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ASSESSMENT OF SODIUM AND POTASSIUM CONTENTS AS NATURAL INDICATORS OF SALINITY IN SOILS OF THE KAMPINOSKI AND SŁOWIŃSKI NATIONAL PARKS (POLAND)

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ABSTRACT

Backgrounds. Widłak (2016) has proposed a soil salinity indicator, defined as the ratio of sodium to potassium (Na/K). At sodium concentrations higher than the potassium concentration, the ratio exceeds the value of 1, which indicates a highly adverse effect on the aeration of the root system and the absorption of nutrients by plants.
Aim. The aim of the research was to test Widłak's index in dune soils of two Polish national parks: the Słowiński National Park (SNP) and the Kampinoski National Park (KNP).
Results. In litter and in all mineral horizons of SNP soils the average salinity index proposed by Widłak was found at values <1.0 (maximum 0.74), which places SNP soils in a group of soils with favourable properties in terms of root aeration and assimilability of nutrients by plants. In KNP soils such favourable conditions were demonstrated for litter and also 5–10 cm and 45–50 cm of soil depth. For the depth of 25–30 cm the Na/K ratio exceeded 1, reaching the value of 1.25. Higher sodium and potassium contents in KNP soils, as compared to SNP, may be a consequence of lower rainfall in the central part of Poland, and thus weaker soil leaching, causing the migration of these elements deeper into the profile. The Na/K ratio may be a measure not only of a better or worse soil status, but also a reflection of climatic conditions.

Keywords: natural salinity indicator, natural forest soils, dunes, climate

INTRODUCTION

Salt accumulation, especially sodium, is one of the main threats to soils (EC, 2005; Kłosowska, 2010; Siyal et al., 2002). Salinity is the cumulative concentration of soluble salts, most often caused by the accumulation of potassium, calcium and sodium chlorides, sulfates as well as carbonates. It may be induced by the natural accumulation of salt in the soil or the effect of human activity. Variations in soil chemistry affect most of the plant requirements: soil structure, osmotic potential of the soil solution, soil aeration, and

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the presence of toxic elements. Thus 'salinity stress' is a complex state mediated by soil chemical processes (Rengasamy, 2016). The impact of salt present in the soil solution contributes to the emergence of ionic stress in plants. This leads to a reduction in the potential capacity of CO_2 assimilation, resulting in an inhibition of plant growth (Munns et al., 2006; Xiong et al., 2002). Increasing salinity leads to the accumulation of ions in the plant over a period of time, subsequently leading to ion toxicity or ion imbalance. However, soil salinity reflects solubility, complexation and precipitation of ionic species in soil solution, factors affecting ion uptake and also root growth (Rengasamy, 2016). Saline and sodic soils are considered as the two main types of salt-affected lands. Saline soils are impacted by high concentrations of soluble salts, whereas sodic ones exhibit high concentrations of exchangeable sodium (Na^+) and low levels of soluble salts. Soils with a high level of both soluble salts and sodium are referred to as saline-sodic soils (McKenzie and Woods, 2010).

The technique to assess sodium risks varies from region to region. Some regions use %Na, whereas others – the sodium activity ratio (SAR), exchangeable sodium percentage (ESP) or the exchangeable sodium ratio (ESR). The SAR value is calculated from the Na^+, magnesium (Mg^{2+}) and calcium (Ca^{2+}) in the saturated paste; while the %Na is 100× the $cmol_c$ of sodium divided by the sum of the $cmol_c$ of potassium (K^+), Mg^{2+}, Ca^{2+}, and Na^+ extracted by ammonium acetate. The denominator in this calculation is often referred to as the effective cation exchange capacity. The inconsistency in the interpretation of analytical values results from a myriad of test methods (Birru et al., 2019).

