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Abiotic Habitat Conditions in Coal Mines Heap Novel Ecosystems Concerning the Biomass Amount of Spontaneous Vegetation

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ABSTRACT

Biomass, primarily derived from photosynthesizing plants harnessing solar energy, is crucial for ecosystem functioning and diverse services. This study delved into the unique ecosystem of coal mine heaps, exploring unexpected relations between abiotic factors and biomass in spontaneous vegetation. Biomass quantity and quality are influenced by such factors as plant photosynthesis efficiency, necessitating an understanding of dynamics on post-mining sites. The conducted investigation focused on diverse spontaneous vegetation on coal mine heaps, analyzing abiotic conditions such as soil texture, water holding capacity, pH, electrical conductivity, nitrogen, carbon, magnesium, sodium, and acidity. Contrary to the adopted hypothesis, nitrogen content negatively correlates with soil total nitrogen, carbon, and water holding capacity. However, the biomass of dominant plant species positively correlates with available phosphorus, pH, calcium, and sodium. These unexpected relationships highlight biomass dynamics complexity in novel ecosystems on coal mine heaps, stressing the need to consider spontaneous vegetation biomass as a valuable resource and ecosystem service in urban-industry landscapes. The obtained findings expand scientific inquiry and have practical implications for post-industrial area reclamation. Understanding biomass potential in identified vegetation types provides insights into biomass character on coal mine heaps, crucial for maximizing spontaneous vegetation potential and transforming post-industrial landscape reclamation approaches.

Keywords: biomass amount; abiotic habitat resources; texture, water holding capacity; biomass as a proxy for ecosystem functioning; circular economy.

INTRODUCTION

Biomass, as a biomaterial, is an organic matter that contains energy in between the chemical bonds of carbon atoms, first derived from the Sun. Biomass amount for biomass materials, photosynthesized by plants, is a crucial metric parameter of plant species abundance, at the vegetation patch, ecosystem, and landscape level scale. Biomass parameters are also one of the crucial ecosystem services aspects. In the vegetation community, the plant species individuals that are creating biomass assembly are the effect of species selection processes caused by competitive exclusion and environmental filtering (Colgan and Asner, 2014; Laux and Torgan, 2015; Silvertown, 2004). The ecosystem functioning processes impact the vegetation diversity, species composition, structural characteristics, and above-ground biomass, including the biochemical and mechanical characteristics (Looney et al., 2016; Lutz et al., 2018). Research results reveal that environmental filtering is an important factor in determining biomass resources for biomass materials productivity, diversity, and plant species assembly in a particular community. The complexity of these relations is dependent on the approach, being a matter of discussion in ecology and environmental studies (Castellanos et al., 2018; Gerhold, Cahill, Winter, Bartish and Prinzing, 2015; Goberna, Navarro-Cano, Valiente-Banuet, García and Verdú, 2014). The question could be addressed in relation to the biochemical and biomaterial point of view in relation to the habitat conditions of vegetation communities biology. Particularly in the disturbed habitats for which the circular economy paradigm could be applied, the question about the nature of the habitat vegetation composition relations is crucial for the assessment and prediction of the biomass material parameters. Two main concepts can be applied: either the biological communities are biological entities separated by ecotone vegetation belts, or the plants and other organisms occur in continuity along the changing value of environmental parameters gradients (Peralta-Maraver et al., 2018).

In the semi-natural and natural ecosystems, some conceptual approaches and theories are presented to explain the links between the biotic ecosystem parameters, such as the quality and quantity of the plant biomass material as well as the abiotic habitat conditions in particular vegetation communities. According to the niche theory, the varied abiotic environmental parameters affect the species occurrence coexistence and growth rate in particular assemblages depending on the resource requirements along the environmental gradient in space and time. In response to the site conditions, the plant species may show different biochemical and mechanical biomass material adaptations to a specific environment (Tilman, 2004; Weiser, Ferreira, Paton, 2018). In the presented study, the post-mineral mining mineral soil substrate may result in unknown biochemical and mechanical properties of the plant biomass material. The post-coal mine soil substrate environment (water, light, nutrients, texture), affects the plant species abundance, distributions, biomass quality, diversity pattern, and coexistence. The mineral habitats of the abiotic factors of post-mining sites contribute to the biotic ecosystem part, including the conditions related to the amount of biomass material, and vary along the time and space scale (Ali et al., 2019; Toledo, Kreuter, Sorice, Taylor, 2012). The possible use of the biomass material that is growing spontaneously on coal mine heaps should be a developing aspect of the circular economy. Regardless, being a crucial question in the biology and ecology of the novel ecosystem establishment. The amount of biomass resources and species composition depend on niche and environmental factors, rather than biotic factors, such as competitor traits (Ali et al., 2020; Tilman, 2004). The biomass material quality and quantity depend on the plant species composition and coexistence mechanism. In the novel ecosystems of the post-coal mine habitats, the non-analogous species composition is the first stage of establishment. The ability of colonization of the particular individuals of the non-analogous species composition can be explained by fitness trait differences between individuals of the plant species vs. stabilizing effects achieved via niche differentiation (Carroll, Cardinale, Nisbet, 2011; Kraft, Valencia, Ackerly, 2008). There are some concepts explaining the links between vascular plant species diversity and the quantity of the above-ground biomass. The positive correlation due to the resource-use partitioning is considered an example of the explanation of the complex compositions of vascular plant species in a vegetation community (Ali and Yan, 2017; Poorter et al., 2015; Yachi and Loreau, 2007). The biomass amount relations are explained best by the mass ratio hypothesis. The theory called "scaling theory" shows that the dominant plant species governing the above-ground biomass quality and quantity is the effect of the continuous interactions between dominant plant species, which is the most abundant species. This approach also reflects the spatial distribution and relationship between the group of weak and strong competitors (Enquist and Niklas, 2001; Grime, 1998). The concept of the theory called "competitive exclusion" is based on the suggestion that in high biomass abundant and diverse structurally developed vegetation the weak competitor plants are excluded. The study performed in natural forests revealed that the negative relations between above-ground biomass and species diversity should be expected (Ali et al., 2020; Carroll, Cardinale, Nisbet, 2012).

In the traditional niche-based theory, the deterministic process is considered, assuming that the species interactions are ruled by the environmental filters. The community species composition and structure are also governed by environmental filters (Chase and Leibold, 2004; Gilbert, 2012). The quantity and quality of biomass material in a given vegetation community depend on the site-specific patch habitat conditions. The abiotic composition of the mineral bedrock is the preliminary habitat condition that affects all the processes of the vegetation community assembly following the ecosystem establishment. This relation is crucial for the biomass material quality and quantity as well as the main research area in community ecology (Hubbell, 2001; Martiny et al., 2006; McGill, 2010). The neutral theory assumes that the plant species individuals are equal from the ecological point of view. According to the neutral theory, the composition of the community is the effect of stochastic processes, including probabilistic dispersal birth, colonization, immigration, and death (Bell, 2001; Hubbell, 2001; Rosindell, Hubbell, Etienne, 2011). The relative importance of the following factors that are driving the ecology of natural vegetation communities reveals that the two aspects are not mutually exclusive. Depending on the habitat conditions, one of the concepts is explaining the observed phenomenon (Hubbell, 2001; McGill, 2010; Vellend, 2016). The metacommunity theory is identifying the processes, and the observed processes in varied spatial scales (Chase and Leibold, 2004; Wilson, 1992). Vellend (2010) presented a system in which the community structure is clarified by analyzing four flowing "high-level processes" including the dispersal process, diversification of varied selection, and the process of ecological drift (Hubbell, 2001; Vellend, 2010, 2016).

