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Short Communication

Effects of Potassium on the Dynamics of Chemical Elements in Brown Soil Reconstructed Profile

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Abstract

High sorption capacities of soils in respect to potassium enable the application of the latter in high doses to meet the nutritional requirements of all plants in crop rotation. However, overstepping a certain level and braking off buffering capacity of soil may appear unfavorable for both the plants and soil environment. Tests were performed on brown soil in profiles reconstructed in plastic tubes 7 cm in diameter and one meter high. Potassium (in KCl form) was introduced down to the level of ploughed humus of the soils in the equivalent quantities of: 0, 25, 50, 75, 100, 125, and 150% of sorption capacities at A_p level and water was poured to simulate 420 mm of precipitation. The applied doses of potassium had an unequal effect on the dynamics of chemical processes. Potassium in high doses strongly extracted magnesium and calcium cations from the surface layers to deeper levels and to the filtrates. It had no effect on hydrogen desorption or on the dynamics of bioavailable forms of phosphorus. The elements Mg>Ca>Na>K, in this order, were most washed out of the profile, whereas K>Mg>Na>Ca, in this order, exhibited the highest dynamics under the effect of fertilization.

Keywords: soil profile, potassium dynamics, filtrate

Introduction

Potassium, a constituent of numerous primary and secondary minerals, can be found in soil almost exclusively in mineral forms. In particular circumstances it can migrate to a water solution within the soil and then be subject to various types of sorption [1] or be eluted out of the soil profile [2-4]. Its contents in surface layers of the earth's crust are relatively high; nevertheless, it is often deficient under Polish soil and climate conditions, namely in sandy and peat soils. Plant fertilization science recommends the use of accumulated doses of potassium that would meet the nutritional requirements of all plants in crop rotation [5]. This yields obvious organizational and economic benefits, but is it rational from an environmental point of view?

Available chemical and agricultural literature includes few publications about the effect of high potassium doses (potassium contamination) on soil chemistry: neither the process nor their intensities of soil thickness were under the influence of interaction with other cations, including their washing out of the soil profile [6-9].

The present model study was aimed at evaluating soil with high potassium doses, selected physicochemical properties, and chemical composition of filtrates.

Material and Methods

Brown soil (Haplic Cambisol-Eutric) [10] used in our study originated from a culmination (235.5 m above sea level) of the area in Rudna Wielka near Rzeszów. Within its profile, its morphological structure up to a depth of 100 cm

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Table 1. Some physicochemical properties of the soil profile from Rudna Wielka.

Horizon	Depth (cm)	pH 1 mol KCl·dm^{-3}	H_w *	Al^{+3} *	H_h *	SEB *	CEC *	BS * %
			mmol(+)·100 g^{-1} soil					
A_p	0-30	4.0	2.28	2.24	4.65	8.0	12.65	63.2
$B_{br}1$	30-44	4.4	0.59	0.57	2.55	10.7	13.25	80.8
$B_{br}2$	44-58	4.6	0.24	0.22	1.95	9.9	11.85	83.5
$B_{br}C$	58-77	4.5	0.24	0.21	1.88	9.3	11.18	83.2
C 1	77-89	4.4	0.31	0.29	1.80	9.1	10.90	83.5
C 2	89-100	4.4	0.28	0.26	1.80	8.6	10.40	82.7

H_w – Exchangeable acidity, Al^{+3} – Exchangeable aluminum, H_h – Hydrolytic acidity, SEB – Sum of exchangeable bases, CEC – Cation exchange capacity, BS – Base saturation

was described, and soil samples from the subsequent layers (thickness 5 cm) were collected to reconstruct its profile in a laboratory. The profile was reconstructed in plastic tubes 1 m in height and 7 cm in diameter, then complete water capillary capacity was adjusted, and the tubes were placed in a support to collect filtrates. The following potassium doses (in the form of KCl, pure for analysis) were introduced into the plough-humus layer: I – 25%, II – 50%, III – 75%, IV – 100%, V – 125%, and VI – 150% of the sorption capacity (according to Kappen's) of A_p horizon, and against the control. Every object was prepared in three replications. All profiles were flooded every day for 20 days with 21 mm of distilled water, which was equivalent to about 6-months of rainfall. The filtrates thus produced were collected. Once soil watering and solution filtration was complete, soil was removed from the tubes; its samples from particular genetic layers were collected and prepared for determinations following procedures applied for soil material from the natural profile.

