Interannual dynamics of available potassium in a long-term fertilization experiment

M. Madaras, J. Lipavský

Crop Research Institute, Prague, Czech Republic

ABSTRACT

Dynamics of the plant-available potassium (K) has been studied in polyfactorial long-term fertilization experiments since 1980. The fertilization scheme includes 10 combinations of K muriate and farmyard manure application rates (annually 0–230 kg K/ha). At medium treatment (annually 153 kg K/ha), the K balance within an 8-year crop rotation reflected crop specific K application rates with positive annual balances in years of growing silage maize and sugar beet (high K input), and negative in two years of growing alfalfa. Available K clearly corresponded to the dynamics of the K balance, with statistically significant fluctuations from 88 to 149 mg K/kg within one crop rotation cycle. Periodic fluctuations of available K induced by crop rotation were observed also in non-fertilized treatments. The variability of available K contents was influenced primarily by crop plants and experimental unexplained factors; interannual weather fluctuations and field differences were of low significance. In the paper, the importance of interannual K dynamics for the construction of correct long-term time trends is shown and discussed.

Keywords: long-term experiments; potassium; soil; nutrient balance; crop rotation

Long-term fertilization experiments provide an opportunity for experimentation in which the effects of manipulation may be separated from other variables (Southwood 1994). The value of long-term trials, even though nowadays it is questioned, is irreplaceable – the long-term trials are the basic platform for examination and quantification of cultivation-based changes in agro-ecosystems and enable the evaluation of the effects of long-term different intensity of fertilization on nutrient dynamics (Merbach and Deubel 2008). In many European countries, the oldest long-term experiments are still being maintained and provide essential information for agriculture and environmental science.

In the Czech Republic, most of the long-term field experiments had been founded and maintained by the Crop Research Institute (CRI), Prague. The oldest trials were established in 1955 in Prague-Ruzyně. The trials were maintained at twelve sites differing in soil and climatic conditions. The main experimental factors investigated were crop nutrition, crop rotation, cultivation technologies and organic manuring (for an overview see Lipavský et al. 2005).

An important question that can be answered with the help of long-term trials is the one concerning the long-term effects of contemporary K management. Fertilizer and manure application rates and timing are based on the optimal nitrogen rate and not on K requirements (Oborn et al. 2005). In addition, changes in the structure and financing of the agronomic sector in the Czech Republic that occurred after 1989, accompanied with continuous increase of input costs led to a dramatic drop in the use of K mineral fertilizers. The actual average annual application rate is 8 kg/ha of mineral K and 17 kg K in manures (Anonymous 2007), that is only 15% of the application rate before 1989. In this type of management, K balance becomes highly negative – outputs are higher than inputs and K is released from internal soil sources.

The issue of sustainable soil K management was partly ignored during the last few decades while the potential environmental impact of agricultural use of nitrogen and phosphorus was considered a more important problem (Simonsson et al. 2007). From this viewpoint, trial plots with low or zero K inputs are of special interest within long-term K fertilization trials. They can provide essential

Supported by the Ministry of Agriculture of the Czech Republic, Project No. MZE 0002700604.

Table 1. Independent experimental factors investigated within the polyfactorial field experiments

Years	Factor					
	1	2	3	4	5	6
1980–1984	N before sowing	N during vegetation	P	FYM	K	stand density
1985–1995	N	lime	P	FYM	K	stand density
1995–present	N	lime	P	FYM	K	Mg

Different application rates of: N – nitrogen; P – phosphorus; FYM – farmyard manure; K – potassium; Mg – magnesium; stand density – number of plants/seeds per hectare

information about the effects of our present common agricultural practices and their possible future impacts on soil quality.

In this paper we evaluate selected data from polyfactorial field experiments, established in 1980 at CRI. Until now, large datasets taken within the experiments were only processed partially and no comprehensive works have been published. In this article we evaluate K inputs/outputs and plant-available K data as a base for analysis of long-term trends. The aim of the article is to evaluate the dynamics of available K and discuss its importance as related to the construction of correct time trends in cases of timely non-regular soil sampling.

MATERIAL AND METHODS

Polyfactorial field experiments were originally established at 9 sites representing different pedo- and climasequences of the arable soils in the Czech Republic. For each experiment, a central scheme of the second order design in incomplete blocks was used, according to Cochran and Cox (1957). At each site the trial consisted of four fields, each consisting of 56 plots of 5 × 12 m, designed in 4 rows. Within the scheme, the influence of 6 independent factors was tested. Some factors were altered during the experiment (Table 1).