The variety of environmental habitat conditions is causing more dissimilar or similar compositions and structures of vegetation communities (MacArthur and Wilson, 2001; Stegen et al., 2013). Inhomogeneous environmental habitat conditions, it will not act intensively and will lead to a similar community composition (low community turnover). Under heterogeneous environmental habitat conditions, it supports the increase in vegetation community turnover. The heterogeneous habitat condition mosaic is colonized by the best-adapted plant species, which is referred to as "heterogeneous selection" (Dini-Andreote, Stegen, Van Elsas, Salles, 2015; Hubbell, 2001; Lowe and McPeek, 2014; Vellend et al., 2014). The diversity has been growing due to the stochastic factors, in response to severe habitat conditions (Rundle and Nosil, 2005). The importance of selection in relation to other processes may be caused by environmental heterogeneity (Östman et al., 2012).

The influence of the presented theories has been considered under natural and semi-natural habitat conditions. The impact of the abiotic factors is different when the spontaneous vegetation communities are developing into ecosystems that cover habitats of novel ecosystems (Hobbs et al., 2006), e.g., post-mining mineral habitats. The de novo established mineral oligotrophic habitats allow studying the interactions between the plant species, (the dominant plant species), and the abiotic mineral substrate conditions. In novel ecosystems, they are the result of unknown non-analogous species composition in the extreme human impact. The biomass material can depend on the non-analogous species composition (Zalasiewicz et al., 2016). Post-mining mineral excavation sites are examples of habitats that are different from the natural ecosystems present in the neighboring landscape (Figures 1 and 2).

Studies show that regardless of the disturbance caused by humans, in particular mining activity, the post-mining mineral sites are inhabited by plants producing biomass, and other living organisms in the process of spontaneous

Figure 1. The heap of mineral material of the coal mine heaps habitats conditions are colonized by pioneer vascular plant species and the seedlings and juveniles of deciduous (*Populus tremula, Betula pendula*), and coniferous (*Pinus sylvestris*) tree species. The varied texture conditions are visualized

Figure 2. The colonization process on the mineral materials of the coal nine heaps habitats is not known from the other sites that undergo spontaneous primary succession. In the upper left corner, there are two young individuals of *Chamaenerion palustre*, in the bottom right corner there are two juvenile individuals of *Pinus sylvestris*

succession, delivering novel non-analogous species compositions of the novel ecosystem (Frouz, 2018; Kowarik, 2011; Tropek et al., 2012). The variety of the physical and chemical characteristics of post-mineral and post-mining substrates have caused the development of the unknown, non-analogous species compositions of the vegetation plant species, and animal organisms (Helingerová, Frouz, Šantrůčková, 2010; Novák and Prach, 2003; Woźniak, 2010). The vegetation patches growing on the post-coal mine heaps of different mineral material microsites give the mosaic of patches dominated by groups of species assembled in a set of microhabitats (Markowicz, Woźniak, Borymski, Piotrowska-Seget, Chmura, 2015; Rawlik, Kasprowicz, Jagodziński, 2018; Woźniak, 2010). The plant species composition representing the early-successional vegetation developmental stages growing on harsh habitat conditions of the mineral substrates is much less well-known (Lamošová, Doležal, Lanta, Lepš, 2010; Orwin, Ostle, Wilby, Bardgett, 2014; Woźniak, 2010). It is interesting how the extreme mineral material abiotic conditions of the coal mine heaps, a novel ecosystem, influence the biomass material biochemistry and amount of the identified vegetation types plant species composition of the coal mine heaps novel ecosystem, being the proxy for ecosystem functioning and ecosystem functioning constituting the basis for each ecosystem service (Aragão, Jacobs, Cliquet, 2016; Baral, Guariguata, Keenan, 2016; Washbourne, Goddard, Le Provost, Manning, Manning, 2020).

In this study, the impact of the abiotic parameters of habitat conditions on the amount of biomass material and character in the spontaneous vegetation types of coal mine mineral heap novel ecosystems was evaluated. The biomass material measured in the identified vegetation types gives general information about the character and quality variety of biomass material that can be obtained from spontaneous vegetation developing on coal mine heaps. Among the abiotic parameters measured in the identified vegetation patches, the following were measured: pH, EC, the soil substratum texture, basic abiotic N, C, Mg, Na, and exchangeable cations; in addition, the water holding capacity WHC was analyzed.

In particular, the impact of the abiotic habitat conditions on the amount of biomass material of the identified variety of the spontaneous vegetation types was analyzed. it was assumed that the nitrogen content will influence the biomass amount significantly, while the abiotic factors will be the less significant condition factors.

MATERIALS AND METHODS

Site description

For the research, the coal mine spoil heaps situated in the Upper Silesian Coal Basin were selected as the primary study subject. The mineral materials found in these coal mine heaps are derived from carboniferous gangue rock located approximately 700 meters below the surface (Kompała-Bąba et al., 2019). Given their origin, the initial mineral substrate of these heaps lacks organic matter, soil microorganisms, or plant propagules (Rahmonov et al., 2022; Woźniak et al., 2021), rendering them inhospitable to biological life. This characteristic makes it an ideal subject for investigating plant succession and diversity, soil formation, and the evolving relationships between plants and associated microorganisms (Frouz et al., 2008; Kompała-Bąba et al., 2019; Woźniak, 2010).

Furthermore, the physicochemical properties of post-mining mineral material pose challenges for plant growth. These materials exhibit acidic pH, locally elevated salinity, and limited nutrient availability, along with unfavorable soil texture (Błońska et al., 2019; Kompała-Bąba et al., 2019; Rahmonov, Pukowiec-Kurda, Banaszek, Brom, 2020). Conversely, after storage, mining mineral material becomes highly susceptible to weathering, leading to the rapid accumulation of a fine mineral soil fraction. This fraction retains soil nutrients and water, creating a substrate conducive to seed germination (Kompała-Bąba et al., 2019; Rahmonov et al., 2022; Woźniak et al., 2021).

Vegetation sampling

In the conducted research, the land cover data from designated research plots situated within uniform vegetation patches were gathered, predominantly featuring the targeted dominant species. These plots were configured in circular shapes with a 3-meter radius. For each research plot, the geographic coordinates of its central point were recorded using a GPS receiver, ensuring precise localization of the study areas. Species composition and the coverage of each vascular plant species were meticulously documented on each plot, employing a ten-point scale (<1%, 1–5%, 5–10%, 10–20%, 20–30%, 30–40%, 40–50%, and so forth, in 10% increments). The collected data served as the basis for computing diversity indices within the analyzed area. Phytosociological investigations facilitated the computation of diversity metrics, including the Shannon-Wiener H' diversity, Evenness uniformity, and Simpson's dominance index. These indices provided a comprehensive understanding of the vegetation structure in the examined area, without considering soil components (Woźniak, 2010).

