J. Elem. s. 305–315 DOI: 10.5601/jelem.2012.17.2.12

EFFECT OF YEARS, FERTILIZATION AND GROWING REGIONS ON THE CONTENT AND FORMS OF POTASSIUM IN SOIL*

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Abstract

The dynamics of potassium (K) in soil was investigated in long-term small-plot field trials at seven stations, where five combinations of fertilization were tested. The objective of the experiment was to estimate the effect of the weather conditions, type of growing region and increasing doses of fertilizers on the content of water soluble K (Sol-K), exchangeable K (Ex-K) and acid soluble K (Ac-K) in soils. The weather conditions had the strongest effect on the total variability of the Sol-K (34.9%), to a lesser extent on the variability of Ex-K (14.1%) and only negligibly on the Ac-K (0.3%). In the individual years of the experimental period, the content of water soluble and Ex-K was particularly affected, chiefly by the weather and due to different demands of crops for this nutrient (leguminous plants consume high amounts and cereals relatively low amounts of K). In fairly dry years (e.g. 1982), the level of potassium (Sol-K and Ex-K) in soil was higher than in years with precipitation above the average. The content of soluble and exchangeable K was positively influenced by the application of potassium fertilization (0.989, 0.994, respectively). Compared to the control, the content of Sol-K and Ex-K in the variant where the fertilizer dose was the highest increased by 69.3 and 55.3%, respectively. Potassium fertilization (compared to the control) raised the level of the Ac-K, but not significantly, also implying that the effect of fertilization on the total variability of the Ac-K (0.6%) was virtually none. The effect of the growing region on the total variability of the potassium content was higher wherever the potassium bonding to the the sorption soil complex was stronger. The diffe-

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*The study was supported by the National Agency for Agricultural Research of the Czech Republic, project no. QD 1326 "Soil fertility stabilization from the viewpoint of phosphorus and potassium plant nutrition".

rences between the average levels of Sol-K characterizing the growing regions were not statistically significant. The levels of Ex-K and Ac-K differed significantly in the sugar-beet growing region, where the reserve was more than 40% higher than in the potato growing region.

Key words: long-term field trials; water soluble K; exchangeable K; acid soluble K.

WPŁYW LAT, NAZWOŻENIA I REGIONU UPRAWY NA ZAWARTOŚĆ I FORMY POTASU W GLEBIE

Abstrakt

Dynamikę zmian zawartości potasu (K) w glebie badano w trakcie wieloletnich doświadczeń polowych małopoletkowych prowadzonych w siedmiu stacjach doświadczalnych, z zastosowaniem pięciu kombinacji nawożenia. Celem doświadczenia było ocenienie wpływu warunków pogodowych, rodzaju regionu, gdzie prowadzono uprawę, oraz wzrastających dawek nawożenia na zawartość w glebie K rozpuszczalnego w wodzie (Sol-K), K wymiennego (Ex-K) oraz K rozpuszczalnego w kwasach (Ac-K). Warunki pogodowe wywarły najsilniejszy wpływ na całkowitą zmienność Sol-K (34,9%), w mniejszym stopniu – na zmienność Ex-K (14,1%), a ich wpływ na zmienność Ac-K był niemal niezauważalny (0,3%). W poszczególnych latach doświadczenia zawartość K rozpuszczalnego w wodzie i wymiennego podlegała szczególnym wpływom badanych czynników, zwłaszcza warunkom pogodowym i zróżnicowanemu zapotrzebowaniu roślin uprawnych na ten składnik odżywczy (rośliny strączkowe zużywają duże ilości potasu, rośliny zbożowe zaś potrzebują niewielkich ilości tego pierwiastka). W stosunkowo suchych latach (np. 1982) zawartość potasu (Sol-K i Ex-K) w glebie była wyższa niż w latach z opadami powyżej średniej. Na zawartość K rozpuszczanego i wymiennego dodatnio wpływało zastosowanie nawożenia potasowego (odpowiednio 0,989 i 0,994). W porównaniu z kontrolą, zawartość Sol-K i Ex-K w wariancie z najwyższą dawką nawozu wzrosła odpowiednio o 69,3 i 55,3%. Nawożenie potasem (w porównaniu z kontrolą) wpłynęło na zwiększenie zawartości Ac-K, aczkolwiek nie był to wzrost statystycznie znaczący, co wskazuje tym samym, że wpływ nawożenia na całkowitą zmienność Ac-K (0,6%) był niemal zerowy. Wpływ regionu uprawy na całkowitą zmienność zawartości potasu był silniejszy w przypadku silniejszego wiązania potasu z kompleksem sorpcyjnym gleby. Różnice między średnimi zawartościami Sol-K w obu regionach nie były istotne statystycznie. Zawartości Ex-K i Ac-K różniły się statystycznie w regionie uprawy buraka cukrowego, gdzie ich rezerwa była o 40% wyższa niż w regionie uprawy ziemniaka.