The majority of salt-affected soils are dominated by sodium salts and hence the exchange phase is dominated by Na (Rengasamy, 2006). Some studies have shown that, in addition to sodium, exchangeable potassium and magnesium may also increase soil swelling and dispersion, thus affecting soil physical properties (Arienzo et al., 2012; Buelow et al., 2015; Oster et al., 2016; Rengasamy and Marchuk, 2011; Zhang and Norton, 2002).

On the basis of experimental data, dealing with the concentrations of sodium [mg/100 g] and potassium [mg/100 g] in soils from the Świętokrzyskie province Widłak (2016) proposed a soil salinity indicator, defined as the ratio of sodium to potassium (Na/K). At sodium concentrations higher than the potassium concentration the ratio exceeds the value of 1. This indicates a highly adverse effect on the aeration of the root system and the absorption of nutrients by plants. Birru et al. (2019) concluded that it is surprising that few salinity and sodicity studies have been conducted in the field over multiple years using undisturbed soil columns. So the aim of the research was to test the index proposed by Widłak (2016) in one of the most natural soil conditions in Poland, in dune soils of two Polish national parks: the Słowiński National Park (SNP) and the Kampinoski National Park (KNP).

RESEARCH AREA

The Kampinoski National Park (KNP) is one of the 23 and the second greatest national park in Poland. Its area comprises over 38 544 ha. The Słowiński National Park (SNP) is one of two Polish seashore national parks and is located along the central coast

Table 1. Climatic data from 2010 and 2015
Tabela 1. Dane klimatyczne z lat 2010 i 2015

Parameter Parametr	Year Rok	Weather station Stacja meteorologiczna		
		Łeba – SNP	Ustka – SNP	Kampinos – KNP
Total annual precipitation, mm Całkowita roczna suma opadów, mm	2010	928.63	948.45	673.4
	2015	490.51	507.23	419.0
Average annual temperature, °C Przeciętna roczna temperatura powietrza, °C	2010	7.0	7.4	7.9
	2015	9.2	9.6	9.4
Average annual humidity, % Przeciętna roczna wilgotność powietrza, %	2010	82.60	84.50	80
	2015	80.90	79.30	72

Source: SNP – https://en.tutiempo.net/climate, KNP – Olszewski and Wierzbicki (2018).
Źródło: SNP – https://en.tutiempo.net/climate, KNP – Olszewski i Wierzbicki (2018).