Biomass sampling

In the research, biomass collection was conducted within the specified study plots. Biomass samples were acquired in a circular pattern with a 3-meter radius, predominantly featuring a specific plant species recognized as the dominant species. This species occupied the largest area within the designated plot in comparison to the surrounding vegetation. Following collection, meticulous packaging was employed, utilizing labeled bags to preserve sample integrity. In the field, the gathered plants were weighed, providing the data on the fresh biomass of the dominant species and other coexisting plants in the vicinity. The determination of research plots involved the use of a representative square that encompassed the dominant species and optimally represented the entire study area. Within this square, the coverage of the dominant species as well as the quantitative interactions between the dominant species and other co-occurring species were assessed. The side length of this square was set at 0.5 meters, enabling accurate evaluation of the dominant species' impact on the overall vegetation in the area.

These investigations yielded valuable insights into the ecosystem's structure, biomass quantity, and interactions among various plant species. The approach of biomass sampling in a circular pattern and examination of a representative square proved to be highly effective, providing a comprehensive understanding of the vegetation at the study site.

Soil substratum physicochemical analyses

The substrate samples intended for physicochemical analyses underwent a series of preparatory steps, including air-drying, grinding, and sieving to achieve a particle size fraction smaller than 2 mm. These substrate samples underwent scrutiny for various physicochemical parameters, namely pH, electrical conductivity (EC), soil organic carbon content (SOC), total nitrogen (TN), phosphorus (P_2O_5) content in available forms, concentration of available magnesium (MgO), exchangeable cations (K^+, Na^+), and moisture. The analysis and visualization were performed using R language and environment (R Core Team 2022) and specialized libraries (vegan, ggplot2). To examine the influence of environmental variables on the species present, canonical correspondence analysis (CCA) was run with 999 iterations of the permutation test. The variance inflation factor

(VIF) was calculated to exclude correlated and redundant variables. The stepwise procedure was done to assess the significance of particular factors. The Venn diagram was performed to show variance partitioning among soil variables (physicochemical and granulometric composition) and biotic data (soil enzymes as well as abundance of nematodes and pot worms (*Enchytraeidae*)). The Spearman rank correlation test was carried out to analyze the relationship between particular environmental factors and biomass of dominant, biomass of remaining species, and total cover of species present in a plot. The level of significance was assumed at $p < 0.05$.

A comprehensive description of the analytical methods applied for these parameters can be found in Bierza et al. (2023). Water holding capacity, defined as the ability of soil to retain and make water accessible to plants, represents a crucial parameter influencing plant growth, particularly in arid periods. The water-holding capacity of soil is contingent on factors such as its structure, organic matter content, mineral type, and other variables. The soils with a high water holding capacity can retain a substantial amount of water, proving advantageous for plant sustenance, especially during prolonged periods without rainfall. Conversely, the soils with low water holding capacity experience rapid water loss and may necessitate more frequent watering to sustain optimal plant conditions. The water-holding capacity of soil also plays a pivotal role in nutrient retention as well as influences the structure and activity of soil microorganisms. Plants absorb water through their roots, and the water-holding capacity of soil regulates the availability of water to plants, impacting their growth and yield. An accurate assessment of soil water holding capacity is crucial for effective plant irrigation planning, especially in agricultural and horticultural practices. The soils characterized by higher water-holding capacity exhibit greater resistance to drought and possess a superior ability to supply water to plants during rainfall-deficient periods. Therefore, in the regions with limited rainfall or arid conditions, opting for the soils with higher water-holding capacity proves beneficial, ensuring an ample water supply for plant development (Bierza et al., 2023).

Data analysis

The analysis and visualization were conducted using the R language and environment (R Core Team 2022) along with specialized libraries (vegan, ggplot2). To explore the impact of environmental variables on the presence of species, canonical correspondence analysis (CCA) was executed with 999 iterations of a permutation test. The variance inflation factor (VIF) was computed to eliminate correlated and redundant variables. A stepwise procedure was employed to evaluate the significance of individual factors. Additionally, a Venn diagram was generated to illustrate variance partitioning between soil variables (physicochemical and granulometric composition) and biotic data (soil enzymes, nematode, and pot worm (*Enchytraeidae*) abundance).

The Spearman rank correlation test was utilized to examine the relationship between specific environmental factors and the biomass of the dominant species, the biomass of the remaining species, and the total cover of species within a plot. The level of significance was set at $p < 0.05$.

RESULTS

During this research, 324 plots were studied in which 210 vascular plant species were recorded along with the detailed soil substratum analysis performed. The preliminary and prerequisite results present the diversity of spontaneous vegetation types. The vegetation type diversity reflects the variety of habitat conditions and enables the clear identification of the measured biomass vegetation/ecosystem unit about the soil substratum abiotic conditions. The analysis revealed different vegetation types (Table 1).

The recorded diversity of vegetation patches (assessed by physiognomic variety (supplementary Figure 3–8) were grouped based on the dissimilarity tests. As a result, thirteen vegetation types were identified. The soil substrate analysis was processed in all identified vegetation groups. This arrangement enabled the abiotic measurement of the soil substratum parameters in relation to the quality and quantity of the biomass material characterized a particular spontaneous vegetation type characteristics.

The analysis revealed that the following soil substratum abiotic parameters have been the main drivers determining the vegetation patched distribution: total nitrogen, organic carbon, and the moisture WHC. Analysis concerning the biomass amount in particular vegetation types showed that they are correlated with the first axis of CCA

Table 1. The list of the distinguished vegetation types with short functional characteristics (grasses and herbs)

Vegetation type	Dominant species	Dominant species life form (Ecoflora; F.PL)	Dominant species life span
Woodland vegetation	*Calamagrostis epigejos*	Hemicryptophyte	Perennials
Grassland vegetation	*Centaurea rhenana*	Hemicryptneophyte	Perennials/bi-annuals and poly-annuals
Wetland vegetation	*Chamaenerion palustre*	Chamaephyte	Perennial
Ruderal vegetation	*Daucus carota*	Hemicryptophyte	Annuals/perennials/annuals/bi-annuals
Wetland vegetation	*Eupatorium cannabinum*	Helophyte; Hemicryptophyte	Perennial
Grassland vegetation	*Festuca sp*	Hemicryptophyte	Perennial
Grassland vegetation	*Lotus corniculatus*	Hemicryptophyte	Perennials
Ruderal vegetation	*Melilotus albus*	Hemicryptophyte Therophyte	Annuals/strict monocarpic
Wetland vegetation	*Phragmites australis*	Helophyte; Hydrophyte	Perennials
Grassland vegetation	*Poa compressa*	Hemicryptophyte	Perennials
Ruderal vegetation	*Solidago gigantea*	Hemicryptophyte	Perennials
Ruderal vegetation	*Tripleurospermum inodorum*	Hemicryptophyte Therophyte	Annuals/bi-annuals
Ruderal vegetation	*Tussilago farfara*	Geophyte; Hemicryptophyte	Perennials

Figure 3. The patch of *Calamagrostis epigejos* dominated vegetation, the grass-dominated vegetation type presents a distinctive group of biomass material

Figure 4. The initial stage of spontaneous vegetation development is related to the occurrence of particular vegetation types, such as the vegetation communities dominated by *Poa compressa*

(Figure 9a). High values of such variables as the Ntot, Corg, and WHC characterize the *Tussilago farfara* group of plots. In turn, the electrolytic conductivity is correlated with the second axis. The second axis assigned the relation to the *Festuca* species vegetation type group and *Poa compressa* dominated group plots. High values of basic phosphatase and pH plot with *Solidago gigantea* are associated. The high participation of nematode and higher value of urease is related to the plots dominated by *Triplospermum inodorum*.

