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The Content of Macro- and Micro Minerals in the Sward of Different Types of Semi-Natural Meadows of Temperate Climate in SE Poland

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Abstract: Seminatural meadows are characterized by a rich botanical composition, which determines their specific type. The content of macro- and micro minerals in sward seems important for ruminant farmers. The aim of the study was to determine the content of macro- and micro minerals in the sward of selected meadow types. The study was carried out in SE Poland from May to July in the years 2010–2017. The relationship between the content of each of the studied elements (N, P, K, Mg, Fe, Mn, Cu, Zn) in soil and plants was investigated, as well as whether there were differences between the average content of elements in the sward of different types of meadows. In some types of meadows there was a correlation for K, Fe, Cu, Mg and Mn. The largest differences in the content of macro minerals in the sward were found for Mg (44%) and K (42%), and in the case of micro minerals for Mn (56%). Large differences resulted primarily from different plant species; composition forming a given meadow community and not the content of these elements in the soil. The results can be applied to the proper management of farms, especially organic ones.

Keywords: grasslands; macro- and micro mineral; elemental composition; grazing land; grassland species; pastures

1. Introduction

In 2016, total utilized agricultural area (UAA) in the EU-28 reached approximately 179 million ha, of which 6.7% constituted organic farming. About 34% of total UAA in the EU-28 was used as permanent grasslands and meadows [1]. However, it is estimated that grasslands occupy 40% of the area worldwide [2]. Grassland serves as a forage area for cattle, sheep, goats and equines. In addition to playing a part in the production of milk and meat, meadows and pastures are a characteristic element of European cultural landscapes and greatly contribute to the protection of biodiversity [3–5].

Grasses are a basic component of the sward of seminatural meadows and pastures, however, as the grass research shows, they contain less macro- and micro minerals than legumes and herbs [6,7]. Studies conducted to date on the mineral composition of the sward usually treated meadow vegetation without dividing it into distinct meadow types [8–10] or determined element contents for individual species of meadow plants [6,11–13]. Seminatural meadows and pastures are characterized by a particularly rich floristic composition delimiting meadow belonging to a particular type. The content of elements for individual species of meadow plants is important; however, from a practical point of view, it is of little use in determining the content of nutrients in the sward of natural and semi-natural meadows. This is because the species composition of the meadow and the proportion of individual species would have to be specified each time. Therefore, it seems reasonable to determine the content of macro- and micro minerals precisely for the sward of individual types of meadows divided on the basis of floristic composition.

Available research results indicate differences in the nutrient content of the sward depending on the season of the year [8], and, in particular, on the amount of precipitation, and thus soil water content [14,15]. Therefore, the assessment of the standardized precipitation and evaporation index is important in grassland management [16]. Soil moisture is also a factor strongly determining meadow botanical composition [17], as well as its proper management [18,19].

In the present study, samples were collected on all meadows in the same period under comparable weather conditions. The aim of the study was to determine the content of macro- and micro minerals in the sward of specific types of meadows in the semi-natural temperate climate of SE Poland.

2. Materials and Methods

2.1. Study Area

The research was carried out from May to July 2010–2017 in various types of seminatural meadows of the highlands, in different conditions of habitat moisture, soil pH and richness in selected macro- and micro minerals. The research area (Figure 1) included physiographically diverse fragments of the Central Beskid Foothills and the Carpathian Foothills (SE Poland: 49.5626–50.4048° N, 21.4815–22.8713° E). The southern part is distinguished by the presence of uniform hills running from northwest to southeast, and their absolute heights range from 250 to 350 m above sea level. Brown, loam and luvisols are the most common soils there, alluvial soil occurs in river valleys and low peats in low basins. The length of the growing season varies from 210 to 225 days and the average annual rainfall from 700 to 800 mm. There are uplifted plains in the central and northern parts of the study area lying at an altitude of 220–250 m a.s.l. Luvisols and brown soils occur in this area, alluvial soils in river valleys, and swamps in drainage areas. The average annual rainfall is 600–700 mm and the growing season lasts 220–225 days.

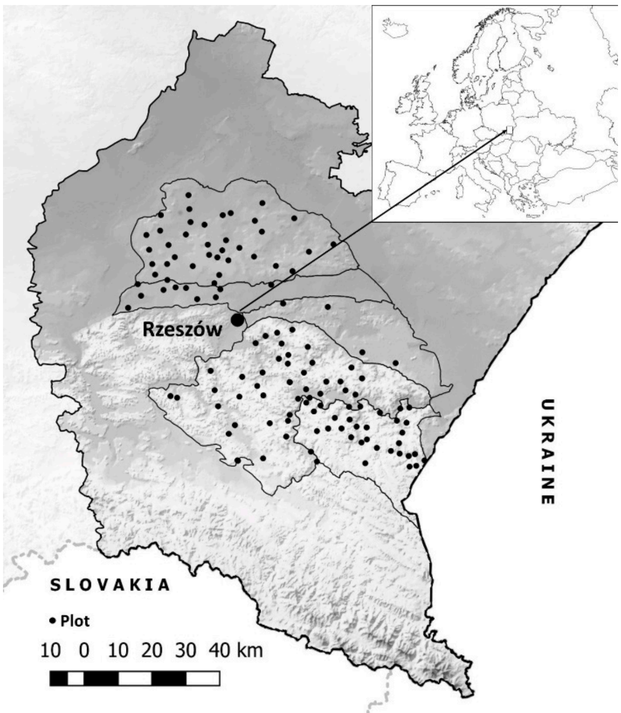

Figure 1. Research area.

