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Development, properties and classification of dune soils in the Curonian Spit National Park, Russian part

Jann Peyrat

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Especially for the Russian part of the Curonian Spit detailed descriptions of dune-soils are lacking. The present work focuses on an ecological soil characterisation carried out across a well-dated sand-dune chronosequence. The soil development is characterised by a fast decalcification combined with a rapid decrease of soil pH and an increase of organic matter and cation exchange capacity with increasing soil age and vegetation cover. Following the international WRB classification (FAO, 2006), the examined soils can be classified as *Calcaric Arenosol*, *Dystric Arenosol*, *Hyperdystric Arenosol*, *Protic Arenosol*, *Dystric Gleysol* and *Haplic Podzol*. It is possible to distinguish three different soil development stages associated with respective stages of plant succession: Initial (*Calcaric*, *Protic* and *Dystric Arenosol*), intermediate (*Hyperdystric Arenosol*) and mature (*Haplic Podzol*) soils.

Key words: arenosols, soil development, soil classification, pedogenesis, podzol, migrating dunes, coastal ecology, the Curonian Spit

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Jann Peyrat. Department of Soil Science, Institute of Biology and Sciences, Carl-von-Ossietzky University, 26111 Oldenburg, Germany. E-mail: jann.peyrat@gmx.de

INTRODUCTION

Since the Middle Ages, soils of the Curonian Spit have been influenced by man: Overgrazing, large game populations and intensive deforestation of the native woods in the 16th century caused degradation of vegetation, thereby exposing the underlying sand to wind erosion. Podzols were eroded or overlain by sand. Today fossil Podzols can be found in the windward slopes of the Migrating Dunes north-west of Morskoye, south-west of Preila and in the south of Nida (Fig. 1). The surfaces of the Podzols indicate the shape and size of the ancient dunes before deforestation. Only the area south of Lesnoye and the area of Juodkrantė (Fig. 1) have never been influenced by Migrating Dunes. In these areas, undisturbed soil development was possible beneath pine forests over a period of 4000 years (Paul, 1953).

Except Pleistocene depositions near Rybachy (Fig. 1), alluvial sands from abrasion processes of the Sambian Peninsula represent the parent material for soil development in the Curonian Spit. Whereas detailed studies of topography and vegetation are present (e. g. Paul, 1944 and 1953; Dolnik, 2003), pedologic studies of dune soils are rare. The research carried out before Word War II was restricted to fossil Podzols (Paul 1953) or chemical



Fig. 1. Curonian Spit with location of the study sites I and II
1 pav. Tyrinėti I ir II vietovių padėtis Kuršių nerijoje

soil examination (Tomuschat, Ziegenspeck, 1930; Rittel, 1931). The geomorphology, aeolian processes and palaeographic development of the Curonian Spit were described by von Wichedorff (1919), Dagfinn et al. (2005), Kharin, Kharin (2005), Dundulis et al. (2006) and Povilanskas et al. (2006). Gaigalas et al. (1991) and Gudelis (1996) documented buried forest soils and their age.

The aim of this study was to reveal changes occurring in young soils formed from dune sands during a period of about 60 years. Also, the development stages of these soils based on their morphological and chemical properties were examined. Finally, a classification following the international soil classification of the WRB (FAO, 2006) was carried out.

MATERIALS AND METHODS, STUDY AREA

The investigation was carried out on the Curonian Spit, a sandy peninsula 97 km long, situated at the southeast Baltic Coast (Fig. 1). The climate of the Curonian Spit is maritime – sub-continent. The mean annual temperature in February is -4.1°C and in August 17.3°C (HELCOM, 1996). Westerly and southerly winds are prevailing on the spit, their mean velocity being 5.5 m/s.