Samples were determined for acidity – with potentiometry in 1 mol KCl·dm^{-3} solution, content of available phosphorus and potassium forms – with Egner-Riehm's method, magnesium concentration – with Schachtschabel's method, hydrolytic acidity and sum of exchangeable bases – with Kappen's method, as well as exchangeable aluminum and exchangeable acidity – with Sokołow's method [11].

After extracting (1 mol NH_4Cl·dm^{-3}) the alkaline cations (Ca, Mg, K, and Na) from the sorption complex, their contents were determined by means of Atomic Absorption Spectroscopy [12].

Furthermore, the granulometric composition of the natural profile of soil was determined by applying Cassagrande's sedimentation method with modification by Prószyński, and organic carbon content was assayed by means of Tiurin's method [11]. The resultant filtrates were determined for acidity as well as contents of potassium, sodium, calcium, and magnesium by applying methods commonly recommended for water analysis [13].

Results and Discussion

Soil used in the study had granulation of silt loams within the whole profile (medium texture). In genetic horizons (in addition, the upper $B_{br}1$ and bottom $B_{br}2$ horizons were distinguished in B_{br} and C horizons, respectively), sand percentage was from 17 to 29%, with coarse silt predominating (from 36 to 45%) among the silt fractions, and clay content was from 14% in A_p horizon to 21% in the upper part of browning level. Soil of A_p horizon contained 0.85% of organic carbon (OC) in the upper part of B_{br}, while in its bottom part it contained 0.13% OC. The examined soil was very acidic (pH 4) in the plough-humus horizon, while pH 4.4 to pH 4.6 was measured in deeper horizons (Table 1). Despite that, its exchangeable acidity in $B_{br}2$ horizon and below was negligible, while its hydrolytic acidity did not exceed 2 mmol(+)·100 g^{-1} soil. In turn, higher values were recorded in A_p – 4.65 and $B_{br}1$ – 2.55 mmol(+)·100 g^{-1} soil. These horizons were also characterized by greater amounts of exchangeable aluminum – 2.24 and 0.57 mmol(+)·100 g^{-1} soil, respectively, as compared to about 0.25 mmol(+)·100 g^{-1} soil (from 0.21 to 0.29) recorded in the deeper horizons.

The sum of exchangeable bases in particular genetic horizons varied slightly – in the upper part of enrichment horizon $B_{br}1$ it amounted to 10.7 mmol(+)·100 g^{-1} soil, while in the other horizons it varied from 8.0 to 9.9 mmol(+)·100 g^{-1} soil. The level of alkaline cation saturation in the surface layer was 63.2%, whereas in deeper horizons it ranged from 80.8 to 83.5%.

Table 2 presents contents of available phosphorus, potassium, and magnesium forms as well as alkaline cations extractable with 1 mol·dm^{-3} NH_4Cl from the examined soil. Data indicate low concentrations of available phosphorus and potassium at slight oscillations within the profile, and a high content of available magnesium that can be attributed to quite a large abundance of native soil.

Calcium was found to predominate in the soil sorption complex within particular genetic horizons: from 80.5% in A_p to 86.3% in $B_{br}1$. Contents of magnesium, potassium,

Table 2. Contents of available and extractable forms in the soil profile from Rudna Wielka.

Horizon	Available			Extracted 1 mol $NH_4Cl \cdot dm^{-3}$			
	P	K	Mg	Ca	Mg	K	Na
	$mg \cdot 100\ g^{-1}$ soil			$mmol(+) \cdot 100\ g^{-1}$ soil			
A_p	3.5	9.0	11.1	3.63	0.22	0.37	0.29
$B_{br}1$	4.1	7.3	16.0	5.82	0.34	0.29	0.29
$B_{br}2$	3.8	6.9	16.8	5.19	0.34	0.25	0.31
$B_{br}C$	3.3	6.6	17.3	4.91	0.31	0.21	0.28
C 1	3.4	6.6	17.5	4.96	0.32	0.21	0.29
C 2	3.1	7.3	17.4	4.64	0.31	0.21	0.31

