

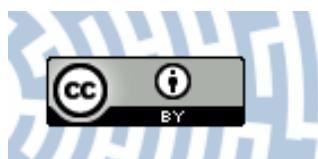


You have downloaded a document from  
**RE-BUŚ**  
repository of the University of Silesia in Katowice

**Title:** Relationship Between Compositions of Grey Hair-Grass (*Corynephorus Canescens* (L.) P. Beauv.) Tissues and Soil Properties During Primary Vegetation Succession

**Author:** Oimahmad Rahmonov, Jacek Różkowski, Artur Szymczyk

**Citation style:** Rahmonov Oimahmad, Rozkowski Jacek, Szymczyk Artur. (2019). Relationship Between Compositions of Grey Hair-Grass (*Corynephorus Canescens* (L.) P. Beauv.) Tissues and Soil Properties During Primary Vegetation Succession. "IOP Conference Series, Earth and Environmental Science" (Vol. 362 (2019), art. no. 012009, s. 1-10), doi 10.1088/1755-1315/362/1/012009



Uznanie autorstwa - Licencja ta pozwala na kopowanie, zmienianie, rozpowszechnianie, przedstawianie i wykonywanie utworu jedynie pod warunkiem oznaczenia autorstwa.

# Relationship Between Compositions of Grey Hair-Grass (*Corynephorus Canescens* (L.) P. Beauv.) Tissues and Soil Properties During Primary Vegetation Succession

Oimahmad Rahmonov <sup>1</sup>, Jacek Rozkowski <sup>2</sup>, Artur Szymczyk <sup>1</sup>

<sup>1</sup> Department of Physical Geography, Faculty Earth of Sciences, University of Silesia in Katowice, Będzińska 60, 41-200 Sosnowiec, Poland

<sup>2</sup> Department of Hydrogeology and Engineering Geology, Faculty Earth of Sciences, University of Silesia in Katowice, Będzińska 60, 41-200 Sosnowiec, Poland

oimahmad.rahmonov@us.edu.pl

**Abstract.** This study focuses on the concentration of trace-, microelement- and organic components in initial horizons of sandy soil (Arenosole) and of the tissues of *Corynephorus canescens*, a pioneer species typical of unstable environments that initiates pedogenic processes by enriching poor quartz sand in organic- and mineral matter from its own tissues. Soil samples were taken from a root-zone humus horizon (A) averaging ~15 cm in thickness and from parent rock. Concentrations of Ca, Mg, K, Na, Fe, Si, Al, Zn, Mn, Co, Cd, Pb, Sr, Mo, C, N and P in plant material and soil were analyzed. High concentrations of Si ( $6368 \pm 16.3$  mg·kg<sup>-1</sup>), K ( $2310 \pm 165.2$ ), Ca ( $302 \pm 24.6$  mg·kg<sup>-1</sup>), Fe ( $2196 \pm 316.3$ ) are found in the above-ground part of the plant whereas Si ( $9150 \pm 20$ ), Fe ( $5948 \pm 43$ ), K ( $3752 \pm 3.21$ ) and Al ( $2370 \pm 52.6$  mg·kg<sup>-1</sup>) dominate in the roots. Soil organic carbon (OC) contents in the humus horizon and in parent rock are  $0.276 \pm 0.041$  and  $0.206 \pm 0.041\%$ , respectively. The concentration of nitrogen in the humus horizon shows a high (0.92) correlation with OC. The soil shows both acid ( $4.2 \pm 0.51$  in KCl) and low-acid ( $5.1 \pm 0.23$  in H<sub>2</sub>O) characteristics. Heavy-metal contents differ significantly among the study sites. Organic compounds of *Corynephorus canescens* and of soil organic matter (SOM) were investigated by pyrolysis-GC/MS (Py-GC/MS). In the organic content of the grey hair-grass tissues, typical compounds such as normal chain aliphatics (29%), and furane- and pyrane derivatives (12%), dominate. Nitrogen-containing substances such as amines, nitro compounds, heterocycles and amines are also important (27%). The main ecopedological role of *C. canescens* involves the fixing of loose sand thanks to its well-developed root system. The xeromorphic structure of stems and leaves allows it to function in such extreme open areas of unstable ground and high insolation. The initial stage of the formation of a humus horizon involving *Corynephores canescens* is documented.

## 1. Introduction

Drifting sands in many regions of Europe are the result of human over-exploitation (logging, sod-cutting, over-grazing) of many ecosystems. The most important association of inland- and coastal sand dune regions is the *Spergula morisonii-Corynephoretum canescantis* association, often with the contribution of lichens initiating the colonization of vary poor sandy ecosystems [1,2,3,4]. One of the habitats of most interest regarding sandy vegetation is the dry acidophilous grassland dominated by *Corynephorus canescens* (L.) P. Beauv., which is attributable to habitat 2330 (inland dunes with open *Corynephorus* and *Agrostis* grasslands) of the Directive 1992/43/EEC [4].