Nine representative soil profiles located at two different sites were examined. Table 1 shows the designation of the soil horizon. Profiles 1–8 were situated in site I (Figs. 1 and 2). They represent soils of increasing age along a transect of 1.9 km across the Curonian Spit, 5 km south of Rybachy. The western part of this site has been reforested with *Pinus sylvestris* since 1945. The eastern part, bordered by the Curonian Lagoon, is characterized by a huge Migrating Dune area with bare sands. The dunes are reaching heights of 35 m and are still actively drifting at a rate of 1.5 m per year (Peyrat, 2007).

Profiles 1 and 2 were located on the beach: profile 1 below, profile 2 above middle high water. Both tidally influenced profiles showed no visible horizon (C) and were classified as *Calcaric Arenosols* according to the WRB classification (FAO, 2006). The other two profiles were located on the windward (3) and leeward (4) slopes of the fore dune ridge dominated by plants of the *Ammophila arenaria* community. These soils, showing an initial humus horizon (Ai / C), were *Calcaric Arenosols*. The soil of profile 5 showed a more developed organic horizon and was classified as *Dystric Arenosol* (Ah/C1/Ai/C2) following the WRB (FAO, 2006). It was located beneath a grassland (*Koelerion glaucae*) 50 m behind the fore dune ridge. The influence of sand erosion and accumulation can be seen in a buried (fossil)

organic horizon. The dominating plants are *Corynephorus canescens*, *Jasione montana*, *Rumex acetosella*, *Festuca rubra*, *Thymus serpyllum*, etc.

Profiles 6 and 7 formed in an area planted with *Pinus sylvestris* about 60 years ago. Profile 6, situated on the top of a fixed dune, showed an initial but already distinctive podzolization and was classified as *Hyperdystric Arenosol* (Oh/Ah/AE/C1/C2). Profile 7 was examined at a distance of 30 m from the previous one in a slack between two fixed dunes. The profile of this *Dystric Gleysol* (Oh/Ah/C1/C2) developed beneath *Betula pendula* and *Pinus sylvestris* and was influenced by a high groundwater level.

The last profile of the transect, profile 8, was situated on the western slope of the Migrating Dune. The area was characterized by bare sand and very few plants like *Corispermum intermedium* and *Cakile maritime* ssp. *baltica*, which were able to colonize this extreme habitat. This profile showed no soil development and was classified as *Protic Arenosol* (C).

Profile 9 was situated in site II (Fig. 1), 30 km south of site I, near the Lesnoye village. During the last 4000 years this area, dominated by a 150-year-old pine forest, has never been influenced by Migrating Dunes (Paul, 1953). The examined profile showed a well developed *Haplic Podzol* (Ol/Of/Oh/Ah/EA/Bh/Bs/C), with a huge 30 cm thick organic layer of mor type humus and a clear eluvial and illuvial horizon with ferric and aluminum properties.

METHODS

Samples were collected from each visually distinctive horizon and analysed in the laboratory. The methods of soil examination follow Schlichting et al. (2005). The classification of the soils is based on the international WRB soil classification (FAO, 2006).

RESULTS

The soils of the profiles consisted of medium-grained sand (85%) dominated by quartz (87 %), feldspar (3%) and heavy minerals (7%).

The pH-values (in CaCl_2) of the first 10 cm of the mineral horizon (A) were decreasing with advancing age and soil development from 6.3 (profile 1) to 3.4 (profile 7). The lowest pH value of 2.6 was found in the mineral horizon of profile 9.