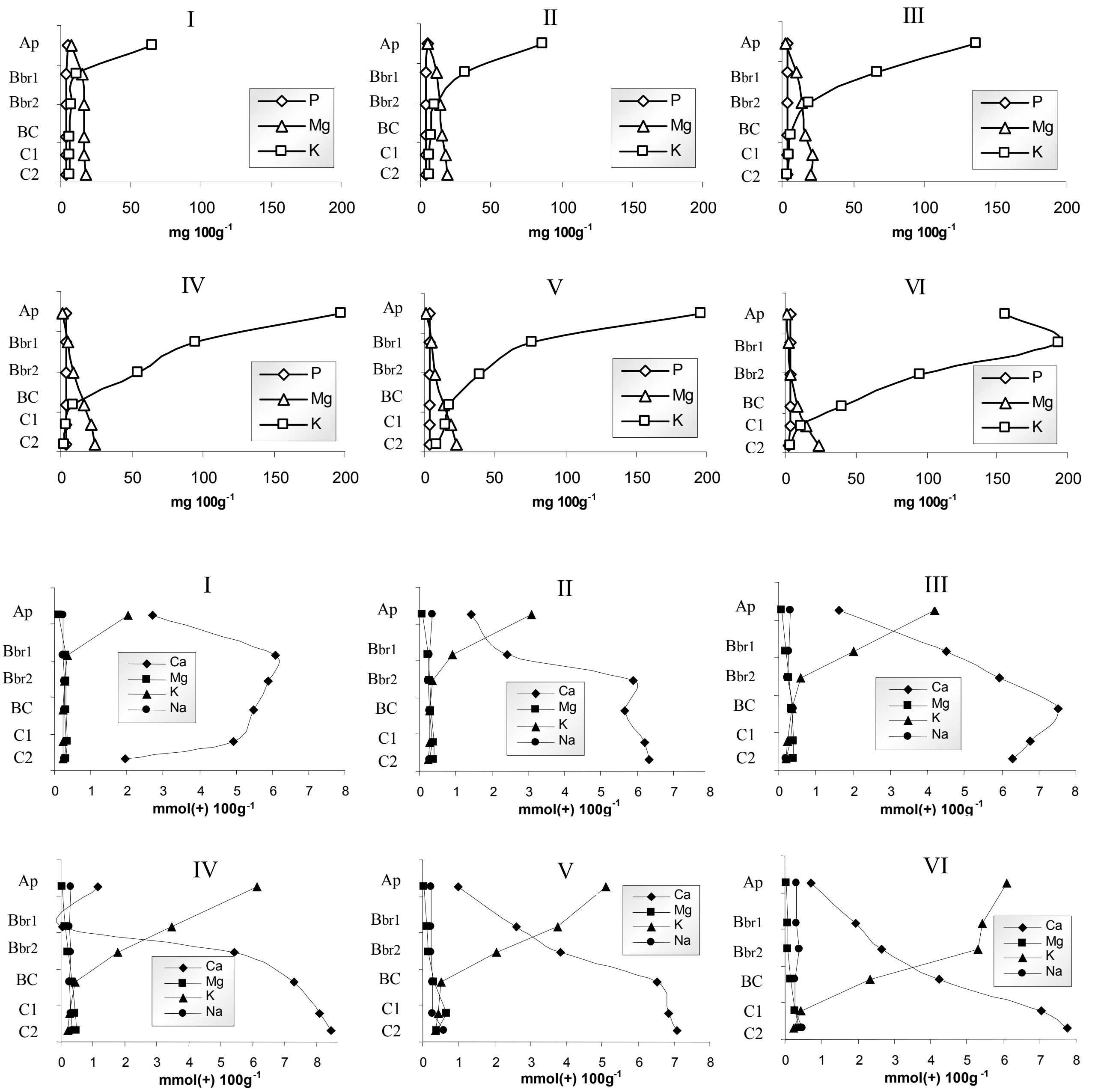

Fig. 1. Contents of available (open symbols) and 1 M NH_4Cl extractable (black symbols) forms of selected elements in particular soil genetic horizons on a background of potassium doses.

Table 3. Effect of potassium doses on physicochemical properties of the soil profile from Rudna Wielka.