Słowa kluczowe: wieloletnie doświadczenie polowe, K rozpuszczalny w wodzie, K wymienny, K rozpuszczalny w kwasie.

INTRODUCTION

Potassium is an essential element for plants and animals, and is considered a major nutrient element together with nitrogen and phosphorus (Oborn et al. 2005). Generally, it is not a limiting element in agricultural systems, but it is a major nutrient for crop quality and yield in intensive grass or lucerne dominated systems and rotations dominated by potatoes and green vegetables (WHITEHEAD 2000). In agricultural production, including many organic farming systems, K has become a limiting element, especially in areas dominated by coarse-textured or organic soils (GOULDING, LOVELAND 1986). Its deficiency may reduce plant production quantitatively as well as qualitatively and typical visible deficiency symptoms are chlorosis and necrosis on the tips and margins of mature leaves.

The total content of K depends on the parent material, soil type and mineralogy. Traditionally, four forms of soil K are recognized: structural or mineral K, non-exchangeable K, also referred to as fixed K, exchangeable K and K in water solution (SPARKS 1987). Exchangeable and water solution K are often considered readily available to plants (SPARKS 1987), while interlayer and fixed K is frequently described as slowly or potentially available and structural K as almost unavailable (PAL et al. 1999, řGAARD et al. 2001). The acid soluble K stands for that part of soil K which forms a transitional form between the exchangeable and non- exchangeable forms, which only minimally contribute to plant nutrition. It is the soil K which is released from inter-lamellar spaces of some potassium alumo-silicates after the disintegration of their crystal lattice. According to HUDCOVA and VOPLAKAL (1981), this fraction more adequately characterizes the natural reserve of potassium in the soil than exchangeable potassium.

There is a dynamic equilibrium between the phases of soil K (SPARKS 1987), hence all factors that affect this equilibrium reactions will indirectly affect the volume of different K forms.

The objective of this study was to determine the effect of year, mineral fertilizers, organic manure and types of growing regions on the content of potassium forms in the soil.

MATERIAL AND METHODS

Experimental design

The experiment was established at 7 sites in potato (altitude 400-650 m a.s.l., annual average temperature 5-8°C, annual average precipitation 550--900 mm, predominant cambisols) and sugar-beet growing regions (altitude 250-350 m a.s.l., annual average temperature 8-9°C, annual average precipitation 500-650 mm, predominant chernozems and haplic luvisols) as a long-term, small-plot stationary trial. It was conducted by the Central Institute for Supervising and Testing in Agriculture between 1982 and 1998. Table 1 gives the characteristics of the sites.

The experiment comprised 5 combinations of fertilization, in 3 replications. Table 2 shows the average content of N, P and K, which were applied in organic fertilizers (farm manure) and mineral fertilizers at three levels (low – $N_1P_1K_1$, medium – $N_2P_2K_2$, high – $N_3P_3K_3$). In both production re-

Table 1

Characteristics of the sites

Site	Growing regions	Altitude (m a.s.l.)	Annual average		Soil type	Soil textural class
			temperature (°C)	precipitation (mm)		
Horazďovice	potato	470	7.4	573	Cambisols	sandy s.
Svitavy	potato	460	6.5	624	Cambisols	sandy s.
Chrastava	potato	345	7.1	798	ha Luvisols	loamy s.
Staňkov	potato	370	8.3	443	ha Luvisols	clay s.
Pusté Jakartice	sugar.-beet	295	8.0	640	ha Luvisols	loamy s.
Uherský Ostroh	sugar.-beet	196	9.2	551	ha Luvisols	loamy s.
Zatec	sugar.-beet	247	8.3	451	Chernozems	clay s.

soil type (FAO soil taxonomy), soil textural class SHEPARD 1954)

Table 2

Treatments of the experiment

Var. No.	Treatments of fertilization	Doses of nutrients in applied fertilizers (kg ha^{-1} $year^{-1}$)					
		nitrogen		phosphorus		potassium	
		PGR	SGR	PGR	SGR	PGR	SGR
1	no fertilization	0	0	0	0	0	0
2	manure	25*	25*	8*	8*	35*	35*
3	manure + $N_1P_1K_1$	25*+58**	25*+58**	8*+23**	8*+21**	35*+57**	35*+51**
4	manure + $N_2P_2K_2$	25*+88**	25*+87**	8*+35**	8*+33**	35*+90**	35*+81**
5	manure + $N_3P_3K_3$	25*+117**	25*+115**	8*+51**	8*+49**	35*+131**	35*+119**