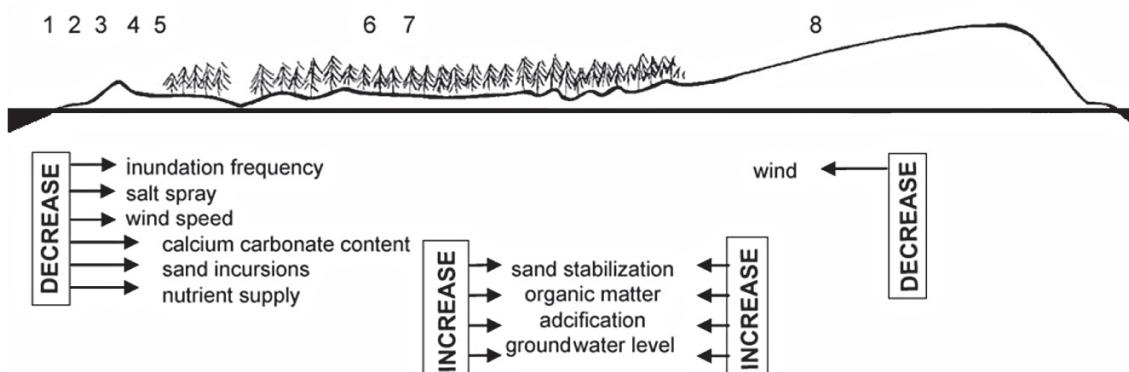


Fig. 2. Abiotic factors of the study site I with location of profiles 1–8
2 pav. Tirtos I vietovės abiotiniai veiksniai ir 1–8 profilių padėtis

Table. Properties of the soil profiles 1–9
Lentelė. Tiltų dirvožeminių ypatumai (1–9 profilių)