Dose of potassium	Horizon	pH 1 mol KCl·dm^{-3}	H_w *	Al^{+3} *	H_h *	SEB *	CEC *	BS * %
			mmol(+)·100 g-1 soil					
I	A_p	4.0	1.02	1.00	4.73	8.20	12.93	63.4
	$B_{br}1$	4.4	0.35	0.34	2.40	10.70	13.10	81.7
	$B_{br}2$	4.5	0.23	0.22	1.18	10.10	11.28	89.5
	$B_{br}C$	4.5	0.24	0.23	1.95	9.80	11.75	83.4
	C 1	4.4	0.36	0.34	1.88	9.70	11.58	83.8
	C 2	4.5	0.37	0.36	1.80	9.40	11.20	83.9
II	A_p	4.0	1.07	1.04	4.68	7.10	11.78	60.3
	$B_{br}1$	4.2	0.45	0.43	2.55	9.70	12.25	79.2
	$B_{br}2$	4.5	0.25	0.24	2.03	10.20	12.23	83.4
	$B_{br}C$	4.5	0.26	0.25	1.95	9.80	11.75	83.4
	C 1	4.4	0.30	0.29	1.88	9.60	11.48	83.6
	C 2	4.5	0.24	0.23	1.73	9.90	11.63	85.1
III	A_p	4.0	0.81	0.79	4.28	6.60	10.88	60.7
	$B_{br}1$	4.2	0.45	0.43	2.93	8.10	11.03	73.4
	$B_{br}2$	4.5	0.24	0.23	2.03	8.80	10.83	81.2
	$B_{br}C$	4.5	0.26	0.25	1.95	8.80	10.75	81.9
	C 1	4.4	0.25	0.24	1.88	8.40	10.28	81.7
	C 2	4.4	0.28	0.27	1.80	8.10	9.90	81.8
IV	A_p	4.1	0.76	0.74	4.28	6.40	10.68	59.9
	$B_{br}1$	4.1	0.74	0.73	3.30	7.40	10.70	69.1
	$B_{br}2$	4.4	0.34	0.33	2.25	10.30	12.55	82.1
	$B_{br}C$	4.5	0.24	0.22	1.87	8.70	10.57	82.3
	C 1	4.4	0.31	0.30	1.95	8.50	10.45	81.3
	C 2	4.5	0.23	0.22	1.80	8.10	9.90	81.8
V	A_p	4.1	0.76	0.74	4.20	6.10	10.30	59.2
	$B_{br}1$	4.2	0.64	0.63	3.15	7.20	10.35	69.6
	$B_{br}2$	4.4	0.31	0.30	2.33	7.60	9.93	76.5
	$B_{br}C$	4.4	0.26	0.25	2.10	8.20	10.30	79.6
	C 1	4.4	0.21	0.20	1.95	7.70	9.65	79.8
	C 2	4.4	0.15	0.14	1.88	8.10	9.98	81.2
VI	A_p	4.1	0.57	0.55	4.22	6.10	10.32	59.1
	$B_{br}1$	4.2	0.58	0.56	3.36	6.50	9.86	65.9
	$B_{br}2$	4.3	0.31	0.29	2.48	6.70	9.18	73.0
	$B_{br}C$	4.5	0.15	0.14	2.03	7.00	9.03	75.3
	C 1	4.4	0.18	0.17	1.95	8.20	10.15	80.8
	C 2	4.4	0.13	0.12	1.87	8.00	9.87	81.0

H_w – Exchangeable acidity, Al^{+3} – Exchangeable aluminum, H_h – Hydrolytic acidity, SEB – Sum of exchangeable bases, CEC – Cation exchange capacity, BS – Base saturation

Table 4. Effects of potassium dose on filtrate pH and quantity of leached elements from the reconstructed soil profile (in mg/tube).

Potassium dose	pH Infiltrate	Element (in mg/tube)			
		K	Na	Ca	Mg
Control	6.96	0.09	3.10	113.10	208.40
I	6.11	0.54	14.02	478.77	421.55
II	6.63	0.97	16.31	649.23	522.19
III	6.25	1.01	18.60	766.01	882.17
IV	6.44	1.22	18.86	709.75	1,094.87
V	6.57	1.55	21.97	760.51	2,143.71
VI	6.27	1.52	24.15	867.60	2,292.33

and sodium were similar, i.e. about 5%, although slightly higher concentrations of univalent cations (Na, K) were found in the A_p horizon as compared to deeper layers.

