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RELATIONSHIPS BETWEEN AVAILABLE AND EXCHANGEABLE
POTASSIUM CONTENT AND OTHER SOIL PROPERTIES

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Abstract. Canonical correlation analysis was applied to the study of interrelationships between two multivariate datasets, one consisting of available and exchangeable potassium content, and second consisting of pH, hydrolytic acidity, and content of exchangeable aluminum, calcium and magnesium, available phosphorus, and total nitrogen. An attempt has been made to provide an overall pattern of interrelationships among soil properties, critically examining the two forms of potassium: available and exchangeable.

Soil is a very complex body, made of biotic and abiotic components. All these components remain in strict relationships between them. The plant-soil interaction must not be ignored, since the soil plays a multiple role in plant life, providing support, space, air, water, and nutrients to the roots. Within the last factor mentioned, nitrogen, phosphorus, and potassium are most commonly applied with fertilizers. Although the potassium is not considered the most important yield-forming nutrient, its uptake by many plants is frequently greater than of nitrogen and phosphorus. Moreover, the effect of potassium on resistance of plants on stress factors, such as pathogens, pests, and draught, cannot be overestimated. Despite, frequently fertilizing with this nutrient is neglected in last years, and the balance of it becomes negative in many countries [2, 3, 10, 17].

There are some papers dealing with interrelationships between various forms of soil K [4, 7, 8, 11, 15]. In some papers, the relationships between selected forms of soil potassium and soil properties, such as granulometric composition, organic

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carbon/matter content, available P, pH, electric conductivity, and others, were considered [1, 5, 9, 11, 15]. In all these studies, different kinds of correlation were used to estimate the relationships between soil properties. However, it is believed that multidimensional analysis is a better tool for studying a relationship pattern within a multidimensional dataset than simple correlation analysis [13]. Because we aim at studying the relationship between two multivariate datasets, one consisting of two potassium forms and the second consisting of other soil properties, the most appropriate, from statistical point of view, is canonical correlation analysis [13].

We have at our disposal many results of various chemical and physico-chemical analyses of soil from long-term fertilizing experiments in Skierniewice (Poland). On the basis of those results, we try to provide an overall pattern of interrelationships between soil properties, giving a special gaze at the two forms of potassium: available and exchangeable. The aim of the paper is to study a relationship between these two K forms content and other properties of the soil, by means of the canonical correlation analysis.

MATERIALS AND METHODS

Plant, soil, and experimental design

The results were obtained from the experiment carried out in the years 1999-2002 at the Experimental Station of Faculty of Agriculture and Biology of Warsaw Agricultural University. The Experimental Station was established in 1922 and is located in Skierniewice in 51° 58' of latitude, 20° 10' longitude, and 120 m of altitude. The climate of the Experimental Station is characterized by average year temperature of 7.9°C and the annual rainfall of 527 mm, conveniently distributed during vegetation period. The trials were conducted on soil defined as stagnic luvisol - loamy sand containing 6-8 % of clay in the plough layer.

In the paper, the results proceeding from long-term static experiment, carried out since 1923, are considered. The complete scheme of this experiment comprises three groups of fields: A1-A4; A5-A8; and AF1 and AF2. The fields A1-A4 and AF have following fertilizing treatments: 0, CaNPK, NPK, PK, NP and NK. The A1-A4 fields are fertilized with nitrogen in a form of ammonium nitrate, and the fields AF with ammonium sulfate, but the doses of N are the same on all fields (90 kg ha⁻¹). The fields A5-A8 are fertilized with ammonium nitrate (as A1-A4), but they have quite different fertilizing treatments: Ca, CaNPK, NPK, CaPK, CaNP and CaNK. The doses and forms of P and K fertilizers are the same on all fields: P – 26 kg ha⁻¹ (superphosphate) and K – 91 kg ha⁻¹ (potassium chloride). The liming is realized every 4 years in dose of 1.6 t CaO ha⁻¹ only on treatments signed with 'Ca'. Our data originate from six fields, namely: the fields AF1, AF2, A2, and A4 with

five fertilizer combinations (CaNPK, NPK, PK, NP and NK) and three replicates; the fields A5 and A8 with one combination (NPK) in three replicates. Thus, there are 66 plots in one year and 264 plots in four years studied. The soil samples had been collected from the plough layer (0-25 cm) every year after harvesting. The study considers two forms of soil potassium, available (Egner-DL method) and exchangeable (1 mol dm^{-3} ammonium acetate), and other properties of soil, namely pH in KCl (1 mol dm^{-3}), Hh – hydrolytic acidity (extraction with calcium acetate, 0.5 mol dm^{-3} , pH 8.2), exchangeable Al (1 mol dm^{-3} KCl), exchangeable Ca and Mg (1 mol dm^{-3} ammonium acetate), available P and total N content (Kjeldahl method modified).