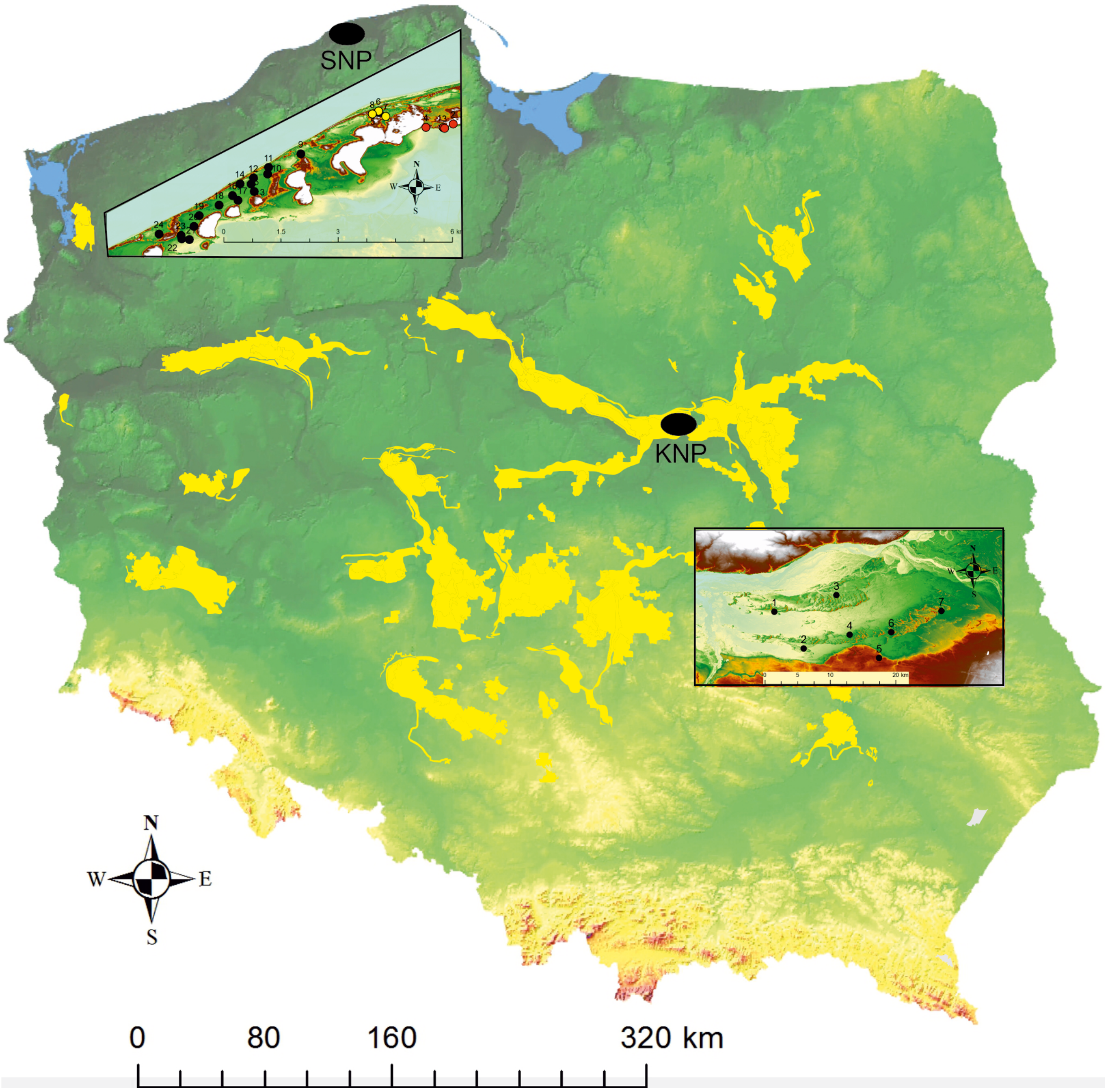

Fig. 1. Location of experimental sites (black dots) on the map of Poland with more important fields of inland dunes (yellow contours): SNP – Słowiński National Park, KNP – Kampinoski National Park. The boxes contain enlarged images of research areas with marked soil sampling points (black points)

Rys. 1. Lokalizacja stanowisk doświadczalnych (czarne kropki) na tle mapy Polski z ważniejszymi polami wydm śródlądowych (żółte kontury): SNP – Słowiński Park Narodowy, KNP – Kampinoski Park Narodowy. Ramki zawierają powiększone obrazy obszarów badawczych z zaznaczonymi punktami poboru próbek gleby (czarne punkty)

of the Baltic Sea with a total area of 32 744 ha. The research areas in both Parks were established on soils formed of dune sands. The differences, important from the research point of view, concern the origin of dunes. In SNP they are coastal dunes, while inland dunes are localized in KNP (Fig. 1). The SNP climate has a lower average annual temperature, a higher sum of annual precipitation and a higher average air humidity. Table 1 comprises data from 2010 and 2015 to show differences between meteorological stations located near both national parks (Ustka near the western border of the SNP, Łeba near the eastern border of the SNP, and the Kampinos Weather Station for the KNP).