Soil type and profile number	Soil horizon	Depth [cm]	Soil texture	pH	CaCO ₃	Organic matter	Sodium (Na)	Potassium (K)	Magnesium (Mg)	Calcium (Ca)	CEC	Base saturation (%)	Soil colour				
													[g kg ⁻¹]	[cmol _c kg ⁻¹]	[g kg ⁻¹]	N _t	C/N
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 Calcaric Arenosol	C1	0–10	sandy sand	6.3	20.7	1.0	n.m.	n.m.	0.1	0.1	108	5.1	0	HUE 2.5Y 7/2	HUE 2.5Y 5/2	HUE 2.5Y 5/2	
2 Calcaric Arenosol	Ai	0–1	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	3.3	0	0	n.d.	n.d.	n.d.
3 Calcaric Arenosol	C1	1–40	sandy sand	5.6	12.4	0.0	n.m.	n.m.	0.2	0.2	93	2.4	0	0	HUE 2.5Y 7/2	HUE 2.5Y 5/2	HUE 2.5Y 5/2
4 Calcaric Arenosol	C2	40+	sandy sand	6.6	20.6	0.0	n.m.	n.m.	0.1	0.1	132	4.7	0	0	HUE 2.5Y 6/2	HUE 2.5Y 5/3	HUE 2.5Y 5/3
5 Dystric Arenosol	Al	1	sandy sand	7.2	26.6	1.9	n.m.	n.m.	0.4	0.4	113				HUE 10YR 6/2	HUE 10YR 6/2	HUE 10YR 6/3
6 Hyperdystric Arenosol	C	1+	sandy sand	8.3	7.2	2.5	n.m.	n.m.	0.2	0.3	68	2.3	0	0	HUE 10YR 6/2	HUE 10YR 6/3	HUE 10YR 6/3
7 Dystric Gleysol	Ah	0–6	sandy sand	6.0	19.4	0.0	n.m.	n.m.	0.8	4.0	21	2.3	0.2	11	HUE 10YR 4/2	HUE 10YR 3/2	HUE 10YR 3/2
8 Protic Arenosol	C	6–15	sandy sand	5.3	n.m.	2.5	n.m.	n.m.	0.3	1.1	24	3.8	0.3	14	HUE 10YR 3.2	HUE 10YR 5/2	HUE 10YR 5/2
9 Haplic Podzol	Al	15–17	sandy sand	6.3	n.m.	5.5	n.m.	n.m.	0.8	0.9	87	1.6	0.1	12	HUE 10YR 3.2	HUE 10YR 5/2	HUE 10YR 5/2
	C	17+	sandy sand	5.0	n.m.	1.1	n.m.	n.m.	0.6	1.0	70	428.4	21.3	20	HUE 10YR 6/2	HUE 10YR 5/2	HUE 10YR 5/2
Oh	8–0	n.d.	3.9	n.m.	367.6	n.d.	n.d.	n.d.	n.d.	n.d.	0	1.6	0	n.d.	n.d.	n.d.	n.d.
Ah	0–3	sandy sand	3.4	n.m.	57.0	n.m.	n.m.	n.m.	0.8	11.4	7	0.1	0.1	1	HUE 10YR 4/2	HUE 10YR 3/1	HUE 10YR 3/1
AE	3–14	sandy sand	4.1	n.m.	3.0	n.m.	n.m.	n.m.	0.2	0.8	24	287.1	14.2	20	HUE 10YR 5/2	HUE 10YR 5/2	HUE 10YR 5/2
Cl	14–36	n.d.	n.d.	n.d.	n.b.	n.d.	n.d.	n.d.	n.d.	n.d.	59.2	2.7	0.1	25	HUE 10YR 6/2	HUE 10YR 4/2	HUE 10YR 4/2
C2	36+	n.d.	n.d.	n.d.	n.b.	n.d.	n.d.	n.d.	n.d.	n.d.	2.7	0.1	34	n.d.	n.d.	n.d.	n.d.
Oh	6–0	n.d.	3.7	n.m.	551.0	n.d.	n.d.	n.d.	n.d.	n.d.	1.9	0.1	0	0	n.d.	n.d.	n.d.
Ah	0–1	sandy sand	4.4	n.m.	364.9	n.m.	0.1	n.m.	1.1	14.7	9	0.9	0	0	n.d.	n.d.	n.d.
C1	1–18	sandy sand	3.9	n.m.	4.2	n.m.	n.m.	n.m.	0.1	2.0	8	1.1	0	0	HUE 10YR 3/2	HUE 10YR 3/2	HUE 10YR 3/2
C2	18+	sandy sand	4.2	n.m.	4.0	n.m.	n.m.	n.m.	0.2	8.6	2	19.9	2	10	HUE 10YR 5/2	HUE 10YR 4/3	HUE 10YR 4/3
	Al	1	sandy sand	6.3	n.m.	0.0	n.m.	n.m.	0.2	0.3	94	41.3	2.1	20	HUE 2.5Y 6/3	HUE 2.5Y 4/3	HUE 2.5Y 4/3
OI	31–25	n.d.	3.5	n.m.	905.2	n.d.	n.d.	n.d.	n.d.	n.d.	12.7	0.2	61	n.d.	n.d.	n.d.	n.d.
Of	25–15	n.d.	2.6	n.m.	871.6	n.d.	n.d.	n.d.	n.d.	n.d.	430.2	19.2	22	n.d.	n.d.	n.d.	n.d.
Oh	1.5–0	n.d.	2.6	n.m.	714.6	n.d.	n.d.	n.d.	n.d.	n.d.	484.9	19.5	25	n.d.	n.d.	n.d.	n.d.
Ah	0–8	sandy sand	2.6	n.m.	222.8	0.2	0.03	n.m.	0.7	38.4	2	417.5	14.3	29	HUE 10YR 3/2	HUE 10YR 2/2	HUE 10YR 2/2
EA	8–53	sandy sand	6.4	n.m.	4.9	n.m.	n.m.	n.m.	0.1	7.2	2	27.9	0.7	40	HUE 10YR 5/2	HUE 10YR 4/2	HUE 10YR 4/2
Bh	53–57	sandy sand	3.9	n.m.	60.4	n.m.	n.m.	n.m.	0.5	16.0	3	2.9	0	0	HUE 10YR 3/2	HUE 10YR 2/2	HUE 10YR 2/2
Bs	57–66	sandy sand	3.7	n.m.	63.3	n.m.	n.m.	n.m.	0.0	22.2	0	12.9	0.3	43	HUE 7.5YR 3/2	HUE 5YR 2.5/2	HUE 5YR 2.5/2
C	66+	n.d.	n.d.	n.b.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	6.1	0.1	77	n.d.	n.d.	n.d.	n.d.

Note. n.d. – not determined; n.m. not measurable (below detection limit).