*Corynephorus canescens* is the main species which builds *Spergulo morisonii-Corynephoretum canescantis* assemblages. This species is common in lowlands and is recognized as an Atlantic species [5,6,7]. The natural *Corynephorus*-grassland grows mainly in acidic sand and oligotrophic sandstone but the particular species grey hair-grass also develops on slightly basic dunes. It also occurs on sands of various origins in coastal and inland areas. It is well adapted to areas poor in nutrients [7,8,9,10]. Low pH, poor nutrient status (e.g., N and P) and low field water capacity of the soil results in this habitat being unfavorable for most vascular plant species. The sparse cover of vascular plants leaves space for less competitive cryptogams well adapted to these adverse conditions [11, 12].

*Corynephorus canescens* should be considered as a species initiating the first stage of vegetation succession and soil development. It develops well on loose sands where the lability of ground is a more important factor than nutrient deficiency limiting plant encroachment [13]. Such examples have been observed in sandy areas of the eastern part of Silesian Upland where, in natural conditions, a limited number of seeds are covered with sand. Germination and development of seeds often occurs along hollows of various origin (e.g., vehicle ruts), which facilitate seed tenacity and the development of vegetation. A second factor allowing colonization of loose sand by pioneer species is trampling. This is a significant ecological factor as it leads to an increase in the effectiveness of generative plant reproduction due to the compaction of seeds under the surface of the sand, i.e. into the zone where conditions for more favorable for sprouting.

The morphology of grey hair-grass is strictly dependent on types of ground and the vegetation-cover density. Clumps are larger when the specimens are not surrounded by other more vigorous and extensive species. In the company of other plants, this grass usually occurs in a less extensive form. The elimination of *Corynephorus canescens* in the late stages of succession due to colonization of other competing species has been demonstrated by Rychnowská–Soudkowá [14].

*C. canescens* as a species creating and occurring in initial ecological systems has been described in detail in ecological terms (contribution in succession) and from the phytosociological point of view. However, not much work has been devoted to the role of this species in the formation of soil cover and the enrichment of habitats with organic compounds [15,16] and minerals [17]. This process involves the decomposition of above- and underground tissues of *C. canescens* and the fixing of loose sand. The released organic- and mineral components resulting are the food base for many microorganisms, and of other late successional species entering in the following years. Below, this study focuses on the concentration of traces and macroelements, and on the organic components, in the initial horizons of sandy soil (*Arenosole*) and in the tissues of *Corynephores canescens* on sandy ecosystem.

## 2. Material and methods

### 2.1. Study area

The research was conducted in the eastern part of the Silesian Upland (southern Poland) in areas where the natural forest was grubbed up and which are characterized by varying aeolian processes of differing intensities. Since the sub-boreal period (5100 BP), the area has been covered by mixed forest with *Pinus sylvestris* as the dominating species [18]. The main parent rocks of the soils are proluvial- and aeolian sands [19]. Rich only in quartz, they are very poor in the potential nutrients essential for vegetation. They are characterized by a low water capacity, limited compactness and high permeability. In such incipient soil, *Corynephorus canescens* develops and initiates fixing of the loose substrate.

### 2.2 Sampling

Samples for chemical analyses were taken from the humus horizon (A) averaging ~15 cm in thickness which represents the main rooting zone of *C. canescens*. The parent rock was also sampled. The analyzed soil generally has an A-C, AC-C or A/C profile structure. Samples were taken in 3 replications from 3 communities.

In the laboratory, air-dried samples were sieved (<2 mm) and analyzed following the standard procedures of Bednarek et al. [20], namely, pH was measured potentiometrically in H<sub>2</sub>O and in 1N

KCl using a glass electrode, total organic C (%) according to Tiurin's method and total N content (%) using the Kjeldahl method in soil and plant [21].

Leaves, stems and the head of *C. canescens* were sampled at the end of the vegetation season (late September and early October). Latex gloves were used to isolate sampled plant material from human skin. The preliminary preparation of the samples for analyses involved washing of the plant material with distilled water, drying at room temperature and at 105°C and homogenization. Concentrations of Ca, Mg, K, Na, Fe, Si, Al, Zn, Mn, Co, Cd, Pb, Sr, Mo and P in plant material and soil were measured using ICP-OES (Inductively Coupled Plasma Optical Emission Spectrometry) after a wet mineralization in nitrohydrochloric acid (3HCl+HNO<sub>3</sub>). The analyses were made by AcmeLabs (Canada).