The study analyzed the content of the following elements: nitrogen, phosphorus, potassium, magnesium, iron, manganese, copper and zinc in soil and plant material.

2.2. Phytosociological Records

Phytosociological photographs (455 images) were taken using the Braun–Blanquet method [20], which assumes taking a single phytosociological photograph on meadows of 100 m^2. The images were subjected to hierarchical numerical classification using the MULVA-5 program v5 (Amsterdam, The Netherlands) [21] and subsequently classified into individual habitats based on species composition, location of the studied meadow in the field and soil type. This analysis allowed the selection of 360 photographs, while the remaining ones were left out because they could not be assigned to any type of meadow. Six types of meadows (A–F) were determined based on their characteristics and dominant species [22] and 60 phytosociological images were assigned to each of them.

Herbage consisted mainly of:

A. Optimally moist habitat, poor soils, fresh meadows: grasses: common bent (*Agrostis capillaris* L.), creeping red fescue (*Festuca rubra* L.), sweet vernal grass (*Anthoxanthum odoratum* L.); legumes: birdsfoot deervetch (*Lotus corniculatus* L.), lesser trefoil (*Trifolium dubium* Sibth.); herbs: bristly hawkbit (*Leontodon hispidus* L.), perforate St John's-wort (*Hypericum perforatum* L.), lady's bedstraw (*Galium verum* L.), ox-eye daisy (*Leucanthemum vulgare* Lam);
B. Optimally moistened habitat, fertile soils, fresh meadows: grasses: tall oat-grass (*Arrhenatherum elatius* L.), yellow oatgrass (*Trisetum flavescens* L.), meadow fescue (*Festuca pratensis* Huds.), smooth meadow-grass (*Poa pratensis* L.), orchard grass (*Dactylis glomerata* L.), timothy grass (*Phleum pratense* L.); legumes: red clover (*Trifolium pratense* L.), white clover (*Trifolium repens* L.); herbs: ribwort plantain (*Plantago lanceolata* L.), common yarrow (*Achillea millefolium* L.), common dandelion (*Taraxacum officinale* F.H. Wiggers coll);
C. Periodically overly moist habitat, fertile soils, periodically wet meadows: grasses: meadow foxtail (*Alopecurus pratensis* L.), tufted grass (*Holcus lanatus* L.), tufted hairgrass (*Deschampsia caespitosa* L.); legumes: alsike clover (*Trifolium hybridum* L.); herbs: club-rush (*Scirpus sylvaticus* L.), plume thistle (*Cirsium rivulare* Jacq.), Ragged-Robin (*Silene flos-cuculi* Greuter & Burdet), yellow loosestrife (*Lysimachia vulgaris* L.), common bistort (*Polygonum bistorta* L.), common sorrel (*Rumex acetosa* L.);
D. Permanently excessively moist habitat, fertile soils, rush grasslands: grasses: reed canary grass (*Phalaris arundinacea* L.), common reed (*Phragmites australis* Cav.), reed mannagrass (*Glyceria maxima* Hartm.), fowl meadowgrass (*Poa palustris* L.); herbs: lesser bulrush (*Typha angustifolia* L.), sweet flag (*Acorus calamus* L.), marsh-marigold (*Caltha palustris* L.), marsh horsetail (*Equisetum palustre* L.), purple loosestrife (*Lythrum salicaria* L.), great water dock (*Rumex hydrolapathum* Huds);
E. Dry, alkaline habitat (pH > 7.0), low fertile soils, xerothermic grasslands: grasses: heath false brome (*Brachypodium pinnatum* L.), Boehmer's cat's-tail (*Phleum phleoides* L.); legumes: mountain clover (*Trifolium montanum* L.), zigzag clover (*Trifolium medium* L.), sickle alfalfa (*Medicago falcata* L.); herbs: whorled clary (*Salvia verticillata* L.), greater knapweed (*Centaurea scabiosa* L.), fern-leaf dropwort (*Filipendula vulgaris* Moench.), hoary plantain (*Plantago media* L.), cream pincushions (*Scabiosa ochroleuca* L.);
F. Dry, acidic habitat (pH < 5.0), poor soils, psammophilic (grasslands): grasses: grey hair-grass (*Corynephorus canescens* L.), matgrass (*Nardus stricta* L.), sheep's fescue (*Festuca ovina* L.), heath grass (*Danthonia decumbens* L.); legumes: hare's-foot clover (*Trifolium arvense* L.); herbs: sheep's sorrel (*Rumex acetosella* L.), mouse-ear hawkweed (*Hieracium pilosella* L.), blue bonnets (*Jasione montana* L.), Shepherd's cress (*Teesdalea nudicaulis* R.Br.).

2.3. Soil and Plant Sampling and Laboratory Analyses

All meadows studied were cultivated. Some were intended for the production of silage or hay. Meadows with inferior sward were mown once a year and plant mass was discharged outside the meadow in accordance with the applicable rules described in EU rural development programs. Fertilization of the described types of meadows is not practiced in the studied area. The distance between individual meadows was large—with a minimum 1 km—and individual test meadows were selected at random. Sward samples were collected during the full vegetation period (the highest number of species was in the initial stage of flowering), i.e., before the first swath was harvested, which for the studied types of meadows occurred from the 3rd decade of May to the 1st decade of July.