Five levels corresponding to each factor were set up in a manner that medium level reflected standard agricultural cropping practice, specific for each crop-plant, and the highest level was supposed to limit plant growth by the excess of the nutrient (or by very high stand density). Zero level means no use of the fertilizer, except in the case of stand density where some low density was chosen. Between the medium and extreme levels, two other levels (higher, lower) were set up, of which the 'higher' was supposed to be optimal or

Table 2. Crop rotation in experiments and application rates (factor levels) for crop-plants. For farmyard manure (FYM) and potassium (K), factor levels are shown in order minimum/lower/medium/higher/excess level. For lime, phosphorus (P), magnesium (Mg) and denstity of crop-plants, only medium levels are shown

Year	Crop–plant	N$	Lime*	P	FYM (10^3 kg/ha)	K	Mg	Stand density seeds/ha
		(kg/ha)				(kg/ha)		
1	clover + oat/alfalfa + oat	40	1750	60	–	0/60/100/140/200	40	16 kg
2	clover/alfalfa	–	–	–	–	–	–	–
3	winter wheat	100	1750	40	–	0/40/70/100/140	40	$4.5.10^6$
4	silage maize	175	1750	50	0/20/40/60/80	0/85/150/215/300	40	8.10^4
5	winter wheat	125	1750	40	–	0/40/70/100/140	40	$4.5.10^6$
6	spring barley	90	1750	40	–	0/30/50/70/100	40	$4.5.10^6$
7	potato/sugar beet	150	1750	50	0/20/40/60/80	0/85/150/215/300	40	$8.5.10^4$
8	spring barley	60	1750	40	–	0/30/50/70/100	40	$4.5.10^6$

$total for all applications; *liming each second year, after 1995 only if necessary, using amelioration dose to reach neutral soil reaction; – factor not used; depending on climatic conditions of the site close-to-optimal in order to satisfy crop demands and reach maximum yield. The influence of the factors was investigated in 8-year crop rotation (Table 2), including 50% of cereals, potato/sugar beet, silage maize and clover/alfalfa (depending on the climate conditions of the site). In fields, rotation was phased in 2-year shifts.

Within trials at given sites each field originally consisted of 47 different treatments. 10 plots had the same treatment with all factors at medium level. This set of 10 equally treated plots was used for the calculation of variability parameters because all other treatments were not replicated within a given field. 32 treatments had different combinations of 'higher' and 'lower' levels, 12 treatments had all factors at medium level and always had one of the factors at 'zero' or 'excess' level. One treatment had all factors at zero level (i.e. 'not treated') and the last treatment had all factors at zero level and the 6^{th} factor at the 'excess' level. This treatment was changed to 'not treated' after 1995.

This set of treatments was the same for all four fields, which differed only in the distribution of treatments within the field. It means that the majority of treatments were replicated four times.

N fertilizers were used in the form of ammonium nitrate or ammonium sulphate; P as super-phosphate; K as K muriate and Mg in the form of Mg sulphate.

After harvest (except in the second year of alfalfa/clover), soil samples (consisting of 5–8 subsamples within the plot) of plough horizon (depth of 0–20 cm) were taken and analyzed for soil reaction, organic carbon content, total nitrogen and available nutrients (P, K, Ca, Mg). Plant material from each harvest was analyzed for total content of N, P, K, Ca and Mg after wet combustion.

The consistency of the experiments was disturbed by several factors, mostly connected with financial issues following 1989. The main changes were: the termination of 4 experimental sites, changes in the crop rotation at some fields and a reduction of soil sampling.

The analytical method of available K determination was also changed. The formerly used method of ammonium acetate/oxalate extraction (according to Schachtschabel, in Hraško et al. 1962) was replaced by Mehlich II/III extraction. In this case data were transformed back to Schachtschabel according to the equations below.

$$K_{Sch} = 0.8187 \times K_{M\ II} + 3.94;$$

$$K_{Sch} = 0.712 \times K_{M\ III} + 9.96.$$

These equations were derived from analyses of a large number of soil samples (based on data published by the Central Institute for Supervising and Testing in Agriculture, Trávník 2008). K balances were calculated as the difference between K input (in farmyard manure and mineral K) and K output by harvested plant material. K leaching and atmospherical deposition were not taken into account.

Data presented and discussed originate from the experiment at Hněvčeves. Data from Kostelec, Humpolec and Pernolec are shown in a lesser extent, with the aim to demonstrate the differences among the experiments at different sites.