All plant and soil samples were analyzed in triplicate. The Spearman correlation rank was applied to check whether there is any relationship between the concentrations of metals in the *C. canescens* plant tissues and in the soil samples.

### 2.3 Analytical conditions of the Curie-point Py-GC/MS

A Curie-point Pye-Unicam pyrolyser (type 795050) working at 770°C was coupled to a Hewlett-Packard gas chromatograph with a HP-5 column (60 m x 0.32 mm x 0.5 µm). The experimental conditions were as follows: carrier gas – He at 15 psi pressure; carrier gas split ratio 1:15; temperature program: 40°C and final temperature 260°C held for 16 min. The mass spectrometer was operated in the electron impact ionization mode at 70 eV and scanned from 30-500 da (full scan). Data were processed using the Hewlett Packard Chemstation software. All compounds were identified by their mass spectra, comparison of peak retention times with those of standard compounds, reference to literature data, and by interpretation of MS fragmentation patterns [15,16]. The main pyrolytic products are given in tables 3 and 4

## 3. Results and discussions

### 3.1 Elemental composition

The chemical composition of tissues is often reflected in the morphology of single species and indicates environmental conditions, including contents of macronutrients and heavy metals. The ecological characteristics of terrestrial vegetation have long been used as an indicator of soil environment [22]. The species studied here has developed on quartz sands deficient in nutrients. The fact that these sands are dominated by silicate and aluminosilicate is reflected in the contribution of silicon (Si) in the tissues *Corynephorum canescens*, both in the aboveground- and underground parts. High concentrations (in mg·kg<sup>-1</sup>) of Si (6368±16), K (2310±165.2), Ca (302±24.6) and Fe (2196±316.3) occur in the aboveground part of plant whereas the roots are dominated by Si (9150±20), Fe (5948±43), K 3752±3.21 and Al (2370±52.6).

In the aboveground tissue of *C. canescens*, the highest concentrations of heavy metals are those of Zn (351±10.3), Mn (55±6.03), Pb (26.1±0.9), Sr (9.40±1.98), Co (5.36±0.37), Mo (4.12±9.03) and Cd (2.72±0.56) whereas, in underground parts, Pb (43.61±0.70), Mo (16.86±0.65), Sr (10.23±0.61), Co (6.26±0.05) and Cd (2.42±0.42).

The roots of *Corynephorum canescens* are more delicate (thin and long) than the roots of *Koeleria glauca* that commonly occurs with it. Because of its xeromorphic stalk and well-developed root system, this species tolerates backfilling processes. Because of its vertical growth and release of adventitious roots, *Corynephorum canescens* develops better when buried [8,23]; in this way, it increases the root mass and, thus, the organic- and mineral potential of soils.

The humus horizon (A) and parent rock (C) of the initial sandy soil under *Corynephorum canescens* are characterized by high large concentrations of Al (4446±112.5), K (2310±165.2) and Fe (2196±316.3) and low concentrations of Mn (57±11.6, 28±7.8); table 1).

**Table 1.** Average concentrations (n=5) of elements in soil and in tissues of *Corynephorus canescens*.

Ca	Mg	K	Na	Fe	Al	Zn	Mn
[mg·kg <sup>-1</sup> ]							
Soil: humus horizon (A)							
302±(24.6)	253(±32.1)	2310±165.2	647(±30.5)	2196(±316.3)	4446(±112.5)	316(±240)	57(±11.6)
Soil: parent rock (C)							
216(±20.9)	132(±7.6)	2283(±104)	631(±36.3)	1179(±20.6)	5516(±102)	75(±13.2)	28(±7.8)
Plant: above ground parts of <i>C. canescens</i>							
3405(4.55)	1449(±16)	6342(±3.51)	119(±0.58)	1858(±7.94)	475(±8.72)	351(±10.3)	55(±6.03)
Plant: Below-ground parts							
1728(±3.0)	605(±2.47)	3752(±3.21)	488(±2.52)	5948 (±43.7)	2370(±52.6)	303(±7.37)	145(±9.50)

Soil organic carbon (OC) contents in the humus horizon (A) and in the parent rock (C) are  $0.276\pm 0.041\%$  and  $0.206\pm 0.021\%$ , respectively. The concentration of nitrogen in the humus horizon shows a high (0.92) correlation with OC. A positive correlation (0.29) observed between nitrogen in the humus horizon (A) and phosphorus in the parent rock (C) and correlations between P and Ca (0.78), P and K (0.79), P and Zn and P and Al (1.00) in the humus horizon are clearly linked to the capacity of the humus horizon. The soil is acid ( $4.2\pm 0.51$  in KCl) or low acid character (in H<sub>2</sub>O  $5.1\pm 0.23$ ). Heavy metal contents differ significantly among the study sites and are typical for sands (table 2).