METHODS

A total of 24 research areas were established in SNP and 7 in KNP. The adopted soil sampling methodology is consistent with what was described by Rutkowski et al. (2016). Soil profiles were established in dune areas: SNP representing coastal dunes and KNP inland dunes. Research plots were established in stands, which age exceeded 100 years. Pine (*Pinus sylvestris*) formed 17 stands in SNP and 7 in KNP. In addition, in SNP 4 areas were established in a beech stand and 3 in *Pinus ×rhetica* communities. Soil samples were collected from the forest litter layer and next from a depth of 5–10, 25–30 and 45–50 cm. The sampling depth is comparable to the procedure indicated by McKenzie and Woods (2010).

Chemical analyses were performed on soil samples dried at ambient room temperature and next sieved through a 2 mm sieve. Basic cations were determined directly in the eluate resulting from washing the soil with a 1M solution of ammonium acetate pH 7.00. The samples were then shaken for 2 hours on a laboratory shaker and allowed to equilibrate for 24 hours. The solution was then filtered through a filter, thereby obtaining a filtrate, in which exchangeable K^+ and Na^+ cations were determined. At the same time, reference standard solutions with known contents of K^+ and Na^+ cations supplemented with the extraction solution (1M CH_3COONH_4) were prepared. An atomic absorption spectrophotometer (AAS 30, Carl Zeiss Jena GmbH) operating in the flame photometry mode was used to determine the concentrations of the elements in the soil extracts.

Soil reaction was measured in KCl and H_2O by the potentiometric method according to PN-ISO10390: 1997. The electrode was calibrated in a buffer at pH 4.00.

RESULTS

Comparison of sodium content in KNP and SNP soils

The results were summarised by providing maximal (Fig. 2), minimal (Fig. 3) and average (Fig. 4) contents of exchangeable sodium in the litter (consisting mainly of pine needles and herbaceous vegetation forming pine forest communities) and in soil samples collected from depths of 5–10, 25–30 and 45–50 cm.

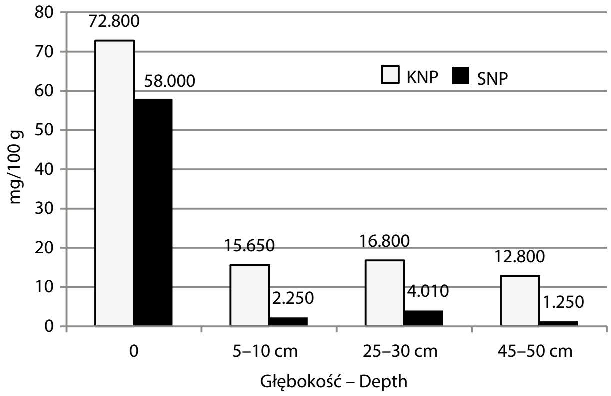

Fig. 2. Maximal Na^+ contents in samples of Kampinoski National Park – KNP and Słowiński National Park – SNP, mg/100 g of soil (rounded to the whole value)
Rys. 2. Maksymalne zawartości Na^+ w próbkach w Kampinoskim Parku Narodowym – KNP i Słowińskim Parku Narodowym – SNP, mg/100 g gleby (zaokrąglone do pełnych wartości)

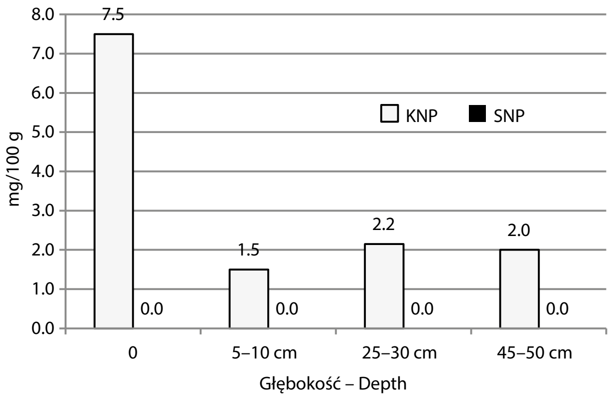

Fig. 3. Minimal Na^+ contents (mg/100 g of soil, rounded to one decimal place) in samples of Kampinoski National Park – KNP and Słowiński National Park – SNP, mg/100 g of soil (rounded to one decimal place)
Rys. 3. Minimalne zawartości Na^+ w próbkach w Kampinoskim Parku Narodowym – KNP i Słowińskim Parku Narodowym – SNP, mg/100 g gleby (zaokrąglone do pierwszego miejsca po przecinku)