Table 3. Basic description of experimental sites and soils. Soil reaction (pH, in 1M KCl solution), organic carbon content (C_{ox}) and available nutrients (P – Egner; K – Schachschabel) before beginning experiments

Location	Soil	Soil texture	Altitude (m)	Average annual temperature (°C)	Average annual precipitation (mm)	pH KCl	C_{ox} (%)	P_{avail} (mg/kg)	K_{avail} (mg/kg)
Hněvčeves	Haplic Luvisol on loess	loam	265	8.1	597	6.4	1.0	73	119
Humpolec	Haplic Cambisol on paragneiss	sandy loam	525	6.6	667	6.1	1.7	27	212
Pernolec	Cambisol on orthogneiss	sandy loam-loam	530	7.1	559	6.0	1.1	71	185
Kostelec n. Orlicí	Haplic Luvisol on loess	sandy loam	290	8.1	696	6.3	1.1	62	119

RESULTS AND DISCUSSION

K balances calculated for one crop rotation (Table 4) correspond well with the data derived from other fertilization experiments. Macháček et al. (2001) reported that the annual balance in common agricultural practice ranges from minus 75 to minus 185 kg K/ha at low or zero K inputs. The correlation between K input and K balance is highly significant ($R^2 = 0.99$, $n = 10$). Zero balance was obtained at the annual input of 163 kg K/ha.

The scheme of the experiment allows 10 combinations of farmyard manure (FYM) and K muriate application rates, which would theoretically give 10 different overall K application rates (marked with letters A–J in Table 4). Some combinations of levels give nearly the same overall K application rates and a similar K balance. The same application rate obtained by different combinations of FYM and K muriate levels allows a rough comparison of the degree of utilization of FYM and mineral K. At low application rates (combinations B and C); the difference between the outputs of K suggests better utilization of K from muriate than that from FYM. When taking into account the uptake from fertilizer (which was calculated as K uptake at the particular treatment minus K uptake at no fertilized control), crops utilized 44% of mineral fertilizer (combination C), and only 9% of K from FYM (combination B), on average.

At higher application rates the data do not indicate that one of the potassium forms has better utilization by crops than another. At the highest application rates, the degree of utilization of both FYM and mineral K (combinations G, H, I) is very low (22–25%). Reduced effectiveness of fertilizer K suggests that plant growth and yield formation is limited by other nutrients (e.g. N, P and Mg; Blake et al. 1999).

Manuring with FYM supplies soil with high inputs of organic matter and nutrients twice during a rotation cycle (for sugar beet and silage maize). Despite the high K demand of these crops, K input by FYM and K muriate is usually higher than K uptake. Only exceptionally, in very favorable weather conditions, K output by a high yield of sugar beet may compensate for high K input. Thus, the curve of K balance has two positive peaks in the 4th and 7th year of the rotation (Figure 1) in fertilized treatments. On the contrary, the high K uptake of these crops in non-fertilized treatments causes a clear drop down of the balance in these years.

The growing of alfalfa (first two years of the rotation) causes high negative balances in all treatments regardless of the application rate. K fertilizer, together with N and P, is used only before sowing of alfalfa and oat to stimulate plant growth. Afterwards, alfalfa stand was not fertilized and a large biomass export associated with several cuttings was not compensated for by any input. The

Table 4. Mean annual potassium balance at Hněvčeves. Different letters (first column) mark different combinations of farmyard manure (FYM) and mineral K fertilizer application rates. Calculated as averages for all 4 experimental fields

Combination	FYM level	K level	Replicates within one field	Input	Output	Balance	Uptake from fertilizer*
				kg/ha/year (standard deviation)			
A (control)	no	no	2	0	122	−122 (19)	–
B	medium	no	1	76	135	−59 (6)	13
C	no	medium	1	77	156	−79 (12)	34
D	low	low	8	88	152	−64 (12)	30
E	medium	medium	10	153	166	−13 (11)	44
F	high	low	8	153	160	−7 (15)	38
G	low	high	8	154	162	−8 (13)	40
H	high	high	8	218	172	46 (15)	50
I	excess	medium	1	229	179	50 (22)	57
J	medium	excess	1	230	172	58 (3)	50

*by subtracting K uptake on non-fertilized plots (control)

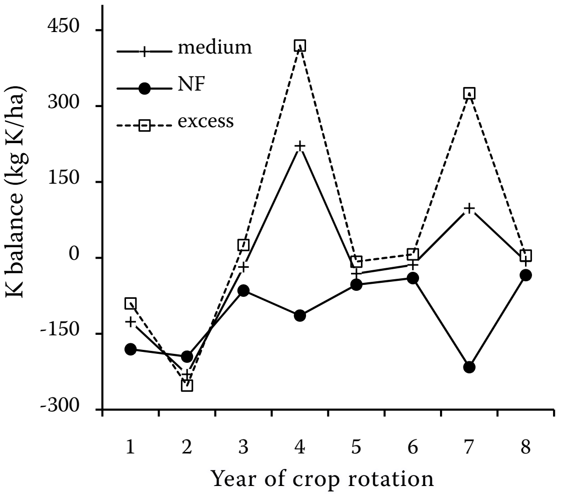

Figure 1. Average annual potassium balances within a crop rotation cycle - non-fertilized (NF), medium K application rate (153 kg K/ha/year) and excess K application rate (230 kg K/ha/year). Hněvčeves, based on 1980–1992 data