**Table 2.** Relationships between some elements in soil and tissues of grey hair-grass.

OC [%]	Nt	P [mg·kg <sup>-1</sup> ]	pH H <sub>2</sub> O	pH KCl	C [%]	N	P [mg·kg <sup>-1</sup> ]
Humus horizon (A)							
Tissues of <i>C. canescens</i>							
0.276(±0.041)	0.298(±0.46)	345(±5.5)	5.1(±0.23)	4.2(±0.51)	48.8(±1.71)	0.761(±0.01)	1059(±28.6)
Parent rock (C)							
Roots							
0.206(±0.041)	0.009(±0.001)	293(±20.9)	4.7(±0.057)	4.3(±0.11)	28 (±1.76)	0.38(±0.02)	484(±21.8)

For a growth of *C. canescens*, an open sandy substratum which is unstable is much more significant than the pH value; this grass can autonomously regulate the soil pH by its root system [9] as results of their decomposition. A similar situation was observed in the current work.

Plant litter incorporated into the soil or deposited on the soil surface enriches the substrate in organic substances. This is one of the most important ways in which plant habitats form; basic matter and energy to the saprophytic components of biocenosis is thus provided. The activity of saprophytes, in turn, affects the edaphic conditions of plant growth, e.g., moisture ratios, the content of mineral nutrients, aeration of the soil and its reaction. These are very important biological- and biochemical processes that determine the rate of development of the initial ecological system.

Sands consist mainly of quartz and, hence, contain only small proportions of nutrients such as phosphorus, magnesium and nitrogen. The ranked order of elements in terms of their concentrations in above-ground/underground parts of *C. canescens* and in the soil and rock beneath is as follows:

Above-ground parts	Si>K>Ca>Fe>Mg>P>Al>Zn>Na>Mn>Pb>Sr>Co>Mo>Cd
Below-ground parts	Si>Fe>K>Al>Ca>Mg>Na>P>Zn>Mn>Pb>Mo>Sr>Co>Cd
Humus Horizon (A)	Al>K>Fe>Na>P>Zn>Ca>Mg>Mn
Parent rock (C)	Al>K>Fe>Na>P>Ca>Mg>Zn>Mn

A minimum amount of nutrients is of much importance for colonizing organisms. Incorporated plant material is the main source of nourishment for plants in areas with mobile sands. As already noted, *Corynephorus canescens* has a xeromorphic stem that protects this species from water loss.

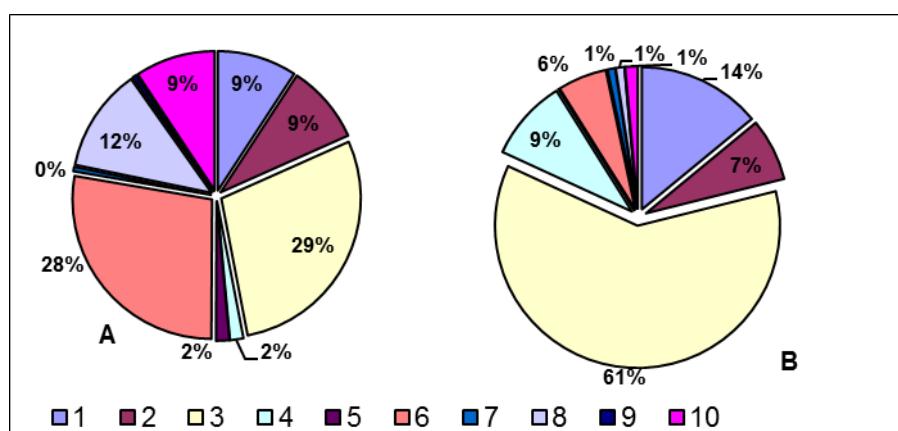
Thanks to this ecological feature, transpiration during drought can be completely stopped. If there is enough moisture in the sand, transpiration increases relatively quickly [14,24]. With unshaded sunlight, and wind dispensing of seeds, *Corynephorus canescens* can colonize a bare sandy substrate within 2-3 years under favorable conditions [5].

### 3.2. Organical composition of *Corynephorus canescens*

*Corynephorus* tissues are dominated by aliphatic compounds with unbranched hydrocarbons dominating (28%; Figure 1A). These compounds are derivatives of cutin and suberin. Cutin occurs together with wax on the surfaces of the leaves and fruits of flowering plants. It is more resistant than wax to weathering and biological degradation. It accounts for 50-90% of cuticle and its formation is stimulated by intensive exposure of plants, water loss and raised temperatures. Suberin found inside the secondary cells of the covering tissue fulfills a similar role to wax and cutin.

Nitrogenous compounds represented by amines, nitro compounds, heterocyclic compounds and, less commonly, by imines are also significant components in *Corynephorus* tissues (Tables 3,4).