At the site of each phytosociological photograph, a soil composite sample was taken from a 0–30 cm layer. The aggregate soil sample for analysis consisted of six soil samples from 100 m^2 of the meadow covered by a phytosociological photograph, with one aggregate sample per one examined meadow.

The general form of N was determined using the Kjeldahl method [23], assimilable forms of P and K with the Egner—Rhiem method [24], for P using a Jasco V-530 UV-VIS spectrophotometer (Jasco International Corporation, Tokyo, Japan) and K using an AAS Hitachi Z-2000 (Hitachi High-Technologies Corporation, Tokyo, Japan). Absorbable forms of Mg were determined using an AAS Hitachi Z-2000, and soluble forms of Fe, Zn, Mn and Cu with the Rinkis method [25], also using an AAS Hitachi Z-2000. The aggregate sample of the sward was taken from the area of 2 m^2 (composed of four samplings of 0.5 m^2) at the place of each phytosociological photograph. N content in the plant material was determined with an electrothermal method using a CHNSO Thermo Flash 2000 elemental analyzer (Thermo Fisher Scientific S.p.A., Milan, Italy), P with the vanado-molybdenum method and Mg, K, Fe, Zn, Mn and Cu using a Jasco V-530 spectrophotometer after prior mineralization of samples in a BERGHOF microwave mineralizer (Berghof Products + Instruments GmbH, Eningen, Germany). Laboratory analyses were carried out in accordance with the methodology of laboratory assays for soils and plants generally accepted in agricultural research [26].

2.4. Statistical Analysis

The Pearson correlation coefficient was used to check whether there was a relationship between the content of each of the studied elements in soil and plants for each type of meadow separately. Sample analyses proved that in all groups (meadow types A–F), some of the dependent variables (macro- and micro mineral contents in the sward) did not show normal distribution for further statistical analysis and non-parametric analysis of variance (ANOVA), Kruskal–Wallis test with median test) was applied for those variables. The following null hypothesis was adopted for testing: lack of differences between the average content of the tested elements in the sward of different types of meadows (A–F). Then, if the null hypothesis was rejected, the post-hoc test (Dunn test) was used for further analysis [27,28]. Statistical significance was adopted at $p < 0.05$. All analyses were performed using Statistica v12 software (StatSoft Inc., Tulsa, OK, USA).

3. Results

3.1. Phytosociological Records

The percentage share of grasses, papilionaceous plants and herbs in individual types of meadows was as follows: A-23, 15, 62; B-35, 17, 48; C-19, 11, 70; D-41, 4, 55; E-21, 20, 59; F-33, 8, 59, respectively.

- Habitat A. Grasses: Agrostis capillaris L. 2, Anthoxanthum odoratum L. 3, quaking-grass (Briza media L.) 1, Dactylis glomerata L. +, Festuca rubra L. 1, Holcus lanatus L. 1, Poa pratensis L. +; legumes: Lotus corniculatus L. 2, large hop trefoil (Trifolium aureum Pollich.) +, Trifolium dubium Sibth. 2, Trifolium medium L. +, tufted vetch (Vicia cracca L.) 1, hairy vetch (Vicia villosa Roth.) +; herbs: common hedgenettle (Betonica officinalis Trevis.) +, clustered bellflower (Campanula glomerata L.) +, spreading bellflower (Campanula patula L.) +, pale sedge (Carex pallescens L.) +, sticky mouse-ear chickweed (Cerastium holosteoides Fr. em. Hyl.) 1, rough hawksbeard (Crepis biennis L.) +, wild carrot (Daucus carota L.) +, Carthusian pink (Dianthus carthusianorum L.) 1, bitter fleabane (Erigeron acris L.) +, annual fleabane (Erigeron annuus Pers) 1, wild strawberry (Fragaria vesca) 2, hedge bedstraw (Galium mollugo) +, Galium verum 1, Hypericum perforatum 2, Leontodon hispidus 2, Leucanthemum vulgare Lam. 2, field wood-rush (Luzula campestris D.C.) 1, Lysimachia vulgaris L. +, wild marjoram (Origanum vulgare L.) +, burnet-saxifrage (Pimpinella saxifraga L.) 1, lesser butterfly-orchid (Platanthera bifolia Rich.) +, common self-heal (Prunella vulgaris L.) +, creeping buttercup (Ranunculus repens L.) 1, common starwort (Stellaria graminea L.) +, Taraxacum officinale F.H. Wiggers coll. +, broad-leaved thyme (Thymus pulegioides L.) +, germander speedwell (Veronica chamaedrys L.) +, heath speedwell (Veronica officinalis L.) +.