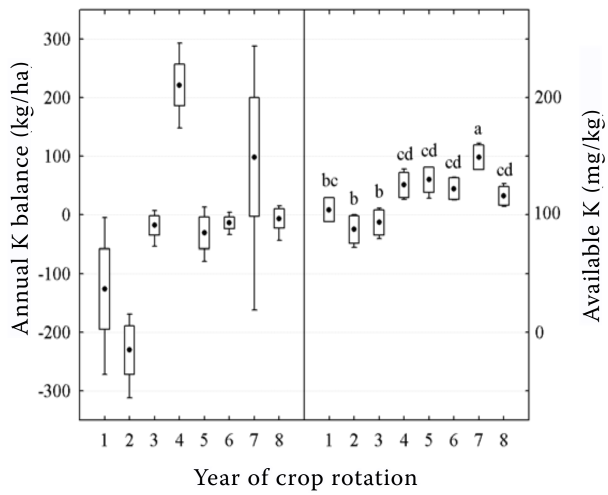

Figure 2. K balance and available K dynamics within a crop rotation cycle. Hněvčeves, medium K application rate (153 kg K/ha/year), based on data from all 4 fields, 1980–1992. Black points show means, boxes standard deviations and segments max-min range. Different letters indicate significantly different averages ($P < 0.05$)

lowest balance was found in the treatments of the highest application rate in the 2nd year, suggesting the lack of K limited the yields of alfalfa.

Further results and discussion on available K during one crop rotation are related to data of medium application rate (combination E), mainly for two reasons: (1) 10 replications of this treatment within each field allow for sufficient statistical evaluation, and (2) we can assume that no long-term changes of soil K are due to a nearly zero balance.

The dynamics of the available K within crop rotation corresponds clearly to the dynamics of K balance (Figure 2); even the amplitude of changes is not as high. Despite quite high variability of the available K contents, many of the between-year differences are statistically significant. The mean for whole rotation cycle is 116 mg K/kg. The lowest contents of available K are connected with the negative balance in the first two years of the rotation, with minimum content of 88 mg K/kg in the second year. Because forage crops take up a substantial amount of K from the subsoil (41–67%, Witter and Johansson 2001), the decrease of available K is not as steep as can be expected from the K balance.

Available K contents after winter wheat harvest in the 3rd year (93 mg K/kg) are not significantly different from that in the second year and that logically corresponds to a nearly zero balance (–13 kg K/ha/year). The positive balance in the 4th year of crop rotation (silage maize) increased available K to 125 mg K/kg, and this increasing trend lasted to the 5th year (130 mg K/kg), despite a slightly negative balance. The second important increase of available K occurred after sugar beet (year 7), where the curve of available K in the rotation reached a maximum of 149 mg K/kg. In the last year of the rotation, the available K contents dropped down to 116 mg/kg even though the balance was not negative. This drop can only be explained as K-loss to subsoil by leaching or K fixation into non-available forms.

Annual K balances influence available K to a large extent also at other sites. ‘Two-peak’ character of the available K curve is a common feature of all the experimental sites (Figure 3). Different positions of the curve (different mean level of available K) are connected with different nutrient status at the beginning of experiments and probably also with soil properties (e.g. clay content and quality, cation exchange capacity).

Polyfactorial field experiments were designed for analyses of the influence of defined factors and for investigation of time trends caused by various application rates of fertilizers. This experimental design has limited possibilities to evaluate other influences. Even though we realize some constraints, we made attempts to provide an evaluation of the factors affecting available K variability.

We can distinguish three known sources of available K variability within the experiment: (1) variability given by the growing of different crops

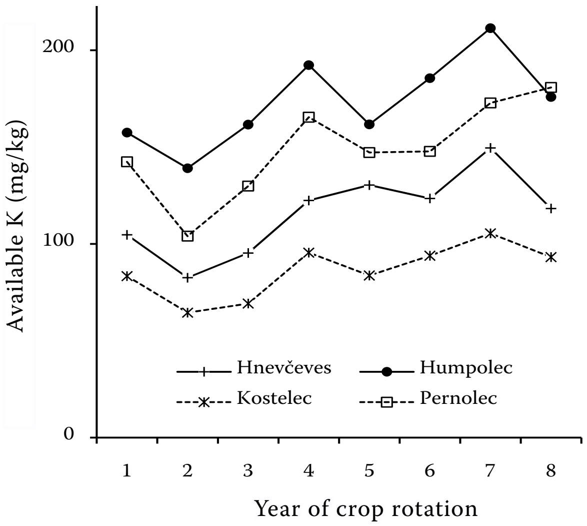

Figure 3. Available K dynamics over a crop rotation cycle. Average values for medium FYM and K muriate application rate (153 kg K/ha/year) based on 1980–1992 data