*Corynephorus* tissues have a much higher content of aromatic compounds of lignin origin compared to cryptograms plants. In pyrolysis products, compounds such as toluene, vanillin, benzene, phenole, p-cresol or 2-metoksy-4-vinylphenol, etc., are found. Also noteworthy are derivatives of furan and piran (9.31%; Fig. 1A). Compared to cryptogam plants, there are far fewer carbohydrate derivatives and sulfur-containing compounds [16].



**Figure 1.** Percent participation of organic compounds in the above-ground part of *Corynephorus canescens* (A) and in the humus horizon (B): 1 – aliphatic branched compounds, 2 – alicyclic compounds, 3 – aliphatic unbranched compounds, 4 – aromatic compounds, 5 – derived carbohydrates, 6 – N-containing compounds, 7 – S-containing compounds, 8 – phenols, 9 – prenyl derived, 10 – furan- and piran derived.

In the organic material from the humus horizon, aliphatic compounds prevail (82%). The share of aromatic compounds (9%) and compounds containing nitrogen (6%) is limited. These mentioned compounds may originate from the decomposition of the above-ground part of *Corynephorus* and of its roots in the mineral layer. The pyrolytic products of the organic humus material from *C. canescens* (Fig 1B) are similar to those of the humus horizon of *Polytrichum piliferum* [16]. Despite its initial character, the soil is rich in organic compounds mainly originating from the root mass distribution. The roots of the analyzed species reach sometimes up to 20 cm on the deflation field, while on hills it can be up to 1 meter and more.

Rychnovská-Soudková [22] records values for root respiration in *Corynephorus* higher than that of any other dune plants and noted that its disappearance at later stages in the succession may be due to decreased aeration inhibiting root growth. Such was confirmed by others [5,7]. This species prefers

non-fixed sand habitats. Plant litter from *Corynephorus canescens* and other plants is transported by the wind.

**Table 3.** Organic compounds from the above-ground part of *Corynephorus canescens* identified by Py-GC/MS

Nr.	Compound	Area of peaks in %	Molecular weight	Formula
1.	Dimethylamine	4,98	45	C <sub>2</sub> H <sub>7</sub>
2.	Butane	4,72	58	C <sub>4</sub> H <sub>10</sub>
3.	1-Propanol	8,98	60	C <sub>3</sub> H <sub>8</sub> O
4.	Ethanol	1,91	60	C <sub>2</sub> H <sub>4</sub> O <sub>2</sub>
5.	Ethylhydrazine oxalate	2,63	60	C <sub>2</sub> H <sub>8</sub> N <sub>2</sub>
6.	Ethylic acid	1,17	60	C <sub>2</sub> H <sub>4</sub> O <sub>2</sub>
7.	Toluene	1,17	92	C <sub>7</sub> H <sub>8</sub>
8.	Acetyl urea	1,94	102	C <sub>3</sub> H <sub>6</sub> N <sub>2</sub> O <sub>2</sub>
9.	N-Methyl-L-alanin	1,16	103	C <sub>4</sub> H <sub>9</sub> NO <sub>2</sub>
10.	Methyl 2-oxopropanoate	3,25	102	C <sub>4</sub> H <sub>6</sub> O <sub>3</sub>
11.	2-Furancarboxaldehyde	1,11	96	C <sub>5</sub> H <sub>4</sub> O <sub>2</sub>
12.	3-Furancarboxaldehyde	2,88	96	C <sub>5</sub> H <sub>4</sub> O <sub>2</sub>
13.	1-Cyclopropylacetone	2,01	98	C <sub>6</sub> H <sub>10</sub> O
14.	2-Oxepanone, 7-methyl-	1,49	128	C <sub>7</sub> H <sub>12</sub> O <sub>2</sub>
15.	2-Methylcyclopentanone	2,73	98	C <sub>6</sub> H <sub>10</sub> O
16.	1,4-Dimethyl-3-pyrazolidinon	1,87	114	C <sub>5</sub> H <sub>10</sub> N <sub>2</sub> O
17.	Caprolactone	1,72	114	C <sub>6</sub> H <sub>10</sub> O <sub>2</sub>
18.	Phenol	3,19	94	C <sub>6</sub> H <sub>6</sub> O
19.	3,4-Dihydroxy-3-cyclobuten-1,2-dion	1,85	114	C <sub>4</sub> H <sub>2</sub> O <sub>4</sub>
20.	Triethylenediamine	1,19	112	C <sub>6</sub> H <sub>12</sub> N <sub>2</sub>
21.	N,N'-Dimethylpiperazine	1,91	114	C <sub>6</sub> H <sub>14</sub> N <sub>2</sub>
22.	Butanal, ethylhydrazone	1,21	114	C <sub>6</sub> H <sub>14</sub> N <sub>2</sub>
23.	2-Methoxyphenol	2,39	124	C <sub>7</sub> H <sub>8</sub> O <sub>2</sub>
24.	Glycyl-L-alanine	1,4	146	C <sub>5</sub> H <sub>10</sub> N <sub>2</sub> O <sub>3</sub>
25.	3-Methylendihydro-2,5-furandion	1,77	112	C <sub>5</sub> H <sub>4</sub> O <sub>3</sub>
26.	2-Methylbenzaldehyde	1,98	120	C <sub>8</sub> H <sub>8</sub> O
27.	2-Methoxy-4-vinylphenol	2,15	150	C <sub>9</sub> H <sub>10</sub> O <sub>2</sub>
28.	Methyl pentofuranoside	1,47	164	C <sub>6</sub> H <sub>12</sub> O <sub>5</sub>
29.	2-Amino-8-pentofuranosylimidazo[1,2-a][1,3,5]triazin-4(8H)-one	0,05	283	C <sub>10</sub> H <sub>13</sub> N <sub>5</sub> O <sub>5</sub>