Calcium carbonate was only measured in the *Calcaric Arenosols* of the beach and the fore dune ridge: profiles 1 and 2 showed contents of calcium carbonate (20.7 and 12.4 g kg⁻¹) in the first 1–2 cm, whereas profiles 3 and 4 showed higher contents (26.0–26.6 g kg⁻¹).

An increase of organic matter is visible and measurable with increasing vegetation cover (Table). The youngest soils, *Calcaric Arenosols* (1–4), showed contents of 0.1–1.9 g kg⁻¹ in the mineral soil. Profiles 5–7 showed an increase of organic matter from 19.4 to 364.9 g kg⁻¹. A slightly increasing content of organic matter was visible in the decrease of chromium in the upper soil horizon. The increase of organic matter is combined with a rising nitrogen content (0–2.7 g kg⁻¹) and C / N-ratio (7–40).

The soils were extremely poor in nutrients (Ca, K, Mg, Na). The only measurable nutrient was calcium, which increased from 0.1 cmol_c kg⁻¹ (profile 1) to 1.1 cmol_c kg⁻¹ (profile 7). 0.7 cmol_c kg⁻¹ calcium was measured in the *Haplic Podzol* (9). The potential cation exchange capacity also increased with advancing soil age from 0.2 cmol_c kg⁻¹ (profile 1) to 14.7 cmol_c kg⁻¹ (profile 7). On the other hand, the base-saturation decreased from 169% to 9%.

DISCUSSION

Distance to the beach, decreasing sand incursions from the Baltic Sea, weathering and precipitation result in rapid leaching losses of calcium during the dune succession. Decalcification is combined with acidification which reaches the lowest pH value (pH 2.6) under the pine plantation (profile 6). This tendency is also described by Eis (1990), Giani and Buhmann (2004) for a sand dune chronosequence on the German Wadden Sea Island of Spiekeroog and by Isermann (1997) for dunes at the German Baltic coast.

Soils from the Migrating Dunes show unexpectedly high values of pH and calcium.

These high values are possibly due to periodic fresh sand supply from the Baltic Sea (Salisbury, 1952).

The development of the vegetation cover is correlated to organics accumulation in the first centimetres of the mineral soil, which allows profile distinction (Eis, 1990; Isermann, 1997; Giani, Buhmann, 2004). The low contents of organic matter in *Calcaric Arenosols* (1–4) occur only at sites with low or missing vegetation cover. Fast decomposition of vegetation, strong winds, sand burial and blowouts prevent the accumulation of plant or organic remains in this area. These conditions ameliorate with increasing dune age as wind velocity and soil movement diminish with the distance from the sea. Organic matter is the most important source for cation exchange in dune soils which are poor in clay minerals.

SOIL DEVELOPMENT

The soil profiles 1–8 represent soil development on the Curonian Spit since the extensive reforestation of the 18th and 19th centuries. The first signs of a bleaching horizon are visible at profile 6 (*Dystric Arenosol*) beneath a 60-year-old pine plantation. The short period for soil formation led to the development of a weak O/Ah/AE/C-profile. Time can be regarded as the limiting factor of podzolization (Eis, 1990; Mücher, 1990). Piotrowska (1988)

also points out that the main factor of soil development in coastal dunes is podzolization, but that mature soils are rare.

The climax of the soil development by *Haplic Podzol* (profile 9) beneath a pine plantation from the 1850s is reached. In this area, which had never been influenced by Migrating Dunes, an undisturbed soil development was possible during the last 4000 years. Podzols on the Curonian Spit were described by several German scientists (von Wichdorff, 1919; Paul, 1944 and 1953). These podzols showed a splendid white bleached sand layer followed by a very solid, dark to nearly black organic and ferric accumulation layer ("Ortstein") (Paul, 1953). Nowadays mature podzols can be found beneath undisturbed forests of the southern and middle parts of the Curonian Spit and in the windward slopes of the Migrating Dunes; they indicate the presence of this soil type before the disastrous deforestation of the Middle Ages.