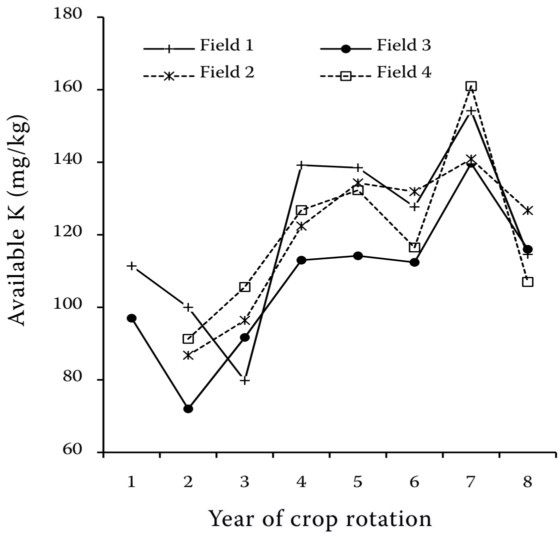

Figure 4. Available K dynamics over a crop rotation. Hněvčeves, medium FYM and K muriate application rate (153 kg K/ha/year), based on 1980–1992 data

(year of crop rotation), (2) variability given by interannual weather fluctuations and (3) variability among fields for a given year of the rotation (Figure 4). The latter is supposed to be minimum; because an important assumption of the experiment is that there are no inner (soil, site) differences among fields of a particular site.

Results of the main factors 'Crop', 'Weather' and 'Field' are shown in Table 5. All factors have statistically significant influence on available K. By comparing the sum of squares, it is clear that the influence of crop factor (34% of total) on data variability is much higher than the influence of weather and field factors (3%). Residual unexplained variability is high (42%), pointing to the existence of other unknown factors affecting available K data (e.g. soil, sampling and analytical variability). All factors combined explain 58% of the data variability (including interactions of factors). Based on this evaluation, it can be concluded that within this trial, the growing of different crops had a dominant influence on available K contents. Differences among fields and interannual weather fluctuations (which influence soil K contents e.g. via affecting crop yields or leaching) were of much less importance.

As for high residual variability found within this trial, unexplained K variability seems to be common in long-term fertilization experiments. Jouany et al. (1996) reported that for a given treatment, differences between two successive sampling dates are sometimes larger than differences between treatments for a given date. Authors consider that this variability is caused by water content at sampling and drying and subsequent release or fixation of K. Merbach and Deubel (2007) reported data of

Table 5. Influence of planting different crops (factor Crop), interannual weather fluctuations (Weather) and differences among experimental fields (Field), on variability of available K contents. Results of Main effects ANOVA. Based on data of Hněvčeves, K application rate 153 kg K/ha, average of years 1980–1992

Factor	SS	SS/Total	df	*F*	*P*
Crop	74 575	0.34	6	37.4	< 0.001
Weather	7 257	0.03	10	2.2	0.019
Field	7 586	0.03	3	7.6	< 0.001
Residual	92 432	0.42	278		
Total	220 034				

SS – sum of squares; df – degrees of freedom; *F* – F statistic; *P* – probability level the Halle trials as 10-year means with the remark that in addition to the given means, graduation of double-lactate K in individual years existed on different levels (± 20 mg K/kg).

Accidental incorporation of various ratios of the subsoil into the plough layer during the ploughing may be one of the possible sources of the high residual variability.

Influence of the interannual K dynamics within three complete crop rotations in field 3 can be clearly identified (Figure 5). For medium and excess application rates, the curves had typical two-peak character within all rotation cycles and the lowest available K contents were always present after the second year of alfalfa.

A very interesting phenomenon is the periodic change of available K content in the non-fertilized treatment. Changes follow the crop rotation cycle but the relation to K balance is not as clear as in the case of fertilized treatments. Generally, the balance is more negative in the first half of the cycle than in the second half (Figure 1), when excluding the balance of the 7^{th} year. This corresponds to lower K contents in the first half of the rotation cycle. However, the balance in the year of sugar beet cropping is even more negative than for alfalfa, but soil K contents stay at a higher level.

This phenomenon might be connected with the physiology of the sugar beet. It is known that sugar beet is more effective in uptake of fixed soil K then cereals (El Dessougi et al. 2002) and due to a deep root system it takes large portions of K from deeper horizons. Simultaneously, K balance includes whole soil profile and only a portion of the K uptake originated in a plough layer. Decreases of the soil K pool are often found to be smaller than the calculated total deficit of K from the cropping systems based on the accumulated field balances (Andrist-Rangel et al. 2007). Anyway, it is unlikely that a crop with high K demands will not affect K contents in plough layer. Another possible explanation may be that high contents are related to the method of sampling. After the harvest of sugar beet, deeper soil horizons with a higher K content may mix with the plough (sampling) layer, consequently increasing measured K contents. Some side transfer of more fertilized soil from adjacent fertilized plots is also possible, even though the agrotechnics is done carefully to minimize the soil translocation. Thorough explanation deserves further attention and verification of data.