Plant remains quickly buried in sand decompose to become the source of a variety of organic- and mineral compounds. They are a significant influence during the initial stages of the formation of soil organic matter. In the humus horizon, the contribution of nitrogen- and sulfur-containing compounds such as 7-Methyl-7-azabicyclo[2.2.1]hept-2-ene, 1H-azepine, hexahydro-1-nitroso, furane, 2-hydroxymethyl-5-nitro-, hydrazinecarbothioamide, 2-(1-methylpropylidene), thiazole, 4,5-dihydro-2-methylamino, 4-methyltetrahydrothiopyran and 3-Methyl 4,5-dihydrofuran-2(3H)-thione is significant (table 4). Nitrogen and phosphorus are deficient elements in the ecosystem, an ecosystem commonly associated with industrial areas. The deficiency in the initial ecosystem is remedied by the decomposition of plant tissues and by other sources, often anthropogenic [25,26].

Decomposed plant tissues of *Corynephorus canescens* are a very important nutrient source for a poor sandy ecosystem developing towards forest biocenosis in temperate and oceanic climates.

The results of this study suggest that the reduction of aeration in the soil is directly associated with the accumulation of humus. It is an important factor limiting the development of *Corynephorus canescens* and, driving its withdrawal as sand is stabilized and interspecies competition for nutrients and light intensifies.

**Table 4.** Organic compounds from the humus horizon under *Corynephorus canescens* identified by Py-GC/MS

Nr	Compound	Area of peaks in %	Molecular weight	Formula
1.	Valeraldehyde	29,34	86	C <sub>5</sub> H <sub>10</sub> O
2.	2-Methyl-1-propene	8,81	56	C <sub>4</sub> H <sub>8</sub>
3.	1- Propyne	12,48	40	C <sub>3</sub> H <sub>4</sub>
4.	(3E)-3-Penten-1-yne	2,05	66	C <sub>5</sub> H <sub>6</sub>
5.	2-Methylpropanal	1,33	72	C <sub>4</sub> H <sub>8</sub> O
6.	1-Hexene	1,94	84	C <sub>6</sub> H <sub>12</sub>
7.	Hexane	1,18	86	C <sub>6</sub> H <sub>14</sub>
8.	Benzene	2,41	78	C <sub>6</sub> H <sub>6</sub>
9.	2-Methyl-1,4-pentadiene	0,63	82	C <sub>6</sub> H <sub>10</sub>
10.	1-Heptene	1,29	98	C <sub>7</sub> H <sub>14</sub>
11.	Heptane	0,65	100	C <sub>7</sub> H <sub>16</sub>
12.	(3-Methylenecyclopentyl)methanol	0,41	112	C <sub>7</sub> H <sub>12</sub> O
13.	Toluene	4,26	92	C <sub>7</sub> H <sub>8</sub>
14.	trans-1-Butyl-2-methylcyclopropane	0,99	112	C <sub>8</sub> H <sub>16</sub>
15.	Styrene	1,4	104	C <sub>8</sub> H <sub>8</sub>
16.	(5E)-5-Undecene	0,78	154	C <sub>11</sub> H <sub>22</sub>
17.	7-Methyl-7-azabicyclo[2.2.1]hept-2-ene	1,99	109	C <sub>7</sub> H <sub>11</sub> N
18.	1-Nitrosoazepane	1,36	128	C <sub>6</sub> H <sub>12</sub> N <sub>2</sub> O
19.	1-Tetradecene	0,46	196	C <sub>14</sub> H <sub>28</sub>
20.	Hydrazinecarbothioamide, 2-(1-methylpropylidene)	0,83	145	C <sub>5</sub> H <sub>11</sub> N <sub>3</sub> S
21.	Thiazole, 4,5-dihydro-2-methylamino	0,42	116	C <sub>4</sub> H <sub>8</sub> N <sub>2</sub> S
22.	3-Methyl 4,5-dihydrofuran-2(3H)-thione	0,61	116	C <sub>5</sub> H <sub>8</sub> OS
23.	Cyclododecane	3,28	168	C <sub>12</sub> H <sub>24</sub>
24.	Heptane, 2,6-dimethyl-	0,41	128	C <sub>9</sub> H <sub>20</sub>
25.	(11E)-11,13-Tetradecadien-1-ol	0,43	210	C <sub>14</sub> H <sub>26</sub> O
26.	1-Hexadecene	0,84	224	C <sub>16</sub> H <sub>32</sub>
27.	6,11-Undecadiene, 1-acetoxy-3,7-dimethyl-	0,45	252	C <sub>16</sub> H <sub>28</sub> O <sub>2</sub>
28.	Isopropyl Palmitate	4,52	298	C <sub>19</sub> H <sub>38</sub> O <sub>2</sub>