Environmental factors do not explain much of species variation (ca. 18%), but the effect of soil variables is higher and amounted to 11% while the other soil factors are 2.3%, and they share almost 4% (Figure 9C). The analysis performed for all the vegetation types together in relation to the coal mine heaps soil substratum revealed some general correlations. The analysis was performed for the amount of biomass material of the dominant plant species (Figure 10) and the species that are the accompanying non-dominant plant species (Figure 11). According to the Spearman rank correlation test, positive relationships between the biomass of dominant species and environmental factors prevail. The highest correlation was demonstrated by

Figure 5. The parts of the coal mine habitats that are frequently waterlogged are characterized by the initial stage of the vegetation patch, dominated by *Phragmites australis*

Figure 6. The vegetation communities dominated by the herb plant *Daucus carota* appear later in the vegetation mosaic

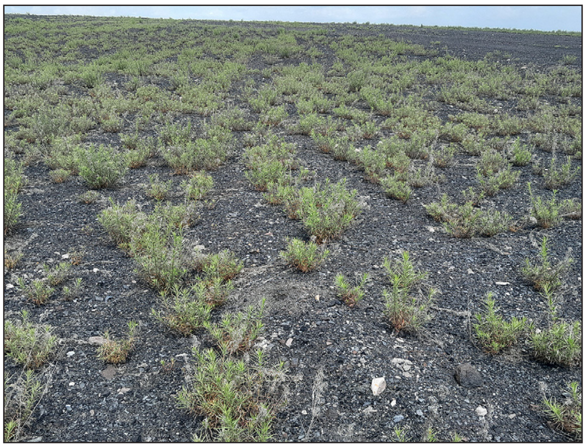

Figure 7. The pioneer perennial vascular plant species *Chamaenerion palustre* covers an extensive area of the coal mine heap, novel ecosystem mineral material

Figure 8. The vegetation community dominated by the herb *Tussilago farfara*

basic phosphate followed by available phosphorus, pH in KCl, acid phosphatase, pH in aqua, as well as calcium ions and sodium content. The negative correlation with biomass of dominant species revealed: organic carbon, available magnesium, total nitrogen, and water holding capacity (Figure 10). The analysis performed for the amount of biomass material of the non-dominant plant species is shown in the figure below (Figure 11).

In the case of the total biomass of remaining non-dominant species, the highest values of positive correlation were with soil enzymes (basic and acid phosphatases), pH, available phosphorus, and content of sodium (Figure 11). The negative correlations were observed with water holding capacity, total nitrogen, and urease.

Apart from the separate analysis performed for the understanding of the relation between the biomass amount of the dominant and non-dominant plant species in relation to the mineral soil substratum of the coal mine heaps novel ecosystem, the analysis of the summarized biomass was performed. The analysis of the relationship between the summarized biomass amount and the soil substratum parameters is based on the value of the percentage total cover of all the plant species in the vegetation patch.

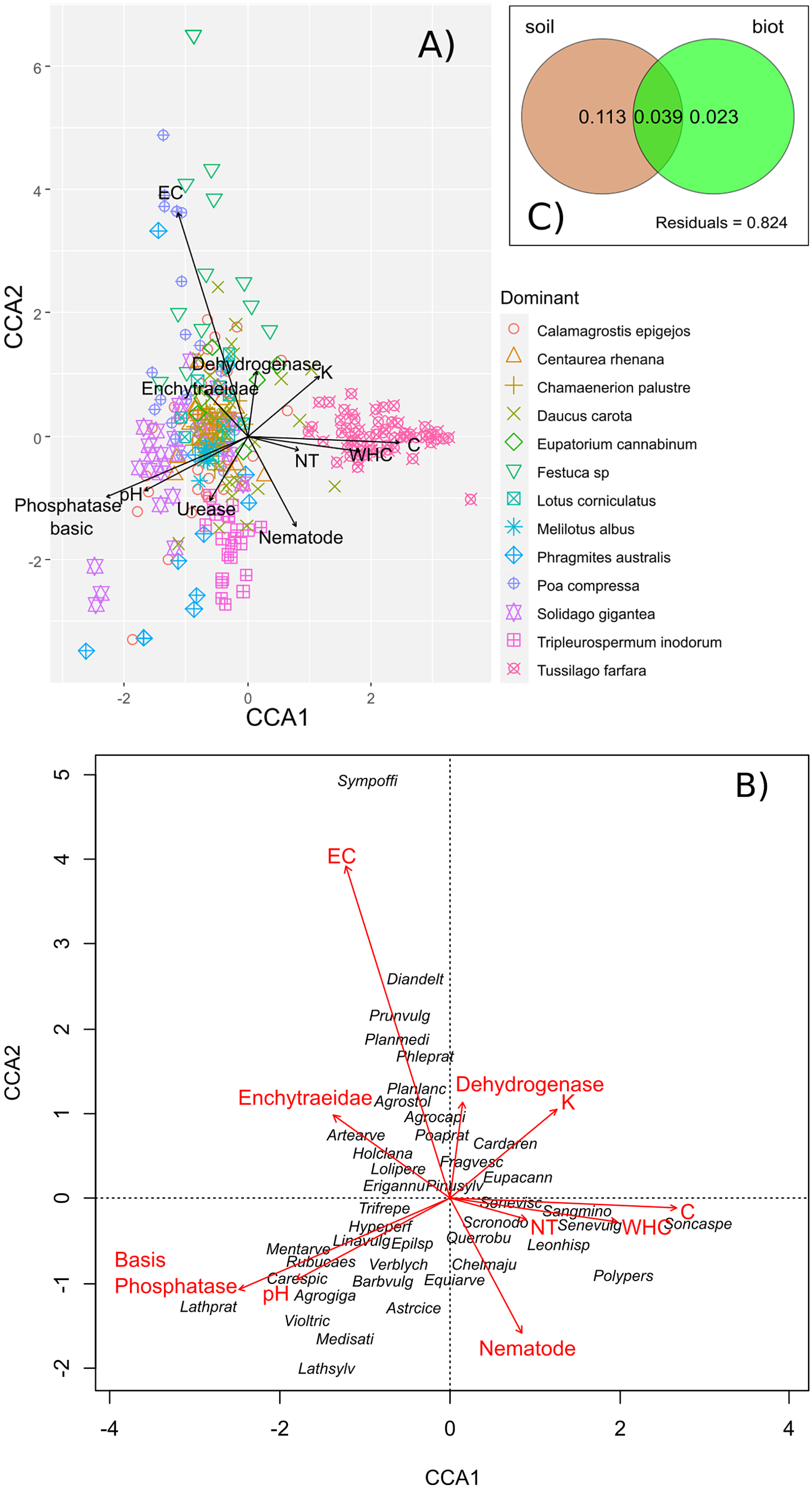

Figure 9. The biplot analysis of CCA presents the vegetation patches distribution along the first two axes. One of the biplots shows the vegetation patch groups characterized by particular dominant plant species (a), the second biplot presents the relationship between the main habitat factors ($p < 0.05$) and particular species value scores (b), as well as the variance parameters of the partitioning among the soil substratum data