Statistical analysis

Firstly, an ordinary correlation analysis has been conducted. Then, to detect a correlation pattern within the studied system presented in Fig. 1, canonical correlation analysis has been applied. One set of variables comprised both potassium forms – K_{exch} (exchangeable potassium content) and K_{avail} (available potassium content), whereas the second set comprised other studied soil properties: pH, Hh (hydrolytic acidity), Al_{exch} (exchangeable aluminum content), Ca_{exch} (exchangeable calcium content), Mg_{exch} (exchangeable magnesium content), and P_{avail} (available phosphorus content). Canonical correlations methodology presented by Rencher [13] has been employed. Statistical analyses were performed using the R language and environment [12].

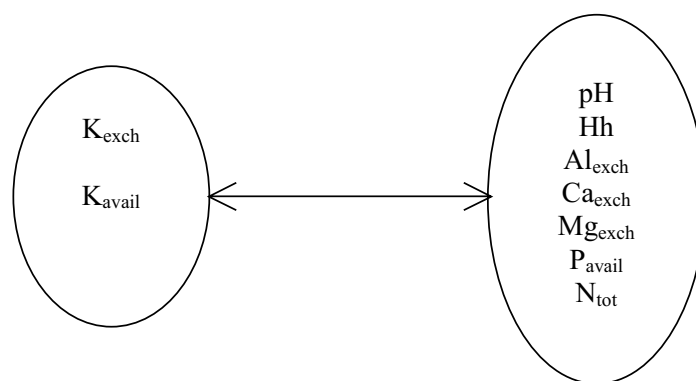


Fig. 1. Diagram of co-relationships among two sets of soil properties: exchangeable and available potassium content (the first set), and pH, hydrolytic acidity (Hh), and content of: exchangeable aluminum, calcium, and magnesium, available phosphorus, and total nitrogen.

RESULTS

Table 1 contains summary statistics for soil properties studied. In Table 2, a correlation matrix for the soil properties is presented. Contents of both potassium forms are quite strongly positively correlated ($r = 0.74$). Moreover, both potassium forms are significantly positively correlated with pH, Ca_{exch} , Mg_{exch} , and N_{tot} , and significantly negatively correlated with Hh and Al_{exch} . Only available phosphorus content is not correlated with K_{exch} and K_{avail} . The two potassium forms appear to be characterized by almost the same pattern of correlation with other soil properties. The most co-related with potassium soil properties are found to be pH, Hh, Al_{exch} , and Mg_{exch} , i.e., the properties strictly correlated with soil acidity.

TABLE 1. SUMMARY STATISTICS FOR STUDIED SOIL PROPERTIES

Soil property	Mean	Standard deviation	Coefficient of variation (%)	Min	Max
K_{exch}	2.92	0.88	30.0	0.99	5.01
K_{avail}	41.04	13.01	31.7	12.00	79.90
pH	3.90	0.66	16.8	3.15	6.40
Hh	30.84	7.70	25.0	13.05	44.25
Al_{exch}	5.37	3.75	69.8	0.13	14.51
Ca_{exch}	17.25	8.16	47.3	4.94	45.01
Mg_{exch}	2.44	1.40	57.5	0.91	8.04
P_{avail}	29.73	8.50	28.6	10.45	48.61
N_{tot}	0.45	0.056	12.4	0.33	0.66

TABLE 2. CORRELATION MATRIX FOR STUDIED SOIL PROPERTIES

	K_{exch}	K_{avail}	pH	Hh	Al_{exch}	Ca_{exch}	Mg_{exch}	P_{avail}
K_{avail}	0.74**	1						
pH	0.41**	0.51**	1					
Hh	-0.49**	-0.56**	-0.91**	1				
Al_{exch}	-0.52**	-0.51**	-0.74**	0.84**	1			
Ca_{exch}	0.46**	0.51**	0.90**	-0.86**	-0.70**	1		
Mg_{exch}	0.39**	0.41**	0.86**	-0.80**	-0.64**	0.88**	1	
P_{avail}	0.06	-0.04	-0.04	0.02	0.02	0.14*	0.01	1
N_{tot}	0.19**	0.16**	0.21**	0.00	-0.08	0.17**	0.23**	0.00

In what follows, we present results of canonical correlation analysis, which can provide a more detailed view on relationships between the two multivariate sets considered. The results are presented in Table 3. Both canonical correlations were significant at $P = 0.01$. The first one (81%, cf. Table 3) is much more significant than the second (19%). Hence, our main attention should be paid to the first canonical correlation, though the second canonical correlation should not be ignored altogether. The eigenvalue for the first pair of canonical variates is not too large (0.416, see Table 3), so the relationship between the investigated sets of soil properties was rather weak (although significant).