Increasing humus and sand stabilization are limiting factors for the development of this plant association [27]. The retreat of *C. canescens* is an indicator of soil enrichment and, thus, the availability of support for further phases of the vegetation succession involving vascular plants with higher nutritional requirements.

#### 4. Conclusions

*Corynephorus canescens* is a pioneer species often initiating primary succession that plays a very important role in the formation of soil organic matter and the mineral enrichment of soil. A key phase in the development of sandy soils is the formation of organic- and humus horizons. This happens after the sand is fixed by this species.

During decomposition of *Corynephorus canescens* tissues, released CO<sub>2</sub>, NH<sub>4</sub><sup>+</sup>, NO<sub>3</sub><sup>-</sup>, PO<sub>4</sub><sup>3-</sup> and SO<sub>4</sub><sup>2-</sup>, become a nutrient source for growing plants. A significant contribution of nitrogen-containing compounds was identified; these undoubtedly influence the rates of vegetation succession and sandy-soil development.

The accumulation of soil organic matter is a most important soil-forming factor. The availability of nutrients in sandy ecosystems depends on an effective biogeochemical cycle within biogeocenosis by which organic components return to the soil in the form of plant litter. In poor sandy ecosystems, *C. canescens* participates significantly to this process, and crucially in the initial stage of succession.

### Acknowledgment(s)

The authors gratefully thank Dr. Pádraig S. Kennan (University College Dublin, Ireland) for his help in improving the English of this paper.

### References

- [1] A. Jentsch, S. Friedrich, W. Beyschlag, and W. Nezadal, "Significance of ant and rabbit disturbance for seedling establishment in dry acidic grasslands dominated by *Corynephorus canescens*," *Phytocoenologia*, vol. 32, pp. 553-580, 2002.
- [2] C. Pinto-Gomes, R. Paiva-Ferreira, E. Cano, and S. Mendes, "Pelouses psammophiles à *Corynephorus canescens* var. *maritimus* Godr. du centre et du sud du Portugal," *Acta Botanica Gallica*, vol. 153(3), pp. 341-354, 2006.
- [3] G. Gheza, S. Assini, M.V. Passadore, "Terricolous lichen communities of *Corynephorus canescens* grasslands of Northern Italy", *Tuexenia*, vol. 36, pp. 121-142, 2016.
- [4] S. Assini, "Vegetazione pioniera dei dossi della Lomellina (PV – Italia settentrionale)", *Fitosociologia*, vol. 44 (2) suppl.1, pp. 299-302, 2006.
- [5] K. Czyżewska, "Syntaksonomia śródlądowych, pionierskich muraw napiaskowych," *Monographiae Botanicae*, vol. 74, pp. 1-74, 1992.
- [6] M. Valachović, "Succession model with *Corynephorus canescens* in abandoned sandy fields (w Slovakia)," *Haquetia*, vol. 11(1), pp. 5-15, 2012.
- [7] O. Rahmonov, W. Oleś, "Vegetation succession over an area of a medieval ecological disaster. The case of the Błędów Desert, Poland," *Erdkunde*, vol. 64(3), pp. 241-255, 2010.
- [8] J.K. Marshall, "*Corynephorus canescens* (L.) P. Beauv. As a model for the Ammophila problem," *Journal of Ecology*, vol. 53, pp. 447-463, 1965.
- [9] M. Rychnovská-Soudková, "An outpost site of *Corynephorus canescens* in the region between the Danube and the Tisza and its causal explanation," *Acta Biologica Hungarica*, vol. 14(1), pp. 57-66, 1963.
- [10] O. Rahmonov, "The role of *Salix acutifolia* as an ecological engineer during the primary forest succession", *17th International Symposium on Landscape Ecology - Landscape and Landscape Ecology, Slovak Academy of Science, Inst Landscape Ecol., Landscape and Landscape Ecology*, pp. 312-318, 2016.
- [11] H. Thilo, F.J.A. Daniëls, "Species responses to experimentally induced habitat changes in a *Corynephorus* grassland," *Journal of Vegetation Science*, vol. 17, pp. 135-146, 2006.
- [12] O. Rahmonov, J. Cabała, R. Bednarek, D. Rożek, and A. Florkiewicz, „Role of soil algae on the initial stages of soil formation in sandy polluted areas," *Ecol Chem Eng S.*, vol. 22(4), pp. 675-690, 2015.
- [13] H. W. Chadwick, and P.D. Dalke, "Plant succession on dune sands in Fremont County. Idaho," *Ecology*, vol. 46, pp. 765-780, 1965.
- [14] M. Rychnovská-Soudková, "*Corynephorus canescens* (L.) P. Beauv. (physiologisch-ökologische studie einer pflanzenart)", *Rozpr. Českoslov. Akad. Věd.*, vol. 71, pp. 1-84, 1961.
- [15] K. G. J., Nierop, B. Van Lagen, and P. Buurman, "Composition of plant tissues and soil organic matter in the first stages of a vegetation succession," *Geoderma*, vol. 100, pp. 1-24, 2001.
- [16] O. Rahmonov, W.J. Kowalski, and R. Bednarek, "Characterization of the soil organic matter