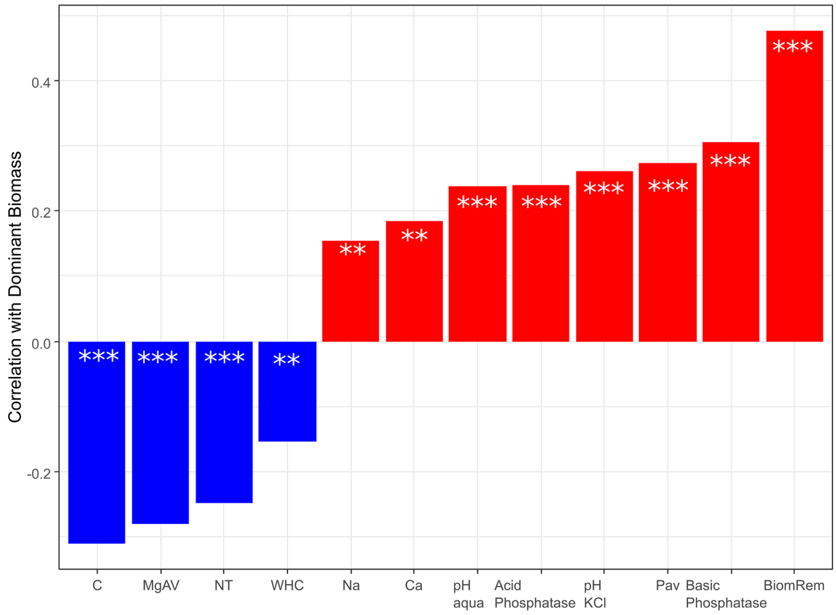

Figure 10. The values of Spearman rank correlation coefficients between the amount of biomass material of dominant plant species and biomass quantity of the accompanying, remaining plant species in the analyzed vegetation patches and abiotic habitat factors. The red color indicates positive correlations, while the blue color denotes negative correlation: *p < 0.05** p < 0.01*** p < 0.001

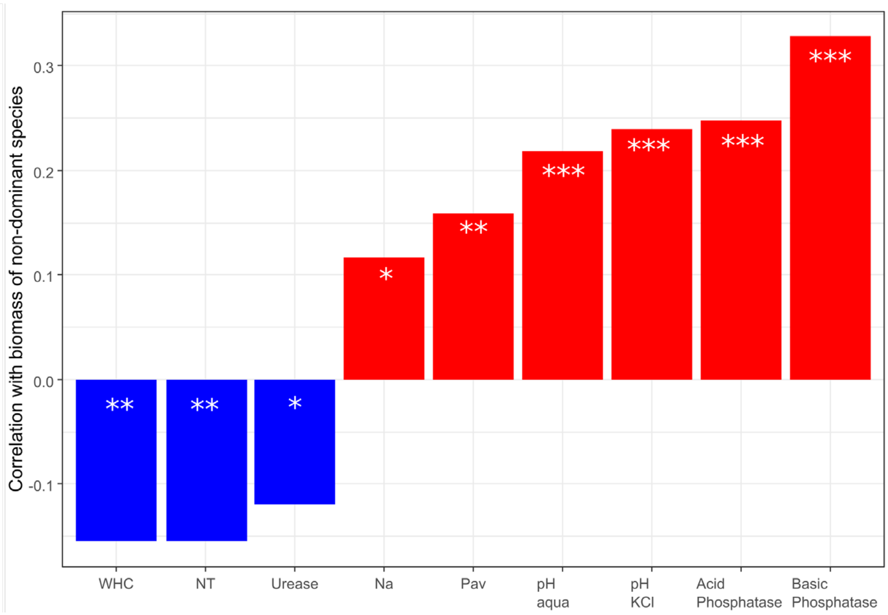

Figure 11. The values of Spearman rank correlation coefficients between the biomass of non-dominant species and environmental factors. Blue color denotes negative correlation and red one-positive correlations: *p < 0.05** p < 0.01*** p < 0.001

The total percentage cover was positively correlated both with the biomass of the dominant and remaining species. As environmental variables are concerned, the highest values of positive correlation were obtained for phosphatases, available phosphorus, pH, and content of calcium ions and sodium. The highest negative correlations were shown for organic carbon followed by available magnesium, total nitrogen, and water-holding capacity (Figure 12).

The analysis performed for all the vegetation types revealed some general trends for the ecosystems of the studied heaps as a whole. It is also very interesting to analyze the parameters

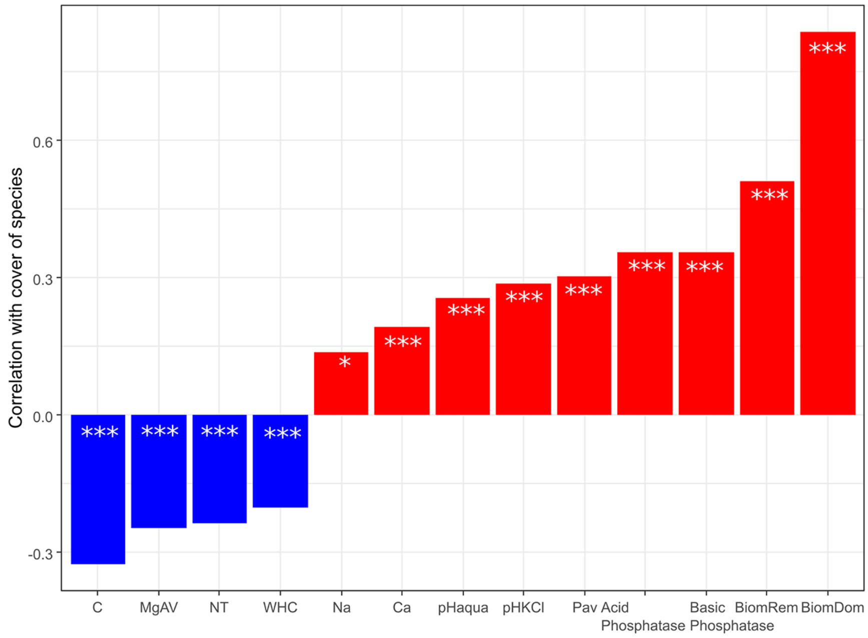

Figure 12. The values of Spearman rank correlation coefficients between the total percentage cover of all species present and habitat condition factors. Explanations: the blue color denotes negative correlation, while the red color indicates positive correlations, *$p < 0.05$** $p < 0.01$*** $p < 0.001$

of soil substratum habitat conditions among vegetation types. This analysis will reveal if and in what respect are the vegetation types that give higher biomass related to the abiotic mineral habitat conditions of the novel ecosystems developing on coal mine heaps.

The detailed analysis of differences in biomass of dominant soil characteristics (nutrient contents, pH, biotic factors) is shown in Table 2. The highest amount of biomass material was stated in *P. australis* vegetation type. Soil reaction (pH) was similar in all types, usually, it was slightly acidic but in *P. australis* and *S. gigantea* vegetation it was neutral. Moreover, in the former, the content of sodium and dehydrogenase turned out to be the highest. In *Poa compressa*, the highest values were recorded in regards to the K, EC, and Ca values, while in the soil substratum from under the patches dominated by *Chamaenerion palustre*, in Mg, Acid phosphatase. In the vegetation type dominated by *Melilotus albus*, the SOM, basic phosphatase, and available magnesium had the highest values. Taking into account WHC and available phosphorus, the highest values were recorded in *Festuca sp* (Table 2).