Washing out the reconstructed soil profile with distilled water (control object) did not change its pH value, acidity, or sorption capacity; only a slight displacement of exchangeable aluminum from A_p to B_{br} horizon was observed. It did not exert any effect on the dynamics of available phosphorus, potassium, and magnesium forms, nor the percentage of alkaline cations extractable with ammonia chloride within the sorption complex.

Eluting the soil enriched with potassium doses resulted in particular reactions and changes in some properties of the soil (Table 3, Fig. 1). No significant changes occurred in the pH value, nor in the exchangeable and hydrolytic acidities; however a tendency for reduced dissolved aluminum concentration was observed within the whole profile, which was important for growing crops [14]. Potassium at dose II (equivalent to 50% sorption capacity of A_p horizon and more) decreased the sorption capacity by 1 to 2 mmol(+)·100 g^{-1} soil in A_p. At doses above 75% of sorption capacity of A_p horizon this also occured in the deeper layers.

A stronger response to the high potassium doses was recorded in the case of available and 1mol $NH_4Cl{\cdot}dm^{-3}$ extractable fractions of particular cations (Fig. 1).

Increasing potassium doses significantly increased contents of its available forms from 65.5 up to 197.7 mg K·100 g^{-1} soil in the ploughed humus horizon, and higher doses – even in the deeper soil layers. When potassium was applied at the dose equivalent to the sorption capacity of A_p (IV) horizon, that influence was apparent in the BC horizon.

Available magnesium was gradually and strongly eliminated from surface layers of the soil profile due to increasing potassium doses. Such a response to potassium treatment was diminished along with its decreasing concentration in the soil. A slight magnesium accumulation occurred within the mother rock (objects III, IV, and V). Nevertheless, the highest potassium dose (object VI) reduced available magnesium level also in the upper layers of the mother rock.

Varied potassium nutrition did not affect the contents of available phosphorus forms within the reconstructed soil profile, and their amounts were from 3.1 to 4.7 mgP·100 g^{-1} soil.

Saturation of the sorption complex was seriously changed by high potassium doses. Potassium sorption showed the greatest dynamics: its content was increasing gradually in particular genetic horizons along with increasing doses, then spread over the deeper soil horizons. Potassium sorption occurred at the expense of release and mobilization of calcium and magnesium cations deep inside the profile; the response of both cations was similar, but with a much higher (about 20-fold) absolute calcium content as compared to magnesium. Varied potassium doses had no impact on sodium dynamics within the reconstructed soil profile. Changes in univalent and bivalent cations in sorption complex saturation affected the hydration level of the soil colloids. A loss of large amounts of bivalent cations and saturating the sorption complex with univalent ones resulted in increased water retention within the profile, which was indicated by varied volumes of the achieved filtrates, where the object with the highest potassium dose produced 1,323 ml, while the control produced 1,447 ml of filtrates. The filtrate pH value was between slightly acidic to almost neutral (from pH 6.11 to 6.96).

Amounts of alkaline cations (extracted and eluted out of the reconstructed soil profile) contained in the achieved filtrates depended on their nature and were associated with the potassium dose (Table 4).

Among the examined elements, magnesium and calcium were the most readily available, while sodium was the most hardly eliminated from the soil profile. In turn, potassium was characterized by slight elimination. A loss of bivalent alkaline cations is associated with their low energy of entering the sorption complex in opposition to univalent ones. Furthermore, the former are subject to chemical sorption (salt-sorption effect) under Polish soil conditions [15, 16].

Conclusions

1. High potassium concentrations in brown soil exerted no effects on desorption of hydrogen ions and changes in acidity of the reconstructed soil profiles.
2. Very high potassium doses strongly extracted the bivalent cations (Mg and Ca) from surface layers by transferring them into the deeper horizons and to the filtrates. Low amounts of potassium were transferred out of the reconstructed soil profile.
3. There was efficient potassium sorption within the A_p horizon, this element was retained in deeper horizons, and at very high potassium doses the saturation balance was reached.
4. Very high potassium doses did not affect the phosphorus dynamics within the reconstructed soil profile.
5. High potassium doses turned out to be the cause of intensive magnesium and calcium elimination from surface layers of the soil. The elements were replaced with a potassium cation, which has no effect on hydrogen ions within sorption complex saturation.

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