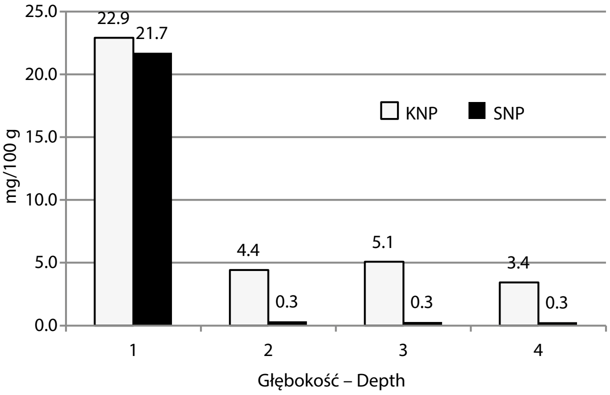

Fig. 4. Average Na^+ contents in samples of Kampinoski National Park – KNP and Słowiński National Park – SNP, mg/100 g of soil (rounded to one decimal place)
Rys. 4. Średnie zawartości Na^+ w próbkach w Kampinoskim Parku Narodowym – KNP i Słowińskim Parku Narodowym – SNP, mg/100 g gleby (zaokrąglone do pierwszego miejsca po przecinku)

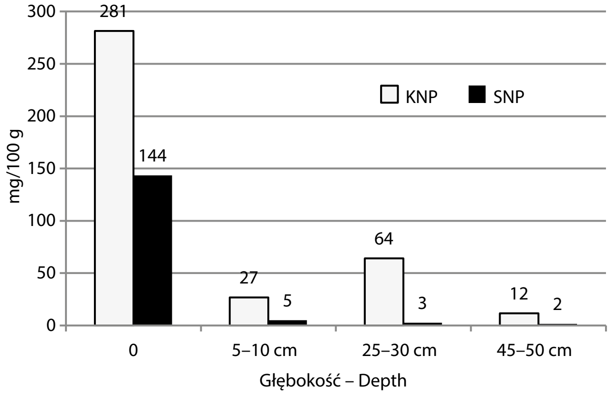

Fig. 5. Maximal K^+ contents in samples of Kampinoski National Park – KNP and Słowiński National Park – SNP, mg/100 g of soil (rounded to the whole value)
Rys. 5. Maksymalne zawartości K^+ w próbkach w Kampinoskim Parku Narodowym – KNP i Słowińskim Parku Narodowym – SNP, mg/100 g gleby (zaokrąglone do pełnych wartości)

In all cases, in relation to the maximal, minimal and average contents both in the litter and in all soil layers the Kampinoski NP had a higher sodium content than SNP, while the maximal sodium content in the litter taken from the KNP was 4 to 5 times higher than in lower soil layers. For the minimal values, these differences were similar (3.4 to 5 times higher). In SNP, with generally lower sodium contents in the litter and soil than KNP, these differences were greater.

We also need to stress here the accumulation of sodium in KNP soils at depths of 25–30 cm, which can be seen in both the maximal (Fig. 1), minimal (Fig. 2) and average values (Fig. 3). In SNP, this relationship is only seen for maximal values. In the case of minimal values this relationship could not be shown, due to zero values obtained in the course of analyses.

Comparison of potassium contents in KNP and SNP soils

Similarly as in the case of sodium, increased potassium accumulation at depths of 25–30 cm was shown in KNP soils, although in this case it is only visible in the graphs showing maximal (Fig. 5) and average values (Fig. 7). For the minimal potassium content in the soil, the highest amounts of this element were recorded at a depth of 45–50 cm.