DISCUSSION

In this study, the authors evaluated the link between the abiotic factors in habitat conditions and the amount biomass material in the identified spontaneous vegetation type communities on a novel ecosystem of the mineral coal mine heaps habitats. Contrary to the authors' expectation, the nitrogen content in the soil substratum of the mineral coal mine heaps habitats has not supported the biomass amount. In contrast, the nitrogen content has significantly negatively influenced the amount of biomass material of both the non-dominant plants and the dominant plant species in the spontaneous vegetation patches.

Does the nitrogen content influence the biomass amount in a most significant way?

Nitrogen content in soil or soil substratum is presented as an important nutrient resource for plant individual growth in terrestrial ecosystems, where the soil is in the younger developmental stage (LeBauer and Treseder, 2008; Vitousek and Howarth, 1991). Nitrogen has been considered a crucial element in determining the photosynthesis process and as a result the biomass amount. In the agricultural practice, the input of nitrogen along with potassium and phosphorus has been applied

Table 2. The differences between the biomass of the distinguished vegetation types and particular soil substratum characteristics include texture, WHC, pH, EC, basic abiotic N, C, Mg, Ca, Na, and K exchangeable cations

Specification	Calamagrostis epigejos	Centaurea rhenana	Chamaenerion palustre	Daucus carota	Eupatorium cannabinum	Festuca sp	Lotus corniculatus	Melilotus albus	Phragmites australis	Poa compressa	Solidago gigantea	Tripleurospermum inodorum	Tussilago farfara
Biomass	97.6 ±29.1	85.3± 25.6	76.4± 12.8	81.8± 22.1	70.0± 25.7	92.6± 25.3	113.7± 21.0	47.5± 47.4	172.7± 47.4	87.7± 27.6	110.9± 30.6	81.3± 26.7	67.0± 16.4
pH ***	6.7 ±1.5	5.9± 1.6	5.6± 1.7	6.5±1.0	6.6±0.1	6.3±0.6	6.8±0.8	6.6±0.4	7.3±0.6	6.8±0.5	7.0±0.9	6.2±1.4	6.1±1.4
K ***	160.5± 48.4	133.2± 29.4	139.2± 28.0	220.5± 77.9	272.0± 63.7	179.4± 62.4	128.2± 45.5	138.6± 59.3	224.3± 91.5	227.0± 72.7	146.7± 51.4	243.8± 106.7	209.5± 92.9
Mg ***	497.4± 324.0	637.0± 301.6	813.3± 908.8	647.4± 279.6	806.3± 312.8	1237.4± 612.9	825.3± 669.7	662.1± 278.8	696.7± 430.6	761.4± 296.9	317.9± 162.1	463,2± 320.3	759.6± 1105.3
SOM ***	10.4 ±6.9	16.6± 5.9	15.0± 3.6	12.7± 5.0	9.3±1.4	6.6±3.3	3.9±2.4	23.3± 5.5	13.6± 9.9	12.2± 4.3	9.4±7.7	13.0±6.6	16.0± 6.8
NT ***	0.27 ±0.13	0.37± 0.09	0.27± 0.05	0.26± 0.08	0.27± 0.18	0.36± 0.26	0.21± 0.10	0.36± 0.12	0.26± 0.19	0.27± 0.14	0.23± 0.11	0.25± 0.08	5.95± 44.13
EC ***	0.28 ±0.28	0.45± 0.23	0.36± 0.21	0.37± 0.25	0.61± 0.29	31.08± 19.10	2.87± 8.29	0.44± 0.27	0.51± 0.40	18.14± 9.07	0.35± 0.17	0.53± 0.41	0.92± 2.86
WHC ***	26.6 ±5.8	29.4± 5.2	19.6± 6.1	27.4± 6.9	33.0± 11.6	37.3± 6.7	32.8± 6.5	33.0± 5.5	19.5±4.6	23.3± 4,7	25.5± 3.5	29.3± 7.0	32.9± 9.0
Ca ***	2468.9 ±2024.5	1784.2± 2191.0	1972.2± 2127.8	2101.2± 1799.3	6053.0± 2991.8	2452.3± 1690.8	1250.9± 584.8	1809.9± 2036.7	3403.0± 1834.8	4412,8± 2304.2	2127.7± 2545.6	3222.4± 1827.4	2001.0± 2151.7
Acid phosphatase ***	1299.5± 1000.5	714.1± 270.0	1995.2± 1748.8	335.3± 201.9	1358.2± 722.3	829.6± 760.4	988.4± 815.9	1706.0± 1140.9	1336.8± 233.3	1880.9± 614.9	1932.4± 656.1	1343.1± 817.6	533.4± 881
Basic phosphatase ***	1963.1± 1266.0	716.2± 87.6	2295.7± 1498.5	1454.4± 1355.5	798.5± 267.5	1642.3± 1480.9	1723.6± 1234.4	4536.9± 2362.2	2453.2± 425.7	2175.1± 762.2	3345.1± 951.1	2400.5± 1156.9	1184.6± 644.9
Dehydrogenase ***	61.8± 160.8	7.7± 0,5	13.1± 1.6	29.9± 25.5	22.6± 18.0	26.0± 24.7	41.6± 28.1	19.5± 10.6	63.5± 17.0	49.4± 166.1	20.3± 32.5	18.0±20.8	41.5± 11.7
Urease ***	0.26± 0.18	0.82± 0.15	0.35± 0.27	0.14± 0.09	0.28± 0.12	0.31± 0.19	0.21± 0.15	1.19± 0.66	0.54± 0.60	0.37± 0.55	0.37± 0.28	0.24±0.21	0.26± 0.13
Enchytridae ***	3.6± 5.1	0.9± 1.1	0.9± 0.9	1.6±1.2	3.1±1.6	2.6±2,0	1.2±1.1	1.4±1.7	0.7±0.8	3.3± 4.5	1.7±1.7	1.2±0.8	1.7±1.6
Nematode ***	1.1± 1.4	1.7± 1.3	1.1± 1.2	1.7±1.6	0.9±0.8	1.9±1.3	2.7±1.5	2.4±0.9	2.9±3.4	0.8±1.5	1.6±1.2	2.8±1.4	2.1±1.6
Na ***	61.3± 46.4	85.7± 47.1	63.7± 53.1	84.8± 84.0	105.2± 25.1	103.6± 82.6	94.8± 48.2	61.8± 55.8	183.1± 201.6	49.3± 12.2	64.7± 47.3	145.8± 81.0	77.0± 73.2
Mg av ***	265.7± 89.8	346.3± 61.6	361.7± 70.6	320.5± 64.9	343.5± 63.9	280.3± 105.3	242.3± 80.9	343.7± 31.1	254.5± 93.8	307.3± 54.6	222.1± 105.6	310.3± 67.0	271.3± 93.0
P av ***	11.2± 9.2	6.2± 3.4	7.8± 19.3	17.0± 27.7	18.0± 4.4	18.6± 8.2	16.6± 4.9	8.9±7.3	18.7± 7.4	18.1± 7.6	18.4± 15.4	14.9± 7.3	9.4±5.8