PGR – potato growing regions, SGR – sugar-beet growing regions;
* – doses of nutrients applied in organic fertilizers;
** – doses of nutrients applied in mineral fertilizers

gions, mineral fertilizers containing phosphorus and potassium were supplied as a reserve in autumn of the preceding year. The source of phosphorus was granulated super-phosphate; potassium was applied as potassium chloride. Nitrogen was applied in ammonium sulphate during pre-sowing soil preparation and ammonium nitrate with lime was applied as additional foliar nutrition. Organic fertilizers were applied twice in the crop rotation; 40 t ha^{-1} of good-quality farm manure was incorporated in the sugar-beet growing region under maize for silage and under sugar-beet, and in the potato growing region – under potatoes (the average doses of nutrients applied in manure are shown in the Table 2).

The crops in the experiment were grown in regular crop rotations. Before 1989 (1981-1989) nine plots were used for crop rotations in both growing regions; from 1990 (1990-1997 and 1998-2005) the crop rotations were arranged in eight plots; 50% of the crops were cereals. The crops grown in the experimental years are mentioned in the Table 3. Table 4 shows the weather conditions during the experiment.

Table 3

The crops grown in the sampling years

Year	Potato growing regions	Sugar-beet growing regions
1982	potatoes	sugar beet
1987	spring barley	spring barley
1991	clover	alfalfa
1995	spring barley	spring barley
1998	oat with underseeding clover	oat with underseeding alfalfa

Table 4

Weather conditions in potato and sugar-beet growing regions during the experiment

Growing regions	Average	Years				
		1982	1987	1991	1995	1998
Potato	temperature (°C)	7.8	6.6	7.2	7.9	8.2
	sum of precipitation (mm)	533	735	540	738	645
Sugar-beet	temperature (°C)	8.8	7.6	8.2	9.0	9.1
	sum of precipitation (mm)	456	645	497	629	601

long term average sum of precipitation and temperature in potato growing regions (664 mm and 7.6°C) and in sugar-beet growing regions (544 mm and 8.6°C)

Soil sampling and analysis

Soil was sampled at all the sites in autumn 1982, 1987, 1991, 1995 and 1998. Soil samples were taken from the 0-30 cm depth. Samples were dried naturally and passed through a 2-mm sieve. The solution potassium of the soil in its dry state (in the text abbreviated as Sol-K) was determined using distilled water solution [ratio of soil to solution of 1:5 (w/v)] (Javorský et al. 1987) and measured by atomic absorption spectrometry (AAS) on a Carl Zeiss Jena AAS-30 apparatus. Exchangeable K of the soil in its dry state (in the text abbreviated as Ex-K) was estimated by the method of Jones (1990), with the soil extracted with solution Mehlich III (NH_4F, NH_4NO_3, CH_3COOH, HNO_3 and EDTA) [ratio of soil to solution of 1:10 (w/v)]. The concentration of K in the extract was measured by atomic absorption spectrometry (AAS). K-HNO_3 was extracted by boiling a soil sample in its dry state in 1 M HNO_3 for 10 min [ratio of soil to solution of 1:10 (w/v)] (Neuberg 1985). After filtration, the K concentration in the extract was measured by atomic absorption spectrometry (AAS). The exchangeable K value was subtracted from the K-HNO_3 value and the difference is called acid soluble K (in the text abbreviated as Ac-K).

Statistical evaluation

The results of chemical soil analyses were computer-processed and set up using the Microsoft Excel editor. The Statistica 7.1 programme was used for determination of the overall characteristics. Arithmetic means were calculated when evaluating the results. In order to elaborate the significance of differences among the arithmetic means of each characteristic, we used one- and two-way analysis of variance, followed by testing at a 95% (p<0.05) level of significance using Tukey's test.

RESULTS AND DISCUSSION

The results of the long-term trial showed that the amount of potassium representing the above forms and its spatial and temporal variability primarily depended on the bonding of potassium to the sorption complex of the soil and exchangeability of the potassium pool. This conclusion is based on a big difference in the effects produced by individual factors (weather during the year, fertilization and growing region) expressing the overall variability of the respective K forms, which was particularly evident between the intensively (water soluble and exchangeable potassium) and extensively (acid soluble potassium) available potassium.