The development of mature podzol profiles (profile 9) on the Curonian Spit takes up to 1100–1600 years (Paul, 1953). Moderate podzolised soils require 600 to 800 years for their formation; the initial podzol stage is reached after about 100 years (Paul, 1953). Sevink (1991) indicates a period of 1000 years for the distinction of podzol characteristics.

Associated with plant succession, three stages of soil development can be classified. The first stage, the initial stage is repre-

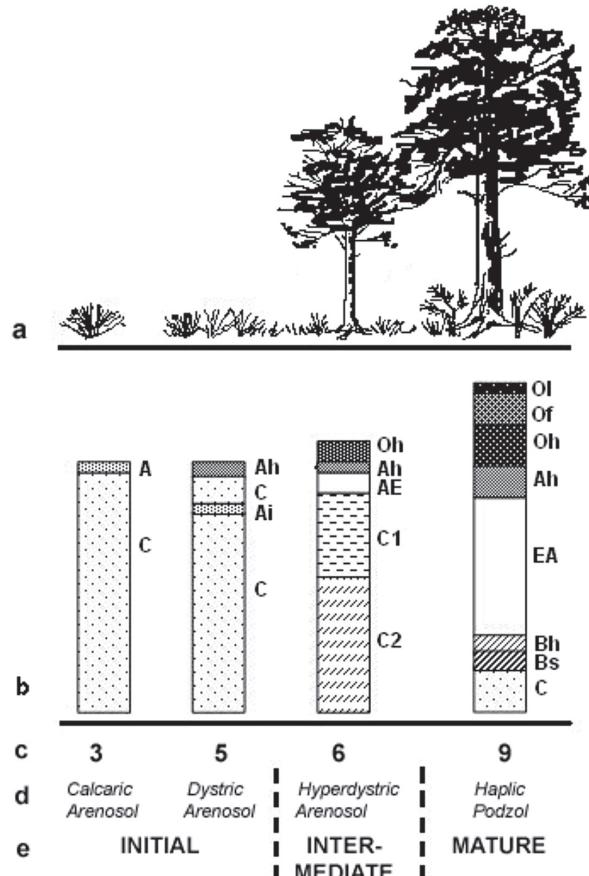


Fig. 3. Soil development in correlation to plant succession: *a* – plant succession, *b* – soil profiles (see table 1), *c* – profile number, *d* – soil name in FAO (2006), *e* – development stages

3 pav. Dirvožemio raidos ryšys su augalų asociacijomis: *a* – augalijos asociacijos, *b* – dirvožemio profilių, *c* – profilių numeriai, *d* – dirvožemio pavadinimai pagal FAO (2006) klasifikaciją

sented by *Calcaric, Dystric and Protic Arenosols* (profile 1–5). These soils develop in poorly vegetated areas exposed to strong winds, sand burial and erosion. They are characterized by primary – often invisible – humus accumulation, alkaline pH values and high calcium carbonate contents. The distance to the beach and the diminishing influence of erosion initialize the intermediate stage of soil development. The vegetation cover gets denser, the first shrubs and trees appear. The accumulation of organic matter becomes apparent, and translocation of mineral compounds to deeper parts of the soil lead to the formation of an eluvial horizon (profile 6, *Hyperdystric Arenosol*). This 60-year-old profile showed no visible and measurable illuvial horizon.

The last, mature stage is represented by *Haplic Podzol* (profile 9). Transformation of mineral and organic compounds, their vertical transport and relocation to deeper horizons are clearly visible. The acid, mor type humus increases with the plant cover and is the cause for the further transformation of the mineral soil. The products of organic matter decomposition (mainly fulvic acids) play an important role in weathering of minerals and in mobilizing free elements combined into organic mineral complexes.

According to Giani and Buhmann (2004), *Arenosols* can represent the climax of soil development when no tree cover is present. They refer to treeless dunes on the German Island of Spiekeroog, where the lack of a nutrient pump, extremely nutrient-poor parent material and the very short nutrient cycle prevent the development of Podzols.