Note: *** $p < 0.0001$ (Kruskal-Wallis test).

to the farmland soils. The addition of easily dissolved minerals caused in a longer perspective significant consequences for the environment, eutrophication, and over-fertilization. The addition of nitrogen reduces the role of other nutrients, including the base cations, limiting the cation exchange, and phosphorus (P) (Małek and Astel, 2009; Yang, Zhu, Gu, Yu, Wang, 2015). The carbon (C) cycling is obtaining increasing attention. However, the crucial C/N dependence is less analyzed and its relation to increased N deposition is not considered in detail in the site-specific approach (Cusack, Silver, Torn, Burton, Firestone, 2011; Sinsabaugh, Gallo, Lauber, Waldrop, Zak, 2005). The research performed by Band et al. (2022) showed that anthropogenic (mainly agriculture over NPK fertilization) eutrophication is an increasing danger to global diversity (Bobbink et al., 2010; Sala et al., 2000; Stevens et al., 2010). According to Band et al. (2022) results, eutrophication (mainly the nitrogen presence increase) is the strong factor causing plant species loss in vegetation patches worldwide (Band, Kadmon, Mandel, DeMalach, 2022; Berg, Mineau, Rogers, 2016). The increase in nitrification and decrease in ammonification suggest the N saturation condition in the soil (Falkengren-Grerup, Brunet, Diekmann, 1998; Tafazoli, Hojjati, Jalilvand, Lamersdorf, 2019; Yan et al., 2008).

The mechanisms governing the availability of the resources that are linked to the decrease in plant species richness and the amount of biomass material are not recognized (DeMalach and Kadmon, 2017; Grace et al., 2016; Harpole et al., 2017). The decline of species richness in the ecosystems characterized by high nutrient availability has been explained by an increase in biomass. Some researchers suspected that the increase in biomass material resources caused the increase in interspecific competition (Grime, 1973; Newman, 1973). As a result, the biomass-driven competition hypothesis has been presented. The biomass-driven competition hypothesis implies that the high level of resources and nutrients in the ecosystem habitat provides a competitive advantage for more fast-growing plant species. It is suggested that this mechanism causes the exclusion of the smaller and slow-growing plant autotrophic plant species from the assembly (Aerts, 1999; Rajaniemi, 2003). Such exclusion is related to competition for light in the first place (Hautier, Niklaus, Hector, 2009).

The opposite results obtained in the presented study might be related to the fact that the studied coal mine heaps are isolated systems, being a kind of environmental island. In this respect, the constructions of post-coal mine mineral heaps might be governed by distinctive processes. The environmental islands have been studied for many years. The environmental islands with lower habitat heterogeneity are governed mostly by stochastic processes. The low environmental heterogeneity might be the reason why the environmental filters are weak, and the species sorting is not the most relevant (Boet, Arnan, Retana, 2020).

The phosphorus (P) element availability is linked to N dynamics, as the P cycle is significantly related to the N cycle (De Groot, Marcelis, Van Den Boogaard, Lambers, 2001). In the not disturbed habitats and ecosystems, such as forest ecosystems, the availability of P is regarded as being the second limiting parameter following the available N (Aber, Nadelhoffer, Steudler, Melillo, 1989). In the presented study, the analysis showed that P significantly positively enhanced the amount of biomass material in the recorded vegetation community types observed on the mineral soil substratum of the studied coal mine heaps novel ecosystem. As a consequence of the available phosphorus presence, the activity of soil enzymes including the base and acidic phosphatase is positively linked to the amount of biomass material established in the spontaneous vegetation patches growing on the man-made mineral material heaps. Phosphorus is considered as a significant but restricted abiotic factor linked to the process of oxide exchange. The exchangeable cations are enabling the release of hydroxyl ions in most of the studied ecosystems (Helfenstein, Tamburini, et al., 2018; Hou et al., 2020; Zhang, Shi, Wen, Yu, 2016). The inorganic mineral phosphorus in varied forms can enrich the soil P bioavailability (Bünemann, 2015; Helfenstein, Jegminat, McLaren, Frossard, 2018; Oberson and Joner, 2005; Rosling et al., 2016; Walker and Syers, 1976). The presence of phosphorus influences the increase of microbial biomass and litter nitrogen, leading to the limitation of nitrogen mineralization (Chen, Dong, Yao, Wang, 2018; Homeier et al., 2012). In this way, the soil acidity is limited. This might suggest that the additional phosphorus acts as a buffering factor and keeps the soil pH stable (Mao et al., 2016; Yang et al., 2015; Zarif, Khan, Wang, 2020).

The carbon in the heap soil substrate and the amount of biomass material

The carbon (C) cycling in the ecosystems is crucial, mostly because it is linked to the increase in nitrogen N deposition (Cusack et al., 2011; Sala et al., 2000). Nitrogen carbon and phosphorus cycles are dependent on each other in soils of varied ecosystems, including forest belowground systems. Nitrogen, carbon, and phosphorus cycles take part in the cycles of other elements, influencing the plant species composition and diversity of vegetation (Fahey et al., 2013; Tafazoli et al., 2019; Zarif et al., 2020). The results of a study conducted in forest ecosystems can imply the probability that in the novel ecosystems developed on mineral coal mine soil substratum, the C: N ratio governs the biochemical uptake of available N in plants. This suggests that the mineral habitat conditions influence the biochemistry of the biomass material established in the studied vegetation types (Eberwein, Shen, Jenerette, 2017; Zarif et al., 2020). In the forest ecosystems soils, acidification causes the leaching of base cations Ca > Na > Mg > K. The leaching of base cations can result in reductions of the base cation budgets and, as a consequence, an imbalance of metal ions in soils (Lu, Mao, Gilliam, Luo, Mo, 2014; Lucas et al., 2011). In the presented study, the base cations enhance the amount of biomass materials due to the positive and significant correlation with the established amount of biomass material, both of the dominant and non-dominant plant species.

The mineral soil substratum texture impact on the amount of biomass material

In the presented research, the texture of the mineral material soil substratum parameter is not significant and is not presented in the result section. Studies show that texture, especially the finest particles, has an impact on the soil processes. The leaching of nitrate because of a weak connection to soil particles (i.e., negative charge on clay particles) causes the decline in soil pH and base cations (Jenkinson, 1990; Lu et al., 2009; Wang, Dalal, Moody, Smith, 2003).

The fine particle heterogeneous clay has an impact on C decomposition and the dynamic models of the soil organic carbon alternation (Hassink, 1997; Müller and Höper, 2004; Six, Elliott, Paustian, 2000). The aggregated clay frequently increases the soil or soil substratum moisture parameters. The wetter the soil or soil substratum, the slower the decomposition of SOC and the C inputs to soils or soil substratum influence the plant biomass material productivity (Six et al., 2000).

The clay particle participation influences the soil or soil substratum nutrient cycling, especially the nitrogen (N) mineralization, although the mechanisms of the impact are not clear. The relations might be strongly dependent on the temperature and water or moisture conditions (Coã Teâ, Brown, Pareâ, Fyles, Bauhus, 2000; Giardina, Ryan, Hubbard, Binkley, 2001; Schimel, 1986). In the presented study, the lack of significant dependence on the texture of the established amount of biomass material of the recorded spontaneous vegetation types developing on novel ecosystems of coal mine heaps can be related to the fact that most of the studied patches grew on highly mineral stony or gravel soil substrate. The indirect impact can be revealed in the significant links of the soil organic matter (SOM) and the amount of biomass material established by the *Melilotus alba* vegetation type.