The effect of the weather conditions of the year

The variability of amounts of water soluble and exchangeable forms of potassium monitored in the individual experimental years (Table 5) was mainly attributed to the changeable weather and to the different demands of the crops for this nutrient. The conclusions of Jouany et al. (1996), Berry et al. (2003) and Holmqvist et al. (2003) confirmed that the climate in a given year was one of the basic factors affecting the K content in soil and had the strongest effect on the total variability of Sol-K (Table 6). The highest K content was detected in the first experimental year and was statistically significantly higher [F (4; 125) = 6.50, p=0.001] than in 1991 and 1995, i.e. by 42.3 and 24.4%, respectively (Table 5). The high content of Sol-K detected in 1982 was probably due to the low sum of precipitation of the year, which was below the long-term average. This is confirmed by Hudcova and Furst (1982), Zeng and Brown (2000) and Mengel et al. (2001), who stated that the content of water in the soil considerably affected the amount of Sol-K. Poss et al. (1991) further discovered that in dry years the uptake

Table 5

Average content of soil soluble K, exchangeable K and acid soluble K (mg kg^{-1} DM soil)

Factors	Soil soluble K		Exchangeable K		Acid soluble K	
	mg kg^{-1} ± SE	ν	mg kg^{-1} ± SE	ν	mg kg^{-1} ± SE	ν
Years						
1982	27.9 ^{b} ± 1.80	38.1	174.0 ^{c} ± 10.4	35.3	579 a ± 40.3	41.1
1987	21.8 ^{ab} ± 1.51	41.1	120.4 ^{ab} ± 8.5	41.9	607 a ± 39.8	38.8
1991	16.1 ^{a} ± 1.13	41.7	108.8 ^{a} ± 9.6	52.2	589 a ± 40.1	40.2
1995	21.1 ^{a} ± 1.58	44.4	129.4 ^{ab} ± 10.2	46.8	586 ^{a} ± 37.7	38.0
1998	22.1 ^{ab} ± 1.89	50.7	147.0 ^{bc} ± 10.3	41.6	621 ^{a} ± 44.1	42.0
Fertilization						
No fertilization	16.6 ^{a} ± 1.21	43.0	105.3 ^{a} ± 7.6	42.7	573 ^{a} ± 38.8	40.1
Manure	17.8 ^{a} ± 1.27	42.2	120.6 ^{ab} ± 9.7	47.4	580 ^{a} ± 39.6	40.4
Manure + $N_1P_1K_1$	22.6 ^{ab} ± 1.42	37.2	142.2 ^{abc} ± 10.0	41.6	613 ^{a} ± 40.6	39.2
Manure + $N_2P_2K_2$	23. 9 ^{b} ± 1.78	44.1	147.9 ^{bc} ± 10.4	41.5	607 ^{a} ± 41.4	40.3
Manure + $N_3P_3K_3$	28.1 ^{b} ± 2.03	42.7	163.5 ^{c} ± 11.8	42.7	610 ^{a} ± 41.6	40.3
Growing regions						
PGR	21.2 ^{a} ± 0.86	40.7	114.8 a ± 4.5	38.9	507 ^{a} ± 18.1	35.7
SGR	22.5 ^{a} ± 1.36	52.5	164.1 b ± 8.1	42.8	715 ^{b} ± 29.0	35.0

SE – standard error, ν – variation coefficient (%), PGR – potato growing regions; SGR – sugar-beet growing regions; Variants with identical letters express statistically insignificant differences (P<0.05 – statistical significance at a 95% level of significance).

Table 6

Relative effect of factors on total variability of examined forms of K (%)

Factors	Water soluble K		Exchangeable K		Acid soluble K	
A: years	34.9	***	14.1	***	0.3	ns
B: fertilization	47.8	***	12.6	***	0.6	ns
C: growing regions	4.4	ns	68.9	***	94.7	***
A × B	1.2	ns	0.4	ns	0.0	ns
A × C	3.2	ns	1.0	ns	1.0	ns
B × C	1.7	ns	0.8	ns	0.2	ns
A × B × C	1.3	ns	0.2	ns	0.1	ns