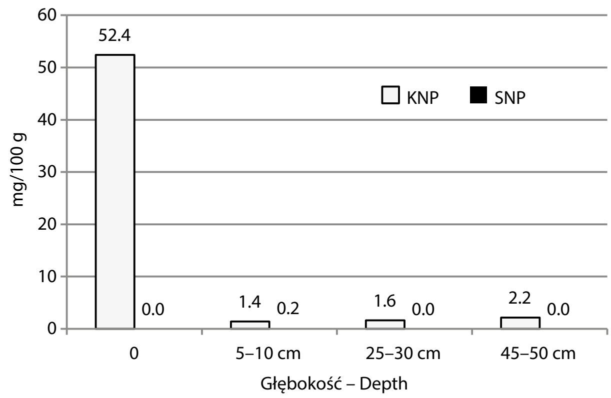

Fig. 6. Minimal K^+ content in samples of KNP and Słowiński National Park – SNP, mg/100 g of soil
Rys. 6. Minimalne zawartości K^+ w próbkach w Kampinoskim Parku Narodowym – KNP i Słowińskim Parku Narodowym – SNP, mg/100 g gleby

In SNP soils the distribution of potassium in the soil varies. The highest values, except for litter, were found at the depths of 5–10 cm. In deeper layers, from which samples were taken, these contents decreased with depth.

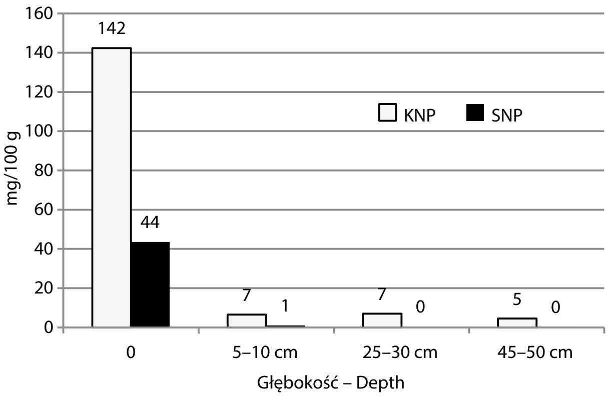

Fig. 7. Average K^+ contents in samples of Kampinoski National Park – KNP and Słowiński National Park – SNP, mg/100 g of soil (rounded to the whole value)
Rys. 7. Średnie zawartości K^+ w próbkach w Kampinoskim Parku Narodowym – KNP i Słowińskim Parku Narodowym – SNP, mg/100 g gleby (zaokrąglone do pełnych wartości)

Assessment of the Na/K ratio

Due to the fact that in the sodium and potassium contents in soils of both national parks zero (0) values were recorded, the Na/K index was not available for minimal and maximal values and it was shown for average values only (Fig. 8). Most indices showed the value <1.0, suggested by Widłak (2016) as a limit, above which the degree of soil salinity has an adverse effect on aeration of the root system and the absorption of nutrients by plants. In this context the results obtained maybe considered favourable for SNP soils at all tested depths, while in KNP soils the Na/K indices exceeded the value 1 at the depths of 25–30 cm, reaching an average value of 1.25.