- Habitat B. Grasses: *Arrhenatherum elatius* P. Beauv. & J. Presl. & C. Presl. 3, crested dog's-tail (*Cynosurus cristatus* L.) +, *Dactylis glomerata* L. 2, *Festuca pratensis* Huds. 1, perennial ryegrass (*Lolium perenne* L.) +, *Phleum pratense* L. 2, *Poa pratensis* L. 2, *Trisetum flavescens* P. Beauv. +; legumes: *Trifolium pratense* L. 3, *Trifolium repens* L. 2, *Vicia cracca* L. +, bush vetch (*Vicia sepium* L.) 1, smooth vetch (*Vicia tetrasperma* Schreb.) +; herbs: *Achillea millefolium* L. 2, lady's mantle (*Alchemilla monticola* Opiz.) 1, *Campanula patula* L. +, brown knapweed (*Centaurea jacea* L.) 1, *Crepis biennis* L. 2, *Daucus carota* L. 1, field horsetail (*Equisetum arvense* L.) +, *Fragaria vesca* L. +, *Galium mollugo* L. 1, meadow crane's-bill (*Geranium pratense* L.) 1, common hogweed (*Heracleum sphondylium* L.) 1, narrowleaf hawkweed (*Hieracium umbellatum* L.) +, catsear (*Hypochoeris radicata* L.) +, autumn hawkbit (*Leontodon autumnalis* L.) +, *Leucanthemum vulgare* Lam. +, *Lysimachia vulgaris* L. +, *Plantago lanceolata* L. 2, *Plantago lanceolata* L. 2, broadleaf plantain (*Plantago major* L.) +, *Platanthera bifolia* Rich. +, meadow buttercup (*Ranunculus acris* L.) +, *Ranunculus repens* L. +, yellow rattle (*Rhinanthus minor* L.) +, *Taraxacum officinale* F.H. Wiggers coll. 2, *Veronica chamaedrys* L. +.
- Habitat C. Grasses: Alopecurus pratensis L. 2, Deschampsia caespitosa L. 1, Festuca rubra L. 1, Holcus lanatus L. 2, Poa pratensis L. +, rough-stalked meadow-grass (Poa trivialis L.) 1; legumes: meadow vetchling (Lathyrus pratensis L.) 1, Trifolium hybridum L. 2, Vicia cracca L. +, Vicia sepium L. +; herbs: wild angelica (Angelica sylvestris L.) 1, Caltha palustris L. 2, fox-sedge (Carex vulpina L.) +, cabbage thistle (Cirsium oleraceum Scop.) +, Cirsium rivulare All. 3, autumn crocus (Colchicum autumnale L.) +, western marsh orchid (Dactylorhiza majalis P.F. Hunt & Summerh.) +, Equisetum palustre L. +, hemp-agrimony (Eupatorium cannabinum L.) +, Erigeron annuus Pers. +, meadowsweet (Filipendula ulmaria Maxim.) 1, common marsh bedstraw (Galium palustre L.) +, common rush (Juncus effusus L.) 1, compact rush (Juncus conglomeratus L.) 1, moneywort (Lysimachia nummularia L.) +, Lysimachia vulgaris L. 1, horse mint (Mentha longifolia L.) +, water forget-me-not (Myosotis palustris L.) +, Polygonum bistorta L. 1, Ranunculus acris L. 2, Ranunculus repens L. 1, Rumex acetosa L. 1, curly dock (Rumex crispus L.) +, Scirpus sylvaticus L. 1, Silene flos-cuculi Greuter & Burdet 2, common comfrey (Symphytum officinale L.) +.
- Habitat D. Grasses: *Phalaris arundinacea* L. 2, *Phragmites australis* Trin. ex Steud 4, *Glyceria maxima* Holmb. +, *Poa palustris* L. 1; legumes: *Lathyrus pratensis* L. +; herbs: *Caltha palustris* L. 2, lesser pond-sedge (*Carex acutiformis* L.) 1, northern water hemlock (*Cicuta virosa* L.) r, *Cirsium rivulare* All. +, water horsetail (*Equisetum fluviatile* L.) 1, *Equisetum palustre* L. 1, *Filipendula ulmaria* Maxim. 1, *Galium palustre* L. +, *Lysimachia nummularia* L. 2, *Lythrum salicaria* L. 1, *Mentha longifolia* L. +, *Rumex hydrolapathum* Huds. 1, *Scirpus sylvaticus* L. +, woodland figwort (*Scrophularia nodosa* L.) +, common skullcap (*Scutellaria galericulata* L.) +, *Symphytum officinale* L. +, *Typha angustifolia* L. +.
- Habitat E. Grasses: *Brachypodium pinnatum* P. Beauv. 3, *Briza media* L. +, *Festuca rubra* L. 1, *Phleum phleoides* H. Karst. 1; legumes: common kidneyvetch (*Anthyllis vluneraria* L.) +, purple crown vetch (*Coronilla varia* L.) +, *Medicago falcata* L. 3, field restharrow (*Ononis arvensis* L.) +, *Trifolium medium* L. 1, *Trifolium montanum* L. 1; herbs: common agrimony (*Agrimonia eupatoria* L.) 1, field garlic (*Allium oleraceum* L.) +, *Betonica officinalis* Trevis. +, *Campanula glomerata* L. +, vernal sedge (*Carex caryophyllea* L.) +, blue sedge (*Carex flacca* Schreb.) +, carline thistle (*Carlina vulgaris* L.) +, *Centaurea jacea* L. +, *Centaurea scabiosa* L. 2, monocarpic thistle (*Cirsium decussatum* Janka) +, crosswort (*Crucuata glabra* Ehrend.) +, greater dodder (*Cuscuta europaea* L.) +, *Dianthus carthusianorum* L. 1, cypress spurge (*Euphorbia cyparissias* L.) +, *Filipendula vulgaris* Moench 1, northern bedstraw (*Galium boreale* L.) 1, cross gentian (*Gentiana cruciata* L.) +, marsh fragrant orchid (*Gymnadenia conopsea* R. Br.) +, field scabious (*Knautia arvensis* J.M. Coult.) +, *Leontodon hispidus* L. +, wood cow-wheat (*Melampyrum nemorosum* L.) +, *Origanum vulgare* L. 2, mountain-parsley (*Peucedanum oeroselinum* Moench) 1, *Plantago media* L. 2, common cowslip (*Primula veris* L.) +, large-flowered