The water soil content and the biomass amount

The moisture gradient is considered to be one of the strongest that governs all the processes in the natural and semi-natural ecosystems under the conditions of terrestrial systems. The moisture gradient is shaping the plant species community composition and the ecosystem functions, including the amount of biomass material (Fodelianakis et al., 2019; Isabwe et al., 2019; Jiao, Yang, Xu, Zhang, Lu, 2020).

In our study, the parameter of the water holding capacity was measured as the amount of biomass material that could be related to the water content in the habitats of the spontaneous vegetation types of coal mine heap novel ecosystem. In the presented study, the amount of biomass material of the dominant species and the accompanying, non-dominant species, is negatively correlated with the WHC abiotic parameter.

Studies present that the observed reduced precipitation has caused the decline in the plant biomass material amount and promoted plant diversity along with heterotrophs, such as insects (Knapp et al., 2002; Xu, Sherry, Niu, Li, Luo, 2013). The study was conducted in grasslands which cover rocky slopes, but provide many ecosystem services, including slope stabilization, erosion protection, livestock forage, and carbon sequestration service due to biomass material (White, Murray, Rohweder, 2000).

There is an agreement that lack of water and moisture in the soil cause the limitations in the primary production and the biomass material amount of plants and other autotrophs (Heisler-White, Blair, Kelly, Harmoney, Knapp, 2009). The deficiency of water in the vegetation patch habitat of an ecosystem changes the plant nutrient quality by increasing the amount of biomass material produced by the drought-resistant C4 plants and limiting the amount of biomass material of C3 plants (Heisler-White et al., 2009). This change in plant species composition of the vegetation leads to ecosystem-level balance modification caused by the plant quality composition due to higher lignin and lower plant tissue nitrogen content (Caswell, Reed, Stephenson, Werner, 1973; Tscharntke and Greiler, 1995). The lack of water can intensify the concentration of elements in individual plants that are facing water stress (Franzke and Reinhold, 2011; Grant, Kreyling, Dienstbach, Beierkuhnlein, Jentsch, 2014). Water deficiency might cause stress and decrease plant defense abilities (Gutbrodt, Mody, Dorn, 2011; Jamieson, Trowbridge, Raffa, Lindroth, 2012; Mattson and Haack, 1987). All these factors affect the biochemistry and construction of biomass material characteristics and amount. It is crucial to understand and be aware of the natural potential abilities of applications.

Amount of plant biomass material in response to salinity stress EC

Photosynthesis is the fundamental process in which biomass is established. Among the crucial environmental conditions necessary for the photosynthesis process to be completed, only abiotic parameters, including water deficiency and soil salinity, are the limiting factors of biomass material production. The responses of individual plants to abiotic factors including stress are of high researcher's interest. The studied vegetation communities developing on the mineral material habitats of coal mine heaps are under both salinity and drought stress. In the conducted study of the vegetation communities, the water-holding capacity is significantly negatively related to the biomass amount of both the non-dominant and the dominant plant species. This might be connected with the fact that the composition of the minerals on heaps, such as, e.g., montmorillonite, can store a lot of water in its tiny layers.

Plant species in vegetation communities in natural and semi-natural ecosystems are susceptible to the changes caused by salinity or drought and generally do not adapt quickly (Lane and Jarvis, 2007). The adaptation processes in individual plants include processes ranging from anatomy, and morphology, to physiology biology and molecular adjustments (Mittler, 2006). Abiotic stresses can influence plant organisms in many ways. The amount of plant biomass material is the weight of plant parts that are above (shouts and leaves) and the (root system) below, the ground. Measured as the weight of organic matter or biomass assimilated by the plant species composition of a community or species on an area of land in a particular unit of time (Roberts, Long, Tieszen, Beadle, 1985).

Exchangeable cations and acidity in relation to the biomass amount

Exchangeable cations are crucial in the soil or soil substratum of the ecosystem functioning. The exchangeable cations are this part of soil elements that can be exchanged by a cation coming from an additional salt solution (Ramos et al., 2018). In the presented study conducted on the coal mine heaps, the admixture of vermiculites and montmorillonite in the mineral substrate was recorded and the most frequently recorded type of acidity – the H ions obtained from the hydrolysis – was measured in the study (Ramos et al., 2018).

In the presented study, the presence of Na^{+} and Ca^{+} was positively correlated with the amount of biomass material of the individuals of the dominant species. The base cations crucial for exchangeable cations along with P dynamics, and soil acidification are related to increased N deposition. These soil characteristics are good ecochemical indicators for soil health and to assess soil acidification (Binkley and Giardina, 1998; Futa and Mocek-Płóciniak, 2016). The soil chemical properties, including exchangeable cations and soil acidity, are related to the chemical and biochemical interactions with the vegetation communities as well as its herb and tree plant species composition (Binkley, Burnham, Lee Allen, 1999; Rhoades, 1996), and the other way around – the changes in the global and local environment factors as well as habitat conditions may determine the composition and diversity of plants communities (Bardgett, Bowman, Kaufmann, Schmidt, 2005; Shi et al., 2016; Zarif et al., 2020). The research performed in forest vegetation showed that the exchangeable soil cations including K^{+}, Mg^{2+}, and Ca^{2+} have not been affected by the additional P input (Bolan, 1991). The increased P addition increased the soil exchangeable base cations (Sinsabaugh et al., 2005).

CONCLUSIONS

The following abiotic habitat conditions: pH, EC, the WHC, the texture of the soil substratum, basic abiotic N, C, Mg, Na, and exchangeable cations (acidity) were studied related to the amount of biomass material established in the spontaneous vegetation types identified on the coal mine heaps novel ecosystem. The ecosystem functioning (ecosystem services) of the herbaceous vegetation was considered as the prerequisite for further developed tree stands and forests.

In particular, the authors tested which of the abiotic habitat conditions influence the biomass amount most significantly. It was hypothesized that the nitrogen content would influence the amount of biomass material. The other abiotic parameters, such as the texture of the soil substratum, the WHC, pH, and EC were not significant parameters influencing the amount of biomass material in the recorded vegetation types.

The analysis performed for the amount of biomass material of the dominant and non-dominant species revealed that the nitrogen content is unexpectedly negatively correlated with the soil substratum total nitrogen. A negative correlation was also stated for carbon content, and water holding capacity. The amount of biomass material of the dominant species is positively related to the available phosphorus (basic and acid phosphatase), pH, calcium, and sodium content. The presented study showed that the non-analogous species composition of the novel ecosystems on the mineral material habitat of the coal mine heaps novel ecosystems results in some unexpected relations between the abiotic habitat factors and the amount of the established biomass.

Additionally, the revealed connections between the biomass of dominant species and available phosphorus, pH, calcium, and sodium underscore the unique dynamics of modern ecosystems on mineral habitats of coal mine heaps, challenging traditional assumptions. The discovery of relationships between abiotic factors and biomass levels provides a robust foundation for strategic planning in the utilization of coal mine heaps, taking into account key elements, such as soil substrate composition, nutrient content, and moisture levels.

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