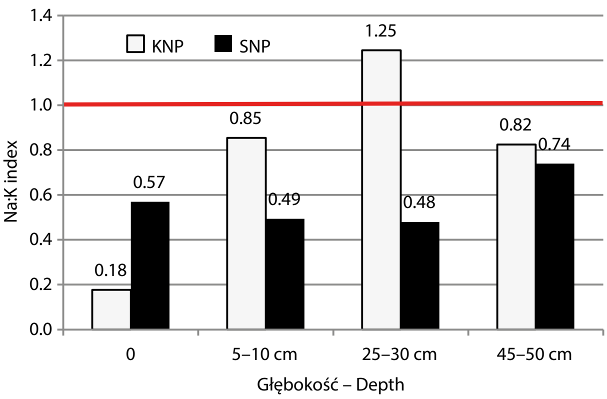

Fig. 8. Average values of the Na/K indices for various Kampinoski National Park – KNP and Słowiński National Park – SNP soil layers. The value 1.0 is marked with a red horizontal line
Rys. 8. Średnie wartości wskaźnika Na/K dla różnych poziomów gleb Kampinoskiego Parku Narodowego – KNP i Słowińskiego Parku Narodowego – SNP. Czerwoną poziomą linią zaznaczono wartość 1,0

Characteristics of pH measurements

Soils of both parks show an acid reaction (Table 2). In SNP for the layer of litter and soil collected from the depth of 5–10 cm an additional salinity and conductivity measurement was made, using an Elmetron microcomputer pH/conductivity meter CPC-551.

Table 2. Soil pH, salinity and conductivity for the investigated parks
Tabela 2. Odczyn (pH), zasolenie i przewodność elektryczna gleb badanych parków

Park	Soil layer Poziom cm	pH_{H_2O}	pH_{KCl}	Salinity Zasolenie mg/dm³	Conductivity Przewodnictwo µS/cm
SNP	O	3.5–4.6	3.2–4.2	55.7–163.1	120–332
	5–10	3.4–4.5	2.9–4.3	0–48	9–104
	25–30	3.8–4.8	3.6–4.7	–	–
	45–50	3.9–5.0	2.5–4.6	–	–
KNP	O	3.7–4.9	2.7–4.2	–	–
	5–10	3.8–4.1	2.9–4.2	–	–
	25–30	4.4–5.3	3.8–4.2	–	–
	45–50	4.6–5.6	4.0–4.4	–	–

DISCUSSION

Sodium occurs in soils, predominantly as salts. It does adsorb onto clay minerals, but the bond is weaker than that of potassium ions and therefore sodium has a higher propensity to be leached. Therefore in areas of high rainfall, such as tropical or sub-tropical climates, soils are generally depleted in sodium, which is leached down into deeper soil layers. In contrast, in arid or semi-arid areas an accumulation of Na in the topsoil frequently occurs, because the rate of evaporation exceeds the replacement of water from the soil. This often results in a deterioration of the soil structure, which has a negative effect on the water and air balance of the soil. In addition, the pH becomes more alkaline with an increasing Na content (Sodium…, 2017).

Primary salinisation is the development of salts through natural processes, mainly including physical or chemical weathering and transport from the parent material, geological deposits or groundwater. Soil may be rich in salts, due to parent rock constituents such as carbonate minerals and/or feldspar. Closely related to this, geological events or specific formations can increase salt concentrations in groundwater and therefore in superimposed soil layers (Daliakopoulos et al., 2016).

The contents of sodium and potassium in soil depend on many factors. These conditions are caused by regional water and salt movements due to the effects of climate, topography, hydrogeology and unreasonable human factors (Cui et al., 2019). A practical rule is that each water depth unit can remove nearly 80% of salts from the same soil depth unit (Abrol et al., 1988; Ayers and Westcot, 1985): for example, a 0.30 m water depth flowing through the soil can remove 70–80% of the existing salts in the top 0.30 m soil layer (Cucci et al., 2016).

This mechanism may explain the differences between Na and K contents in the litter and SNP and KNP soils. In the former park soils developed on coastal dunes, thus they may be influenced by the accumulation of salt floating in the air from the sea towards the land. Theoretically, the Na content in SNP soils should be higher. On the other hand, SNP areas generally have higher amounts of precipitation than KNP, which can contribute to the leaching of salts from the topsoil deeper into the profile. Hence, lower Na and K contents are found in SNP soils. From the data of the current study it can be clearly seen that the process of moving Na deep into the profile in KNP soils retains this element at a depth of 25–30 cm (Figs. 3–5). In turn, SNP litter showed a wider Na/K ratio compared to KNP (Fig. 8), which may confirm Na accumulation from salts transported by air masses reaching from the sea. The results may therefore confirm the impact of precipitation on the salt content in the soil, but it may also be assumed that the differences in the salt content in the soils of both parks reflect the climatic differences between the parks. The soil salinity index can therefore be treated indirectly as a measure of climatic conditions.