selfheal (*Prunella grandiflora* Scholler.) 1, bulbous buttercup (*Ranunculus bulbosus* L.) +, common buckthorn (*Rhamnus catharticus* L.) r, meadow clary (*Salvia pratensis* L.) +, *Salvia verticillata* L. 3, salad burnet (*Sanguisorba minor* Scop.) +, *Scabiosa ochroleuca* L. 2, *Thymus pulegioides* L. +.

- Habitat F. Grasses: *Corynephorus canescens* L. 3, *Danthonia decumbens* D.C. 2, smooth crabgrass (*Digitaria ischaemum* Muhl.) +, *Festuca ovina* L. 1, creeping soft grass (*Holcus mollis* L.) +, *Nardus stricta* L. 1; legumes: *Trifolium arvense* L. 2; herbs: horseweed (*Erigeron canadensis* Cronquist) 1, maiden pink (*Dianthus deltoides* L.) +, *Equisetum arvense* L. +, spring draba (*Erophila verna* Chevall.) +, black-bindweed (*Fallopia convolvulus* L.) +, small cudweed (*Filago minima* Fr.) +, dwarf everlast (*Helichrysum arenarium* Moench) +, *Hieracium pilosella* L. 2, *Hypochoeris radicata* L. +, *Jasione montana* L. +, common evening-primrose (*Oenothera biennis* L.) +, *Rumex acetosella* L. 2, common soapwort (*Saponaria officinalis* L.) +, perennial knawel (*Scleranthus perennis* L.) 1, woundwort (*Solidago virgaurea* L.) 1, morrison's spurrey (*Spergula morisonii* Boreau) 2, breckland wild thyme (*Thymus serpyllum* L.) +, *Teesdalea nudicaulis* R. Br. 3, common mullein (*Verbascum thapsus* L.) r, dillenius' speedwell (*Veronica dillienii* Crantz) +.

Explanations: coverage area: 4–62.5%, 3–37.5%, 2–17.5%, 1–5%, + –0.5%, r–0,1%. This is the so-called mean percentage share of the species in the surface coverage. The "+" value conventionally refers to 0.5% coverage; in fact, it was from two to five specimens of the species. The "r" value conventionally refers to 0.1% coverage; in fact, there was only one specimen of the species [20].

3.2. Data Analysis

The obtained results revealed the highest content of N and P in the sward of type B meadows, the highest content of K and Cu in the sward of type D meadows, the highest content of Mg in the sward of type C meadows and the highest content of Fe, Mn and Zn in the sward of type A meadows. The lowest content of N, P, K, Mg, Fe, Cu and Zn was measured for type F meadows; the lowest content of Mn was measured for type B meadows. Regarding macromineral content in the sward of the six examined meadow types, the differences were as follows (Table 1): for N, 36%, for P, 32%, for K, 42% and for Mg, 44%. The differences in the micromineral content in the sward of the six examined meadow types were as follows (Table 1): for Fe, 39%, for Cu, 39%, for Mn, 56% and for Zn, 24%.

Table 1. Macro- and micro mineral concentrations dry mass (DM) in the sward (mean ± SD). A—optimally moist habitat, poor soils, fresh meadows; B—optimally moist habitat, fertile soils, fresh meadows; C—periodically excessively moist habitat, fertile soils, periodically wet meadows; D—permanently excessively moist habitat, fertile soils, rush grasslands; E—dry, alkaline habitat, low fertile soils, xerothermic grasslands; F—dry, acidic habitat, poor soils, psammophilic (grasslands).

Type of Meadows/n	g kg^{-1} DM				mg kg^{-1} DM			
	N	P	K	Mg	Fe	Cu	Mn	Zn
A/60	13.9 ± 4.1	2.1 ± 0.6	12.9 ± 2.7	2.1 ± 0.6	97.5 ± 30.4	5.5 ± 1.5	231.2 ± 147.9	29.0 ± 7.0
B/60	17.7 ± 3.4	2.5 ± 0.6	18.7 ± 4.5	2.3 ± 0.6	94.0 ± 41.7	5.2 ± 1.6	103.0 ± 71.6	25.8 ± 7.5
C/60	16.8 ± 3.4	2.2 ± 0.5	17.3 ± 6.2	2.5 ± 0.5	83.1 ± 58.4	6.3 ± 2.1	103.1 ± 93.6	28.3 ± 9.3
D/60	16.2 ± 3.3	2.4 ± 0.6	19.8 ± 5.4	2.0 ± 0.6	85.0 ± 31.1	6.6 ± 1.3	131.2 ± 55.1	26.0 ± 5.9
E/60	15.4 ± 2.2	2.2 ± 0.4	15.8 ± 2.7	2.3 ± 0.5	75.5 ± 20.6	5.0 ± 0.8	393.8 ± 82.3	28.3 ± 6.3
F/60	11.2 ± 2.4	1.7 ± 0.4	11.5 ± 2.4	1.4 ± 0.3	60.2 ± 21.6	4.0 ± 0.4	201.3 ± 35.4	22.0 ± 3.6