CONCLUSIONS

Erosion and burial processes of the mobile dune landscape of the Curonian Spit, which appeared under anthropogenic impact in the Middle Ages, hampered soil formation in many places. Reforestation and fixation of Migrating Dunes in the 18th and 19th centuries initialized soil development.

The following conclusions can be drawn:

1. Soil formation is characterized by a fast decalcification combined with a rapid decrease of soil pH and accumulation of organic matter with advancing the soil age and increasing the vegetation cover.

2. Podzolization effects appear in 60-year-old soils with the formation of an eluvial horizon, but accumulation of organic or ferritic compounds in deeper horizons is not measurable.

3. Podzolization is the main trend in the evolution of the study soils. This process is modified by the character of the nutrient-poor parent material, plant cover and climatic conditions.

4. The study soils can be classified into three soil development stages depending on vegetation succession: initial, intermediate and mature.

5. The climax of soil formation is reached in the podzol stage which appears beneath a 160-year-old pine forest in an area that has not been influenced by Migrating Dunes for the last 4000 years.

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Jann Peyrat

KURŠIŲ NERIJOS NACIONALINIO PARKO (RUSIJOS DALIS) KOPŲ DIRVOŽEMIŲ RAIDA, SAVYBĖS IR KLASIFIKAVIMAS

Sant rau ka

Straipsnyje atkreptas dėmesys į kopų smėlyje paplitusių dirvožemiu ekologinę charakteristiką. Dirvožemiu kopų smėlyje raida pasižymi de-kalcizacija, pH mažėjimu, taip pat padidėjusiais organinės medžiagos ir katjonų mainais dėl amžiaus ir augalijos. Autorius suklasifikavo pagal tarptautinį standartą (FAO 2006) tirtus dirvožemius ir išskyre tris su augalijos raida susijusias stadijas: pradinę, vidurinę ir brandos.

Dirvožemiu raidą lemia jaurinio sluoksnio formavimasis dėl organinių komponenčių neturtingos pirminės medžiagos, augalijos dangos ypatumo ir klimato. Šis procesas ryškus 60 metų senumo dirvožemiuose su eliuvio horizontu ir vos pastebimu organinės medžiagos ir feritinės junginių kaupimusi. Dirvožemis pradėjo formuotis, kai išaugo miškas ir stabilizavosi kopų judėjimas. Raidos maksimumą pasiekę dirvožemai atitinka jaurinę stadiją. Jie randami 160 metų brandumo pušynų plotuose, nepaliestuose kopų migracijos per pastaruosius 4000 metų.

Янн Пейрат

РАЗВИТИЕ, СВОЙСТВА И КЛАССИФИКАЦИЯ ДЮННЫХ ПОЧВ РОССИЙСКОЙ ЧАСТИ НАЦИОНАЛЬНОГО ПАРКА КУРШСКОЙ КОСЫ

Резюме

В статье обращается внимание на экологическую характеристику почв, распространенных в дюнных песках на Куршской косе по российской стороне. Хронологическая последовательность развития почв в дюнных песках сопровождается декальцитизацией со снижением pH, увеличением органики и масштаба ионного обмена под влиянием растительности и возраста. Автором выполнена классификация изученных почв по международному стандарту (FAO 2006) и выделены три стадии их развития, связанных с влиянием растительности: начальная, средняя и зрелая.

Формирование почв сопровождается образованием подзола из-за бедности первичного материала органическими веществами, специфики растительного покрова и климата. Этот процесс проявляется в разрезе почвы возрастом 60 лет, в котором наблюдается элювиальный горизонт, небогатый органикой и с едва заметной аккумуляцией железистых соединений. Формирование почв началось после закрепления подвижных песков под лесом. Развитие почвы соответствует подзолистой стадии. Они наблюдаются на дюнных песках в участках соснового леса возрастом 160 лет, которые не подвергались миграции в течение 4000 лет.