TABLE 3. CANONICAL CORRELATIONS FOR TWO SETS OF SOIL PROPERTIES: K EXCHANGEABLE AND AVAILABLE VERSUS THE REST OF STUDIED SOIL PROPERTIES

No.	Eigenvalue	Canonical correlation	Wilks Lambda	Chi-Square	df	P-Value	Significance (%)
1	0.416	0.645	0.526	165.6	14	0.0000	81
2	0.098	0.313	0.902	26.7	6	0.0002	19

The first canonical variate is affected by both potassium forms, but especially by K_{avail} (from the first set) and by pH, hydrolytic acidity, and exchangeable calcium content (from the second set); cf. Tables 4 and 5. It means that the relationship between the two sets results especially from the relationship between

TABLE 4. COEFFICIENTS OF CANONICAL VARIATES FOR THE FIRST SET OF SOIL PROPERTIES

Variable	1st canonical variate	2nd canonical variate
K_{exch}	0.439	1.429
K_{avail}	0.630	-1.336

TABLE 5. COEFFICIENTS OF CANONICAL VARIATES FOR THE SECOND SET OF SOIL PROPERTIES

Variable	1st canonical variate	2nd canonical variate
pH	-0.798	-1.772
Hh	-1.218	0.164
Al_{exch}	-0.170	-0.986
Ca_{exch}	0.720	-0.146
Mg_{exch}	-0.471	1.113
P_{avail}	-0.092	0.369
N_{tot}	0.419	0.198

available potassium content and hydrolytic acidity, pH, and exchangeable calcium content. It is also influenced by the relationship between exchangeable potassium content and the three mentioned properties.

The second canonical correlation is also significant, but about four times less significant than the first one. The second canonical variate is affected by both potassium forms; the exchangeable form affects it positively, whereas the available form negatively. Among the second set, especially pH has its negative influence on this canonical variate, but also exchangeable magnesium (positive) and aluminum content (negative) has.

DISCUSSION

The positive correlation between exchangeable and available forms of potassium, obtained in this work, has been also obtained by other authors [e.g., 8, 14], it seems to be clear, because the exchangeable form is considered to be the main source of available potassium.

The relationships between the available and exchangeable potassium forms and other studied soil properties occur to be rather weak, because the eigenvalue for the first canonical correlation is small [13]. However, the relationship is significant; it results mainly from the negative co-relation between both potassium forms (but especially the available one) and hydrolytic acidity and pH. The relationship between the two potassium forms and soil acidity is difficult to foresee. Potassium is a basic cation, although less important than calcium and magnesium, and the soil acidification results from leaching of basic cations from soils. It means that there should be a positive correlation between pH value of soil and both potassium forms, on the contrary to the correlation between hydrolytic acidity and both potassium forms. On the other hand, an intensive fertilization with potassium may increase leaching of Ca and Mg from soil, causing soil acidification [16]. It suggests negative correlation between pH of soil and both potassium forms.

In this paper, the positive Pearson correlation is obtained between pH of soil and exchangeable and available potassium forms. Similar result was reported by Domska *et al.* [6], although another authors found no relationship between pH of soil and exchangeable potassium [4, 8] or between pH and available K [1, 8]. Moreover, Panwar *et al.* [11] found negative correlation between pH value of soil and water soluble potassium.

However, the results of canonical correlations analysis indicate the opposite character of relationship between pH of soil and both K forms considered, than Pearson correlations. The only sensible explanation of this situation is that, what we have mentioned before, the multivariate statistical approach (as canonical correlations) is methodologically more appropriate than the univariate approach (as Pearson's correlation) in studying the relationships within a multivariate

dataset [13]. Therefore, in our opinion it is the conceivable evidence that the multivariate approach is more appropriate than a set of univariate analyses (Pearson's correlations), when seeking of the patterns of co-relationships between two multivariate sets.

CONCLUSIONS

1. A relationship between content of the available and exchangeable potassium forms and other studied soil properties has been found to be weak, although significant.

2. This relationship is mainly a result of the negative co-relation between both potassium forms (but especially the available one) and hydrolytic acidity and pH.

3. Canonical correlation analysis has been proved to be a powerful multivariate statistical method to provide a detailed and multidimensional view of relationships between two co-related sets of soil properties.

4. Canonical correlations and Pearson's correlations may provide different conclusions on the relationships within a multivariate dataset, which makes us claim that Pearson's correlations, still being a common approach in such multivariate investigations, may lead to untrue conclusions.

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ZWIĄZKI POMIĘDZY ZAWARTOŚCIĄ DOSTĘPNEGO I WYMIENNEGO POTASU ORAZ INNYMI WŁAŚCIWOŚCIAMI GLEBY

Zastosowano analizę korelacji kanonicznych w celu zbadania związków między dwoma wielowymiarowymi zestawami zmiennych. Jeden z tych zestawów obejmuje zawartość dostępnego i wymiennego potasu, natomiast drugi uwzględnia pH, kwasowość hydrolityczną oraz zawartość glinu, wapnia i magnezu wymiennego, fosforu dostępnego i azotu ogólnego. Na podstawie analizy przedstawiono ogólny schemat związków pomiędzy właściwościami gleby a dwoma postaciami potasu, tj. dostępnego i wymiennego.