In turn, the results of soil samples indicated that the highest content of N, Mg, Cu and Zn was deposited in the soil of type D meadows, the highest content of P, K and Mn was deposited in the soil type E meadows, and the highest content of Fe was deposited in the soil of type C meadows. The lowest content of N, P, K, Mg, Cu, Mn and Zn was deposited in the soil of type F meadows and the lowest content of Fe was deposited in the soil type A meadows. The differences regarding macro mineral content in the soil of the six examined meadow types were as follows (Table 2): for N, 69%, for P, 48%, for K, 54% and for Mg, 81%. The differences in micromineral content in the soil of the six examined meadow types were as follows (Table 2): for Fe, 72%, for Cu, 58%, for Mn, 27% and for Zn, 45%.

Table 2. Macro- and micro mineral concentrations in soil (mean ± SD).

Type of Meadows/n	mg kg^{-1}							
	N *	P *	K*	Mg	Fe	Cu	Mn	Zn
A/60	11.8 ± 3.7	20.9 ± 9.2	82.6 ± 34.3	104.1 ± 49.1	17.1 ± 8.9	10.1 ± 3.7	452.8 ± 177.0	50.1 ± 14.9
B/60	14.1 ± 2.3	25.8 ± 11.3	101.4 ± 35.0	142.8 ± 66.2	17.9 ± 5.0	11.9 ± 3.8	505.8 ± 170.2	52.4 ± 14.5
C/60	12.0 ± 2.1	23.1 ± 11.9	97.7 ± 31.8	149.5 ± 38.5	61.7 ± 25.3	12.7 ± 5.4	509.6 ± 170.7	55.3 ± 13.4
D/60	17.8 ± 4.6	25.1 ± 12.6	86.7 ± 40.0	170.9 ± 64.4	20.5 ± 9.0	15.9 ± 2.5	495.2 ± 179.9	61.3 ± 17.1
E/60	8.9 ± 3.2	27.5 ± 10.5	164.8 ± 48.1	83.8 ± 23.0	57.7 ± 29.9	11.2 ± 2.6	576.1 ± 150.0	52.4 ± 12.2
F/60	5.6 ± 2.2	14.4 ± 4.6	75.8 ± 18.2	33.4 ± 10.2	35.2 ± 14.2	6.7 ± 1.9	420.5 ± 94.8	33.5 ± 13.5

* Dudek et al. 2020 [22].

Subsequently, the Pearson correlation coefficient was used to analyze whether there was a relationship between the content of each of the studied elements in soil and in plants for each meadow type separately. In type A and F meadows, no such relationship was observed for any of the tested chemical elements. It was demonstrated in type B meadows that there was a statistically significant correlation between K content in soil and plants; however the value of the Pearson coefficient showed only a weak correlation. A correlation was also found in type C meadows for K and Mg content in soil and plants. In both cases, it was a moderate correlation. A weak correlation was obtained in type D meadows for Fe content in soil and plants, and a moderate correlation for Mn content. A weak correlation for Cu content in soil and turf was found in E type meadows. However, not taking into account the division into meadow types, it was found that there was a correlation in the content of most of the studied elements in soil and plants, except for Fe and Zn, although it was a weak or moderate correlation (Table 3).

Table 3. Soil–sward relationship (Pearson correlation value) in respect to macro- and micro mineral status.

Type of Meadows/n	N	P	K	Mg	Fe	Cu	Mn	Zn
A/60	−0.027	−0.052	0.016	0.140	0.188	0.124	−0.097	−0.128
B/60	−0.138	−0.056	0.263 *	−0.018	−0.198	0.009	0.174	−0.041
C/60	0.201	0.184	0.321*	0.380 *	0.244	0.066	−0.104	−0.197
D/60	−0.066	0.016	0.175	−0.164	−0.260 *	0.025	0.344*	−0.094
E/60	−0.002	−0.146	0.058	−0.111	0.148	−0.266 *	−0.067	0.071
F/60	0.130	0.178	0.026	−0.065	−0.001	−0.174	−0.038	0.068
A-F/360	0.314 *	0.156 *	0.174*	0.291 *	−0.066	0,321*	0.105 *	0.051

* Significant at 0.05 level.

In all groups (meadow types A–F), a part of the dependent variables (macro- and micro minerals tested) did not show normal distribution. Therefore, non-parametric ANOVA, the Kruskal–Wallis test and median test were used for further statistical analysis in such cases.

The post-hoc test was used for further analysis because the null hypothesis about the lack of differences in the content of tested macro- and micro minerals between meadow types was rejected for all cases (Table 4).

Table 4. Results of the Kruskal–Wallis test (H) and median test (Me); df = 5, n= 360, element content in mg kg^{-1}, independent variable plot (A–F), p < 0.001.