* $\alpha = 0.05$, **$\alpha = 0.01$, *** $\alpha = 0.001$, ns = not significant

of potassium from the soil and from fertilizers decreased, while the content of K in the soil increased. Table 5 shows that also the content of Ex-K was statistically the highest in 1982 [F150 (4; 125) = 7.15, p<0.001]. Most of this form of K was absorbed and hence the reserve in the soil was the lowest in 1991, when red clover was incorporated in the crop rotation, confirming the fact that of all leguminous plants absorb most of potassium (Pal et al. 1999, Wang et al. 2000). In 1987, 1995 and 1998, the average amount of Ex-K ranged between 120 and 147 mg kg^{-1}. The crop rotations then included cereals, which – according to Kuhlmann and Wehrmann (1984) and Askegaard et al. (2003) – have a relatively low demand for potassium. This development corresponds with the conclusions of Mengel et al. (2001), who stated that changes in the content of Ex-K are caused by the succession of crops in crop rotations. The trend in time-related variability of this potassium fraction was closely correlated with the trend in Sol-K. The conclusions of Brar et al. (1986) confirmed this fact. However, the weather conditions of the year affected the exchangeable form of K to a lesser extent (Table 6) and their effect on the overall variability of the Ac-K was virtually zero. This corresponds to the statistically insignificant differences between the content discovered in the individual years of the experiment [F (4;125) = 0.11, p=0.979] – Table 5. The greatest difference was observed between the years 1982 and 1998; the Ac-K increased by 7.3%.

The effect of fertilization

Fertilization was the decisive factor affecting the variability of the content of the Sol-K (Table 6) [F (4;125) = 8.91, p<0.001]. The correlation coefficient r=0.989 expresses the positive effect of this factor on the water soluble form of K and is consistent with the opinion of Hudcova and Sirovy (1981), Hudcova (1989), Heming (2004) and Fortune et al. (2005), who discovered that the concentration of the Sol-K is dependent primarily on potassium fertilization. In our trial, fertilization with 160 kg K ha^{-1} increased the content of this form of K by 69.7% compared to the unfertilized variant (Table 5). Bansal et al. (2002) also confirmed the positive effect of 177 fertilization; they discovered that in the course of 10 years the average content of Sol-K in unfertilized soil decreased from 14.5 to 11.3 mg kg^{-1}. Analogously, the correlation coefficient (0.994) of Ex-K showed its strong dependence on increasing doses of K fertilizers. Hudcova (1985) and Askegaard and Eriksen (2002) reached the same conclusions; the latter found a positive correlation between Ex-K and increasing doses of fertilizers, also in combination with liming and particularly with organic fertilization. In the present experiment, the statistically significantly lowest content of Ex-K was monitored in the control variant (Table 5) and the highest one appeared in variant 5 [F (4;125) = 6.42, p<0.001]. Hrtanek (1987) likewise reported an increased content of the Ex-K from 117 mg kg^{-1} (unfertilized variant), to 174 mg kg^{-1} (variant fertilized with 113 kg K ha^{-1}) to 244 mg kg^{-1} in the variant fertilized with the highest dose (226 kg K ha^{-1}). Richter et al. (2002) likewise discovered that this form of K was much dependent on fertilization (r=0.762 – 0.964). These authors further reported that after the application of 1 kg of K fertilizers the level of exchangeable potassium increased by 0.15-0.42 mg kg^{-1} depending on the soil type In our experiment, the increase was very much the same, ranging between 0.30 and 0.50 mg kg^{-1}. The data given in the table 5 indicate that potassium fertilization (compared to the control) also increased the level of the Ac-K. However, among the individual variants, including the control, no significant differences were found (Table 5) [F (4;125) = 0.19, p=0.944]. The effect of fertilization on the total variability was negligible (Table 6). Also Hudcova and Sirovy (1981) proved that fertilization did not considerably affect the acid soluble potassium. But other results presented by Hudcova and Voplakal (1981) indicated that intensive NPK fertilization increased the content not only of Ex-K, but also of forms with stronger potassium bonds (acid soluble K and total K). Also Takac and Peslova (1994) proved that especially potassium supplied in fertilizers produced this form. On the contrary, Hrtanek (1987) discovered that increasing doses of fertilizers had no effect on the content of Ac-K.

The effect of the growing region

The results confirmed that the growing region is an important factor affecting mainly the content of the Ac-K. Table 6 shows that the effect of the factor on its total variability increased with the increasing intensity of the bonding of potassium to the sorption soil complex. The differences between the average content of Sol-K characterizing the growing regions were not statistically significant (Table 5) [F (1; 125) = 0.82, p=0.367]. A significant difference was detected in the Ex-K [F (1; 125) = 34.99, p<0.001] and Ac-K [F (1; 125) = 30.32, p<0.001]. The amounts of both of these fractions of potassium were 40 % higher in the sugar beet growing region than in the potato growing region (Table 5).

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