmowe, stwarzają najlepsze warunki do ograniczenia procesu rozkładu materii organicznej w poziomach akumulacyjnych i próchnicznych o charakterze murszowym, co jest niezwykle istotne w obliczu zmian klimatycznych.

Appendix 1. Summary phytosociological table

Plant species	*Molinietum caeruleae*			*Alopecuretum pratensis*			*Arrhenatheretum elatioris*			*Lolio-Cynosuretum*			com. *Poa pratensis-Festuca rubra*		
	No.[1]	C[2]	D_{mean}[3]	No.[1]	C[2]	D_{mean}[3]	No.[1]	C[2]	D_{mean}[3]	No.[1]	C[2]	D_{mean}[3]	No.[1]	C[2]	D_{mean}[3]
Species characteristic of the class *Molinio-Arrhenatheretea*															
Achillea millefolium	4	III	25	3	II	37.5	9	III	28.1	2	I	3.8	12	IV	37.5
Anthoxanthum odoratum							2	I	6.3	4	II	12.5	3	III	9.4
Avenula pubescens							10	III	31.3						
Cardamine pratensis	12	V	50	15	V	44.4	6	II	18.8				5	II	13.1
Centaurea jacea	2	I	1.7				2	I	1.3						
Cerastium holosteoides	9	IV	37.5	7	III	21.9	11	IV	62.5	5	II	13.1	7	III	21.9
Festuca pratensis	9	IV	329.2	2	I	6.3				10	III	31.3	6	III	46.9
Holcus lanatus	2	I	7.3	14	V	212.5	8	III	81.3	7	III	21.9	7	III	21.9
Lathyrus pratensis	1	I	4.2	4	II	12.5	1	I	3.1				2	I	6.3
Odontites serotina	3	II	12.5												
Plantago lanceolata	6	III	62.5	7	III	21.9	13	IV	40.6	7	III	21.8	9	III	218.8
Prunella vulgaris	7	II	29.2												
Ranunculus acris				14	V	43.8	13	IV	68.8	5	II	13.1	14	IV	100
Rumexa cetosa				9	III	28.1	12	IV	65.6				9	III	28.1
Trifolium pratense				4	II	12.5	16	V	106.3				12	IV	37.5
Vicia cracca	2	I	8.3	4	II	12.5	2	I	1.3				2	I	6.3
Species characteristic of the order *Molinietalia caeruleae*															
Alopecurus pratensis				16	V	4844	12	IV	121.9	12	IV	65.6	15	V	159.4
Carex cespitosa	8	IV	33.3												
Cirsium oleraceum				2	I	3.8									
Deschampsia caespitosa	10	IV	41.7										3	II	9.4
Equisetum palustre	2	I	1.7										1	I	0.6
Filipendula ulmaria	1	I	0.8	4	II	10				1	I	0.6			
Lathyrus palustris	4	II	13.3												
Lychnis flos-cuculi	5	III	14.2	9	III	25.6	4	II	40.6	2	I	6.3	15	V	156.9
Lysimachia vulgaris	8	IV	33.3				1	I	3.1						
Lythrum salicaria	3	II	5.8												
Molinia caerulea	12	V	3583												
Poa palustris				13	IV	125	2	I	6.3	1	I	3.1	13	IV	309.4
Symphytum officinale							1	I	3.1						
Thalictrum flavum	2	I	5	3	II	9.4							6	II	18.8
Viola pumila	2	I	8.3												
Species characteristic of the order *Arrhenatheretalia elatioris*															
Arrhenatherum elatius							16	V	4063				3	I	37.5
Bellis perennis										11	IV	34.4	9	III	84.4
Bromus hordaceus							6	II	18.8	9	III	28.1			
Dactylis glomerata	1	I	4.2	5	II	15.6	13	IV	40.6	8	III	25	4	II	12.5