Dependent Variable	H	Me	Chi^2
N_{sward}	110.08	15030.60	92.27
P_{sward}	66.46	2100.00	45.15
K_{sward}	133.79	15229.60	106.67
Mg_{sward}	118.04	2100.00	82.08
Fe_{sward}	66.03	79.25	34.67
Cu_{sward}	132.97	5.18	104.67
Mn_{sward}	175.56	187.00	116.27
Zn_{sward}	41.91	24.68	27.60

The results of the post-hoc test (Table 5) indicated that the null hypothesis about the lack of differences between the average contents of selected elements in the sward of different types of meadows can be rejected with 95% (*) or 99% (**) probability. Statistically significant differences in the content of all tested elements were observed in type D and F meadows. Of these two types, type D meadows had a higher content in the sward of all elements tested, except for Fe (Table 1). Statistically significant differences in the content of seven out of eight elements tested in the sward were noted for the following pairs of meadow types: E:F (no differences in Fe content), C:F (Mn), B: F (Zn). In turn, the lowest differences in the content of elements were recorded for the following pairs of meadow types: B:C (the differences were not statistically significant for6 elements), B:D (7), B:E (6) (Table 5).

Table 5. Post-hoc test results (Dunn test–Z value).

Type of Meadows	N_{sward}	P_{sward}	K_{sward}	Mg_{sward}	Fe_{sward}	Cu_{sward}	Mn_{sward}	Zn_{sward}
A:B	5.1114 *	3.2794 *	6.7697 **	2.4118	1.4592	1.1250	5.7504 **	2.7816
A:C	3.9267 **	0.9061	4.4491 **	3.8566 **	0.9320	3.4754 **	1.6443	1.2031
A:D	3.0724 *	2.6281	7.4180 **	0.4737	2.1500	3.7706 **	4.0184 **	2.0202
A:E	2.1311	1.9548	4.1070 **	1.9908	3.3816 *	1.5425	6.3360 **	0.3026
A:F	4.0864 **	3.8632 **	1.7281	5.8934 **	6.2675 **	6.0759**	0.0088	5.5820 **
B:C	1.1846	2.3732	2.3206	1.4447	2.3912	4.6004 **	4.1061 **	1.5785
B:D	2.0390	0.6513	0.6482	2.8855	0.6908	4.8956 **	1.7320	0.7614
B:E	2.9803 *	1.3246	2.6627	0.4211	1.9224	0.4175	12.0864 **	2.4789
B:F	9.1978 **	7.1425 **	8.4978 **	8.3053 **	4.8083 **	4.9509**	5.7592 **	2.8004
C:D	0.8544	1.7219	2.9689 *	4.3303 **	3.0820 *	0.2952	2.3741	0.8171
C:E	1.7956	1.0487	0.3421	1.8658	4.3136 **	5.0180 **	7.9803 **	0.9004
C:F	8.0131 **	4.7693 **	6.1772 **	9.7500 **	7.1996 **	9.5513 **	1.6531	4.3789 **
D:E	0.9412	0.6732	3.3110 *	2.4645	1.2316	5.3132 **	10.3544 **	1.7175
D:F	7.1588 **	6.4912 **	9.1461 **	5.4197**	4.1175 **	9.8465 **	4.0272 **	3.5618 **
E:F	6.2175 **	5.8180 **	5.8351 **	7.8842 **	2.8860	4.5333 **	6.3272 **	5.2794 **

* Significant at 0.05 level, ** significant at 0.01 level.

4. Discussion

The literature provides the information that herbs (common chicory (*Cichorium intybus* L.), *Plantago lanceolata* L., caraway (*Carum carvi* L.), *Sanguisorba minor* L.) have a higher concentration of macro- (P, Mg, K, S) and micro minerals (Zn and B) than grasses and even legumes [6,7]. Moreover, a study by Lindström et al. (2012) [13], regarding the content of micro minerals in plants, indicated that herbs and legumes were the richest in micro minerals (Co, Cu, Fe, Zn), with the exception of Mn (grasses). Other studies demonstrated that the addition of legumes to grasses caused an increase in feed nutritional value as well as an increase in micro minerals content [14,29]. In addition, with respect to earlier harvests, forage digestibility was shown to be greater for grassland rich in herbs compared to grassland rich in grasses; however, at the end of the season, this situation was reversed [30]. It was also found that dried hay obtained from permanent pasture had a higher feed value than fresh feed [31]. In the case of grassland where grazing had ceased, the composition of functional groups (grasses, herbs, legumes) was rapidly changing towards species best adapted to a given habitat [32]. In contrast, intensive continuous grazing could lead to the dominance of the most grazing-resistant species and undesirable plant species that animals do not consume [33]. Overgrazing is the most common cause of grassland degradation [34,35]; although the complexity of this process remains unexplained, a model developed by Tiscornia et al. [36] provides some hope for its elucidation. The present study determined the total content of elements in the sward, while element content for individual species was not calculated. *Plantago lanceolata* L. was found on type B meadows and the content of N and P in the sward of these meadows was the highest, while the content of other elements was high. These two elements determined plant growth the most, although, as research has shown, a reduction in P inhibits plant growth to a greater extent than a decrease in N [37]. In order to preserve N, surface soil must be protected from erosion [38].