- and plant tissues in an initial stage of plant succession and soil development by means of Curie-point pyrolysis coupled with GC-MS," *Eurasian Soil Science*, vol. 43(13), pp. 1557-1568, 2010.
- [17] M. Kulik, M. Warda, A. Król, M. Oleszek, A. Lipiec, T. Gruszecki, and W. Bojar, "Total protein and macroelement content in selected psammophilous grassland species under free-range sheep grazing in Kózki Nature Reserve," *Journal of Elementology*, vol. 22(1), pp. 183-193, 2017.
  - [18] I. Okuniewska-Nowaczyk, O. Rahmonov, V.A. Snytko, T. Szczypek, "Palynological record of the history of vegetation in the sandy areas of southern Poland," *Geography and Natural Resources*, vol. 39 (4), pp. 396-402, 2018.
  - [19] O. Rahmonov O., V.A. Snytko, and T. Szczypek, "Phytogenic hillocks as an effect of indirect human activity," *Zeitschrift fur Geomorphologie*, vol.53(3), pp. 359-370, 2009.
  - [20] R. Bednarek, H. Dziadowiec, U. Pokojska, Z. Prusinkiewicz, "*Badania ekologiczno gleboznawcze*". Warszawa, Polish Scientific Press, pp. 343, 2004.
  - [21] O. Rahmonov, J. Banaszek, K. Pukowiec-Kurda, "Relationships between heavy metal concentrations in Japanese knotweed (*Reynoutria japonica* Houtt.) tissues and soil in urban parks in southern Poland," *IOP Conference Series Earth and Environmental Science* 221, DOI: 10.1088/1755-1315/221/1/012145, 2019.
  - [22] I. F. Spellerberg, "Monitoring ecological change," Cambridge University Press, UK. pp. 391, 2005.
  - [23] J. K. Marshall, "*Corynephorus canescens* (L.) P. Beauv. Biological flora of the British Isles," *Journal of Ecology*, vol. 55, pp. 207-220, 1967.
  - [24] U. Berger-Landefeldt, and H. Sukopp, "Zur Synökologie der Sandtrockenrasen, insbesondere der Silbergrasflur," *Verh. Bot. Ver. Brandenburg*, vol. 102, pp. 41-98, 1965.
  - [25] J. Różkowski, K. Różkowski, O. Rahmonov and H. Rubin, "Nitrates and phosphates in cavewaters of Kraków-Częstochowa Upland, southern Poland," *Environmental Science and Pollution Research*, vol. 24 (33), pp. 25870-25880, 2017.
  - [26] J. Różkowski, K. Różkowski and O. Rahmonov, "Heavy metals in the unsaturated and saturated zone of the Upper Jurassic carbonate massif in the vicinity of Krakow," *Journal of Elementology*, vol. 20(2), pp. 395-406, 2015.
  - [27] O. Rahmonov, M.A. Rzetala, M. Rahmonov, E. Kozyreva, A. Jagus and M. Rzetala, "The formation of soil chemistry and development of fertility islands under plant canopies in sandy areas," *Research Journal of Chemistry and Environment*, vol. 15. 823-829, 2011.