CONCLUSIONS

The results, including the contents of sodium and exchangeable potassium, as well as the Na to K ratio in SNP and KNP soils indicate the following relationships:

- the Kampinoski National Park soils show higher contents of sodium and potassium in litter and in all mineral levels analysed than SNP soils
- sodium and potassium contents in the litter in both national parks significantly exceeded the contents of these elements in mineral soil levels
- apart from litter, for three tested mineral soil horizons (5–10, 25–30 and 45–50 cm), in KNP soils the highest sodium content was always recorded at a depth of 25–30 cm; in SNP soils, this relationship was not shown; however, it may be the result of generally very low – close to zero – Na contents
- a similar relationship to that of Na was found for the potassium content in KNP soils; in SNP soils, due to the low contents of Na and K, no such relationship was found
- in litter and in all mineral levels of SNP soils the average salinity index proposed by Widłak took values <1.0 (maximum 0.74), which in SNP soils in a group of soils with favourable properties in terms of root aeration and assimilability of nutrients by plants; in KNP soils, such favourable conditions were demonstrated for litter and 5–10 cm and 45–50 cm horizons; for the depth of 25–30 cm the Na/K ratio exceeded 1, reaching the value of 1.25
- higher sodium and potassium contents in KNP soils, as compared to SNP, may be a consequence of lower rainfall in the central part of Poland and thus weaker soil leaching, causing the migration of elements deeper into the profile
- the Na/K index may be a measure not only of soil conditions, but also a reflection of climatic conditions.

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OCENA ZAWARTOŚCI SODU I POTASU JAKO NATURALNEGO WSKAŹNIKA ZASOLENIA W GLEBACH KAMPINOSKIEGO I SŁOWIŃSKIEGO PARKU NARODOWEGO (POLSKA)

ABSTRAKT

Wstęp. Widłak (2016) zaproponowała wskaźnik zasolenia gleby, zdefiniowany jako stosunek sodu do potasu (Na/K). Przy stężeniach sodu wyższych niż stężenie potasu iloraz przekracza wartość 1. Oznacza to bardzo niekorzystny wpływ na napowietrzanie systemu korzeniowego i wchłanianie składników pokarmowych przez rośliny.
Cel badań. Celem badań było przetestowanie tego wskaźnika w glebach wydmowych dwóch polskich parków narodowych: Słowińskiego (SNP) i Kampinoskiego (KNP).
Wyniki. W ściółce i we wszystkich poziomach mineralnych gleb SNP średni wskaźnik zasolenia zaproponowany przez Widłak wykazywał wartości <1,0 (maksymalnie 0,74), co plasuje gleby SNP w grupie gleb o korzystnych właściwościach napowietrzania korzeni i przyswajalności składników pokarmowych przez rośliny. W glebach KNP wykazano także sprzyjające warunki dla ściółki i głębokości 5–10 cm i 45–50 cm. Na głębokości 25–30 cm stosunek Na/K przekroczył 1, osiągając wartość 1,25. Wyższa zawartość sodu i potasu w glebach KNP, w porównaniu z SNP, może być konsekwencją mniejszych opadów w środkowej części Polski, a tym samym słabszego przemywania gleby powodującego migrację pierwiastków w głąb profilu. Wskaźnik Na/K może być miarą nie tylko lepszych lub gorszych warunków glebowych, ale także odzwierciedleniem warunków klimatycznych.

Słowa kluczowe: naturalny wskaźnik zasolenia, naturalne gleby leśne, wydmy, klimat