In papers evaluating soil properties in long-term experiments, the most usual ways of presenting the time series are calculating means for some period of years or showing values of regular sampling with constant periodicity of several years. If sampling is only occasional, data are collected non-regularly and then trends have to be evaluated by comparison of these isolated data. In the case of our data, some of the treatments were sampled almost regularly in periodicity of 1 or 2 years (combinations A, B, C, E, I and J). For these data, trend evaluation is

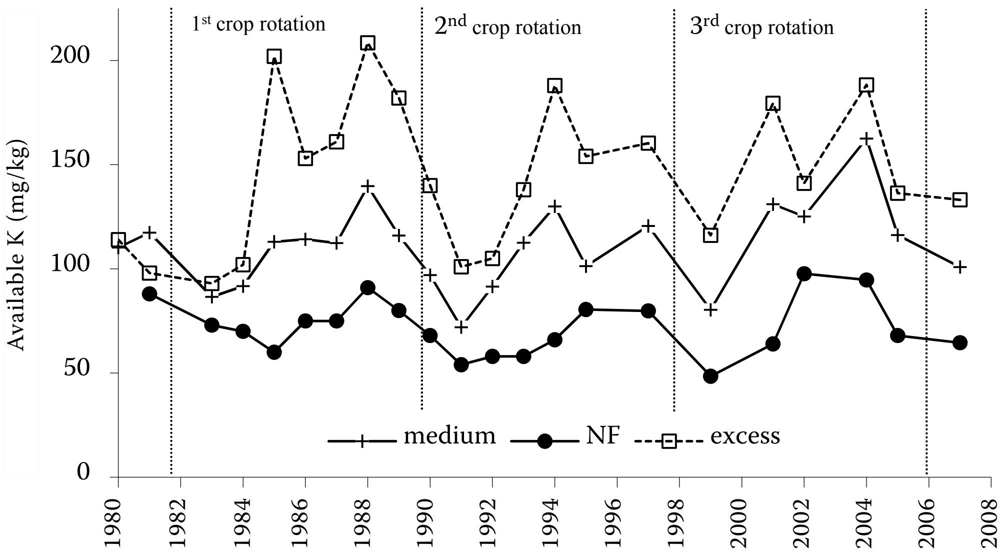

Figure 5. Available K contents during the experiment. Hněvčeves site, field 3
NF – non-fertilized; medium – application rate 153 kg K/ha/year; excess – application rate of 230 kg K/ha/year

possible by calculating a mean of average values for whole crop rotation cycles.

The regular sampling of the other treatments was disrupted after 1988; all plots were then sampled again in 1995 and in 2007. This reveals evident problems of how to compare these data and to construct time trends. 1988 is the 7th year of the crop rotation, year 1995 is the 6th and year 2007 is the 2nd year of the crop rotation. The problem of comparing data is that means of the 2nd, the 6th and the 7th year differ significantly from each other (see Figure 2).

The direct comparison of values and calculating time trends are therefore not correct for treatments with combinations of application rates D, F, G and H, which were sampled only in the above-mentioned years. In this case, data should be adjusted to the same level. We decided to use year 2007 (the 2nd year of crop rotation) to recalculate values from years 1988 and 1995. We used a ratio between average K content of the 2nd and the 6th year of crop rotation (0.72) to adjust data from year 1995 and the ratio between the 2nd and the 7th year of crop rotation (0.59) to adjust data from year 1988. For other combinations of application rates, contents in years 1983, 1991 and 1999 were taken to calculate time trends (the 2nd year of crop rotation).

Data used for the construction of time trends and calculated slopes are shown in Table 6. For a given combination of application rates, a slope of the regression line was calculated from 4 time points. Between regression trends, calculated from adjusted and non-adjusted contents, are important differences. Calculated slopes of time trends can be approximately the same (combination F), but may differ in absolute values (combination H) or can even indicate a different direction of time changes (combination D).

The highest slopes correspond to annual increases more than 2 mg K/kg (ca 1.5% of available K content) and were detected for combinations H and J. At the same time, variations caused by growing of different crops were found in the range of 88–149 mg K/kg, i.e. ± 26% of the mean. It implies that interannual increases caused by long-term trends are of much lower extent (order of magnitude lower) than K variability caused by crops.