N content in the sward (from 11.2 to 17.7 g kg^{-1} DM) was determined depending on the type of meadow. These values were similar to those obtained for grasses (13.4 g kg^{-1} DM) and herbs (15.0 g kg^{-1} DM) and much lower than for legumes (31.6 g kg^{-1} DM) found in meadows of northern Europe [6]. P content in the sward (1.7–2.5 g kg^{-1} DM) obtained in the present work was similar to the average for the sward of meadows of Dynowskie Foothills SE Poland (2.1 g kg^{-1} DM) [7] and grass and legumes of Denmark meadows (2.5–2.7 g kg^{-1} DM), while lower than for meadow herbs of Denmark (3.4 g kg^{-1} DM) [6] and significantly higher than for mountain meadows of NE China (0.78 g kg^{-1} DM) [8]. Other studies have shown that P concentration in plants increases with increasing grazing intensity [39]. K content (11.5–19.8 g kg^{-1} DM) obtained in the study was close to the average for the sward of Dynowskie Foothills meadow communities (16.0 g kg^{-1} DM) [7], lower than for grasses (24.7 g kg^{-1} DM), legumes (24.5 g kg^{-1} DM) and herbs (30.5 g kg^{-1} DM) of Denmark meadows [6] and much higher than for the mountain meadows of NE China (3.48 g kg^{-1} DM) [8]. Mg content (1.4–2.5 g kg^{-1} DM) obtained in the current study was similar to the average for the sward of Dynowskie Foothills meadow communities (2.3 g kg^{-1} DM) [7], higher than for grasses (1.3 g kg^{-1} DM), lower than for legumes (3.0 g kg^{-1} DM) and herbs (3.3 g kg^{-1} DM) of Denmark meadows [6] and similar in the lower range to mountain meadows of NE China (1.49 g kg^{-1} DM) [8]. Such differences in the content of elements in the sward of meadows of SE Poland, Denmark and mountain meadows of NE China may result from different climatic conditions, which are the mildest in Denmark and the harshest in the mountains of NE China. This thesis is confirmed by the results obtained under similar climatic conditions in the meadows of the Dynowskie Foothills in southern Poland. Plant species composition, and especially the percentage of individual plant groups forming swards—legumes, herbs and grasses—is certainly the second factor affecting the differences in the content of macro- and micro elements in the sward of meadows from different regions.

Grass species and papilionaceous plants valuable for ruminants, were clearly only dominant in the species composition of type B meadows, and this was due to the more favorable soil conditions in which they grew. Vegetation in types D and F, as well as grasses growing in them, were worthless for animal feed production. Meadows in types A and E could be used for grazing animals with lower nutritional requirements, e.g., sheep and goats. Papilionaceous plants are most abundant in meadows with optimal soil moisture and not very high acidity. The proportion of dicotyledonous herbs was high in all types. The studied meadows were in fact long-standing, semi-natural areas that had not been sown in the past with forage legume species. In addition to the production function, type C and D meadows perform ecological functions in the landscape (water retention, carbon accumulation, water purification from pesticides, biodiversity protection) due to their high soil moisture.

It can be concluded that F type meadows—dry, acidic habitat, poor soils and psammophilic were the poorest in all macro- and micro minerals, with the exception of Mn. Enri et al. [40], who conducted research in the Western Italian Alps, and came to similar conclusions. The latter authors observed that more nutrients were found in mesophilic grasslands than in dry grasslands.

The relationship between the content of individual elements in soil and plants, determined in the present study, indicated a different flow intensity of these elements from soil to plants depending on the type of meadow. It cannot be said that a higher element concentration in the soil directly corresponded to its higher content in the sward. An example could be P, which in type E meadow soils was almost twice as high as in soils of type D meadows, while its concentration in the sward of type E meadows was 25% lower than in the sward of type D meadows. The obtained results can be partly explained by the study of Radkowski and Radkowska [41], who unequivocally found that the flow of elements from soil to plants was affected by the composition of soil microorganisms, which affected the efficient use of soil nutrients. Soil microorganisms were not the subject of this study, but it could be assumed that their species composition would be related to the species composition of meadow vegetation and soil type. Hence, different intensities of element flow from soil to plants were observed in various types of meadows.

5. Conclusions

On type A and F meadows, there was no correlation between the content of Mg kg^{-1} and any other tested elements in soil and plants. Element contents in the sward of type A and F meadows did not depend on the content of these elements in the soil. A weak correlation was shown for K in type B meadows and a moderate one in type C meadows. The amount of K in the sward of type B and C meadows slightly depended on the amount of this element in soil. In type C meadows, with the increase in the Mg in the soil, the amount of this element in the sward also increased, and this correlation was moderate. The same relationship was observed in type D meadows for Mn. The amount of Fe in the sward of type D meadows depended on the content of this element in soil. A similar relationship could be observed in type E meadows for Cu; however, this correlation was weak in both cases.

The highest differences in macro mineral contents in the sward of the studied meadow types were found for Mg (44%) and slightly lower difference were found for K (42%); with regards to micro minerals, the greatest difference was recorded for Mn (56%). Such large differences resulted primarily from different plant species composition forming given meadow communities, and not from the content of these elements in the soil.

Our results provide detailed information on the content of basic macro- and micro minerals in both soil and sward of six typical semi-natural meadows of temperate climate in this part of Europe. The results can be used for proper feeding management on farms, especially organic ones, where milk or meat production by ruminants takes place in pastures for most of the year and the basic feed is fresh, grazed meadow vegetation and hay and silage harvested from these meadows. We have also determined the relationships of the content of elements in soil and sward, which are indicative of the flow of individual elements from soil to plants and can help in the better planning of fertilization.

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