continue – Appendix 1. Summary phytosociological table

Plant species	***Molinietum caeruleae***			***Alopecuretum pratensis***			***Arrhenatheretum elatioris***			***Lolio-Cynosuretum***			**com. *Poa pratensis-Festuca rubra***		
	No.[1]	C[2]	D_{mean}[3]	No.[1]	C[2]	D_{mean}[3]	No.[1]	C[2]	D_{mean}[3]	No.[1]	C[2]	D_{mean}[3]	No.[1]	C[2]	D_{mean}[3]
Daucus carota				3	II	6.9				1	I	0.6			
Festuca rubra	12	V	50										9	III	112.5
Galium mollugo				7	III	21.9	16	V	106.3	4	II	12.5	12	IV	37.5
Geranium pratense							1	I	0.6						
Heracleum sphondylium				4	II	12.5	13	IV	40.6	1	I	0.6	5	II	15.6
Leontodon autumnalis	5	II	17.5							3	I	9.4			
Leucanthemum vulgare							5	II	15.6				2	I	6.3
Lolium perenne	1	I	4.2	5	II	43.8	10	III	31.3	16	V	3938	2	I	6.3
Poa pratensis	10	IV	550	15	V	925	15	V	668.8	16	V	515.6	16	V	3563
Polygala comosa	1	I	0.8												
Saxifraga granulata							4	II	10						
Taraxacum officinale	2	I	8.3	12	IV	65.6	15	V	46.9	10	IV	143.8	13	IV	40.6
Trifolium dubium							2	I	6.3						
Trifolium repens	2	I	8.3	8	III	25	3	II	37.5	10	IV	115.6	12	IV	278.1
Species characteristic of the orders *Trifolio fragiferae-Agrostietalia stoloniferae* and *Plantaginetalia majoris*															
Agrostis stolonifera	10	IV	154.2							6	II	18.8	7	III	21.9
Alopecurus geniculatus				2	I	6.3				1	II	3.1			
Carex hirta										4	II	12.5			
Festuca arundinacea	4	II	13.3	4	II	68.8									
Inula britannica	3	I	50												
Plantago major				2	I	6.3	7		21.9	9	III	84.4	6	II	18.8
Poa annua										3	I	9.4			
Potentilla anserina	11	V	334.2				4	II	12.5						
Potentilla reptans	3	I	12.5				1	I	3.1	1	I	3.1	2	I	6.3
Ranunculus repens	9	IV	150	8	III	25	8	III	25	6	II	18.8	16	V	50
Rumex crispus				4	II	12.5	1	I	0.6	1	I	0.6	1	I	3.1
Triticum repens										1	I	3.1	1	I	3.1
Species characteristic of the class *Phragmitetea*															
Carex acuta	8	IV	70.8	8	III	25	1	I	3.1				9	III	28.1
Galium palustre	2	I	1.7										3	II	9.4
Iris pseudacorus	2	I	5												
Mentha aquatica	12	V	50										4	II	12.5
Peucedanum palustre	3	I	2.5												
Phalaris arundinacea	2	I	5	11	IV	90.6	1	I	3.1				11	IV	231.3
Phragmites australis	12	V	50				1	I	0.6						
Rumex hydrolapathum				2	I	6.3									
Sium latifolium													2	I	1.3

continue – Appendix 1. Summary phytosociological table

Plant species	***Molinietum caeruleae***			***Alopecuretum pratensis***			***Arrhenatheretum elatioris***			***Lolio-Cynosuretum***			com. ***Poa pratensis-Festuca rubra***		
	No.[1]	C[2]	D_{mean}[3]	No.[1]	C[2]	D_{mean}[3]	No.[1]	C[2]	D_{mean}[3]	No.[1]	C[2]	D_{mean}[3]	No.[1]	C[2]	D_{mean}[3]
Others															
Artemisia vulgaris													1	I	0.6
Bromus inermis										1	I	3.1			
Calystegia sepium	6	III	15	2	I	6.3									
Capsella bursa-pastoris				5	II	13.1	3	II	9.4	2	I	3.8	1	I	3.1
Cerastium arvense							1	I	3.1						
Chenopodium album							1	I	0.6						
Cirsium arvense	1	I	4.2				2	I	6.3						
Conyza canadensis							1	I	0.6						
Cynoglossum officinale							1	I	0.6						
Echinochloa crus-galli							1	I	0.6						
Eupatorium cannabinum	4	II	10												
Glechoma hederacea	2	I	8.3	4	II	12.5	1	I	3.1				1	I	3.1
Hydrocotyle vulgaris	11	V	120.8												
Hypericum perforatum	1	I	0.8												
Hypochoeris radicata	6	III	15												
Juncus articulatus	10	IV	41.7												
Lactuca serriola	1	I	0.8												
Linaria vulgaris							2	I	6.3				1	I	3.1
Luzula multiflora	3	II	12.5												
Melandrium album							6	II	15.6				1	I	0.6
Melandrium rubrum	1	I	0.8												
Polygonum persicaria	1	I	0.8	3	I	6.9				2	I	6.3	2	I	6.3
Rorippa palustris				2	I	6.3									
Rubus gracilis	3	II	12.5												
Rumex obtusifolius				4	II	12.5							1	I	0.6
Stellaria media				4	II	12.5	2	I	6.3	1	I	0.6	1	I	3.1
Urtica dioica				3			1	I	0.6						
Veronica arvensis				3	I	9.4	2	I	6.3	3	II	9.4	2	I	6.3
Veronica chamaedrys				3	II	9.4	6	II	18.8						
Veronica persica							2	I	6.3						
Vicia hirsuta	2	I	1.7										3	I	4.4
Vicia sepium				2	I	6.3									

[1] – number of occurrences, [2] – phytosociological constant, [3] – mean cover index

16	species characteristic of the vegetation syntaxonomic units
11	species with the highest cover index in the vegetation syntaxonomic units