Slopes are highly correlated with K balance (Figure 6, correlation is statistically significant at $P < 0.05$). From the regression equation it can be calculated that a zero slope, i.e. a stabilized available K level, corresponds to an average annual K balance of minus 78 kg K/ha. It means that, for example, at an application rate of 77 kg K and a medium application rate of nitrogen and phospho-

Table 6. Available K contents during the experiment (mg K/kg). Slopes of time trends calculated from 4 time points, with and without adjustment to crop-induced interannual dynamic. Hněvčeves, field 3

K input (kg K/ha/year)	Combination of K and FYM apllication rates	1983	1988	1995	2007	Slope (adjusted)	Slope (non-adjusted)
88	D	76	67*	69*	81	0.32	–0.28
153	F	70	82*	74*	89	0.63	0.77
154	G	82	80*	81*	117	1.51	–0.10
218	H	83	106*	100*	142	2.22	1.29
		1983	1991	1999	2007		
0	A	73	54	48	65	–0.39	
76	B	80	58	65	72	–0.21	
77	C	76	70	73	76	0.05	
153	E	87	72	80	101	0.64	
229	I	96	114	116	130	1.29	
230	J	90	88	116	137	2.10	

*content adjusted with regard to crop-induced interannual dynamic

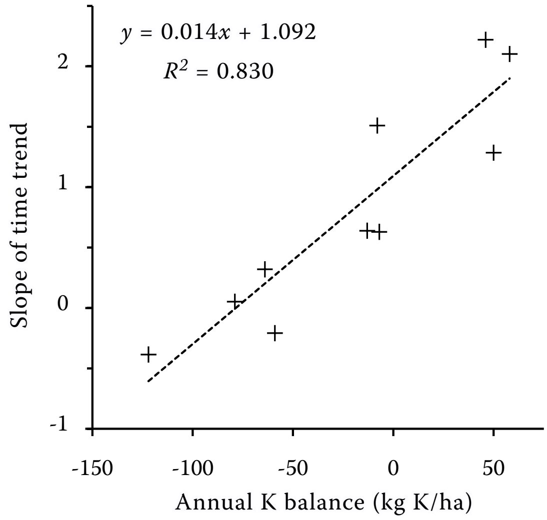

Figure 6. Relationship between K balances and slopes of time trends of available K contents. Hněvčeves site

rus (combination C), soil K will be continuously replenished from soil sources at an annual rate of 79 kg K/ha to keep the same level of ca. 76 mg K/kg (in long-term view).

We would like to pinpoint one interesting consequence that arises from calculated long-term trends. In soils of high starting available K, substantial changes in available K content at plough layer may occur after two 8-year rotations (decrease from ca 250 mg K/kg by 121 mg K/kg; Lauringson et al. 2004). In the soil of Hněvčeves, which had much lower starting available K (119 mg K/kg), the decrease of available K in non-fertilized treatments was not as steep (up to 65 mg K/kg in 2007) and the available K contents stayed at approximately the same level (48–65 mg K/kg) during the last 20 years, at an annual balance minus 122 kg K per hectare. If we consider the average bulk density of plough layer to be 1.3 Mg/m^3 and the thickness of plough layer to be 25 cm, 1 mg/kg available K is then equal to 2.5 kg K/ha. Therefore, in non-fertilized plots, soil sources other than those extracted for available K, release annually ca 50 mg K/kg.

As was previously mentioned, the balance covers the whole soil profile and therefore this comparison is not fully correct, as we did not analyze subsoil available K contents. However, it is obvious that available K is continuously restored. The reason of this restoration is K mobilization from slow release forms. K is replenished by (1) the weathering of mineral soil particles (annually 3–82 kg K/ha depending on soil properties; Holmqvist et al. 2003), and (2) by the release of fixed (reserve) K pool, the content of which is in average 3-times larger than that of available K (Fotyma 2007). Even though we did not analyze the pool of fixed K in the soils at Hněvčeves, we expect that the rate of K output was high enough to cause substantial depletion of fixed K.

Nowadays, our crop production depends highly on the mobilization of internal soil K sources. Negative K balance is a reality and probably also a future aspect of our agriculture; the change of this trend cannot be expected in the near future. The annual K application rate should increase manifold (to level ca 170 kg K/ha) to reach stabilization of available K. Moreover, prices of K fertilizers are increasing, contrary to prices of agricultural products. Farmers will not be motivated to use K fertilizers until soil sources are exhausted. Attention should be therefore focused on the extent of these sources and the sustainability of their continuous exploitation. Understanding and quantifying K mobilization processes is one of the important challenges for future research.

Observed interannual dynamics of soil K are driven by agricultural management and of course are specific for a particular type of that management, crops in rotation, fertilization practices, and soil and site properties. The crop rotation used in our trial is probably more K-demanding than the others. However, results have important consequences for evaluation of long-term data not only from these static fertilization experiments, but also for data taken within large (national) soil monitoring programs. In occasionally sampled sites or when the period of sampling is several years, agricultural management has to be inevitably known. Otherwise, construction of time trends will be strongly affected by short-term influences. The impact of the management could inadvertently cover up long term trends and finally, the results would not reflect real time trends.

Within the long term polyfactorial fertilization experiments, periodic interannual fluctuations of available K were observed, with statistically significant differences from 88 to 149 mg K/kg within one crop rotation cycle. These fluctuations were driven by the dynamics of the K balance that originated mainly in crop-specific K inputs. The variability of soil-K contents was primarily influenced by crop plants and experimental unexplained factors; interannual weather fluctuations and field differences were of low significance.

REFERENCES

Andrist-Rangel Y., Edwards A.C., Hillier S., Oborn I. (2007): Long-term K dynamics in organic and conventional mixed cropping systems as related to management and soil properties. Agriculture, Ecosystems and Environment, *122*: 413–426.

Anonymous (2007): Agriculture 2007. Ministry of Agriculture of the Czech Republic, 127. (In Czech)

Blake L., Mercik S., Koerschens M., Goulding K.W.T., Stempen S., Weigel A., Poulton P.R., Powlson D.S. (1999): Potassium content in soil, uptake in plants and the potassium balance in three European long-term field experiments. Plant and Soil, *216*: 1–14.

Cochran W.G., Cox G.M. (1957): Experimental Designs. John Wiley and Sons, New York, 611.

El Dessougi H., Claassen N., Steingrobe B. (2002): Potassium efficiency mechanisms of wheat, barley, and sugar beet grown on a K fixing soil under controlled conditions. Journal of Plant Nutrition and Soil Science, *165*: 732–737.

Fotyma M. (2007): Content of potassium in different forms in the soils of southeast Poland. Polish Journal of Soil Science, *40*: 19–32.

Holmqvist J., Ogaard A.F., Oborn I., Edwards A.C., Mattsson L., Sverdrup H. (2003): Application of the PROFILE model to estimate potassium release from mineral weathering in Northern European agricultural soils. European Journal of Agronomy, *20*: 149–163.

Hraško J., Červenka L., Facek Z., Komár J., Němeček J., Pospíšil F., Sirový V. (1962): Soil Analyses. SVPL, Bratislava, 342. (In Slovak)

Jouany C., Colomb B., Bosc M. (1996): Long-term effects of potassium fertilization on yields and fertility status of calcareous soils of south-west France. European Journal of Agronomy, *5*: 287–294.

Lauringson E., Talgre L., Roostalu H., Vipper H. (2004): The effect of tillage and crop rotation on the content of available nitrogen, phosphorus and potassium. Agronomy Research, *2*: 63–70.

Lipavský J., Ludva L., Hromadová M., Kubát J. (2005): An overview of the long-term static field experiments in the Czech Republic. In: Voříšek K. et al. (eds.): The role of long-term field experiments in agricultural and ecological sciences and practical solutions for managing optimum C and N content in agricultural soils III. Conference Proceedings. Czech University of Agriculture and Research Institute of Crop Production, Prague, 143–147.

Macháček V., Čermák P., Klír J. (2001): Potassium Fertilization in Czech Republic. Country Report 2. International Potash Institute and Research Institute of Crop Production and Central Institute for Supervising and Testing in Agriculture, Prague, 59. (In Czech)

Merbach W., Deubel A. (2007): The Long-Term Fertilization Trials in Halle (Saale), Germany. GWV, Fachverlage GmgH, Wiesbaden, 189.

Merbach W., Deubel A. (2008): Long-term field experiments – museum relics of scientific challenge? Plant, Soil and Environment, *54*: 219–266.

Oborn I., Andrist-Rangel Y., Askekaard M., Grant C.A., Watson C.A., Edwards A.C. (2005): Critical aspects of potassium management in agricultural systems. Soil Use and Management, *21*: 102–112.

Simonsson M., Andersson S., Andrist-Rangel Y., Hillier S., Mattsson L., Oborn I. (2007): Potassium release and fixation as a function of fertilizer application rate and soil parent material. Geoderma, *140*: 188–198.

Southwood T.R.E. (1994): The importance of long-term experimentation. In: Leigh R.A., Johnston A.E. (eds.): Long-term Experiments in Agricultural and Ecological Sciences. CAB International, Wallingford, Oxon.

Trávník (2008): Monitoring influence of graduating fertilization intensity on crop yields and on agrochemical soil properties. Evaluation of analytical methods for soil available nutrients (final report from long-term experiments). CISTA, 26. (In Czech)

Witter E., Johansson G. (2001): Potassium uptake from the subsoil by green manure crops. Biology, Agriculture and Horticulture, *19*: 127–141.

Received on February 26, 2009

Corresponding author:

RNDr. Mikuláš Madaras, PhD., Crop Research Institute, Drnovská 507, 161 06 Praha 6- Ruzyně, Česká Republika
phone: + 420 233 022 352, fax: + 420 233 310 636, email: madaras@vurv.cz