Depth profiles of potassium and its isotope ratio ($^{40}K/K$) in several forest soils

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Abstract

Depth profiles potassium and its isotope ratio ($^{40}K/K$) were investigated in several forest soils from different geological and climatic backgrounds. The ratio was found not to be constant (0.0117 %) but varied appreciably from 0.0085 to 0.0167 % among different soils. Possible factors affecting variability of $^{40}K/K$ values were considered by a multivariate factor analysis which suggested that aqueous parameters like humidity and pH might be a controlling factor in the surface soils. The amount (and probably chemical forms) of iron oxide may be another one influencing $^{40}K/K$ values in mineral components at deeper portions.

Keywords: potassium, isotope ratio, forest soil, multivariate factor analysis

Introduction

Potassium is one of the 17 elements necessary for plant growth and reproduction. It helps plants to resist drought and diseases and to protect from excessive temperatures.

The element potassium has three isotopes (^{39}K, ^{40}K and ^{41}K) in which only ^{40}K is radioactive. This nuclide is classified to be primordial, and its half life is in the order of 10^9 years. The isotopic ratio of $^{40}K/K$ is known to be 0.0117 % in common materials in nature.[1,2] Activity measurement of ^{40}K has therefore been carried out to obtain total potassium contents of natural samples.

It is believed that this nuclide is distributed in soil rather homogeneously within a horizon of interest.[3,4] However, in our previous study depth profiles of ^{40}K in some soils were not regarded as homogeneous distribution.[5,6] We also found that radio-potassium was present only in the uppermost portion of a tropical forest soil in Alto Mayo in northern Peru where the bed rock is acidic sand stone with little potassium content.[6] It was not known how trees could survive in severe environment with poor nutrient. Those findings may partly be ascribed to biological activities, such as root uptake and recycling of nutrients, and bioturbation by moving micro (and macro) organisms in soil as well as labile properties of potassium, especially in surface soils.[7]

Only a few research works have been published on isotope composition of radio-potassium in natural samples so far, which includes the studies on human bones and on meteolites.[8,9] The purpose of this study is i) to evaluate isotope ratio of radio-potassium ($^{40}K/K$) in several forest soils of different geological and climatic backgrounds, and ii) to consider possible factors influencing $^{40}K/K$ values in soil by a multivariate factor analysis. The soils investigated in this study were collected from the cool temperate deciduous woods in Sapporo, Japan in 2006, temperate deciduous and coniferous forests in the Czech Republic in November 2004 and semi-arid tropical forests in northern Peru (El Angolo) in March 2006.

Materials and methods

Location and properties of the sites

Sapporo (Japan)[10,11]

The site (N43º 03’, E141º 21’) is located in a cool temperate deciduous stand on the campus of Hokkaido University in Sapporo, Japan. Mixed vegetation exists such as Alnus davidiana var. japonica, F. mandshurica var. japonica group and Quercus mongolica var. grosseserrata. Geology of the site was of alluvial sediment from nearby Tohohira and Hassamu rivers. Annual mean temperature and precipitation are 8.5 ºC and 1130 mm, respectively. Snowy season begins in late November and ends in April. The observation site is flooded with melting snow in April.

Lysina, Nacetin and Pluhuv Bor (Czech Republic)[12,13,14]

Three sites (Lysina, Pluhuv Bor and Nacetin) under temperate coniferous stands were selected for the present study. All the sites, Lysina (N50º03’, E12º 40’), Pluhuv Bor (N50º04’, E12º46’) and Nacetin (N50º35’, E13º15’) located in north-western to western part of the Czech Republic have similarity in climate and vegetation. In Lysina about 99% of the vegetation is Norway spruce with 58 years old in mean age, whereas this species occupies about 92% and the remaining portions is Pinus sylvestris in Pluhuv Bor. The mean stand age is 102 and 60 years old in Pluhuv Bor and Nacetin, respectively.[12]

El Angolo (Peru)[6]

El Angolo located in northern part of Peru is a national game hunting preserve of 650 km^2 in total area, which was established in 1975 in Cerros de Amotape National Park Region in north-western Peru. The soils formed from Tertiary and Quaternary sediments drain poorly and belong to the vertisol and yermosol groups. The climate in this region is modified by several factors: the cold marine Humboldt Current and the Andean Cordillera impose an environment that is predominantly sub-arid with cloud and fine precipitation. Seasonal rains occur during December-March. The vegetation depends on the climate: the predominant species in thorn forests are Acacia macracantha and Prosopis pallida. Ceiba trichistandra is the most conspicuous species in premontane deciduous forests.

Soil sampling, pretreatments and leaching experiments

Soil samples investigated in this study were collected with hands at 2 or 3 cm intervals from the uppermost down to a depth of 40 cm in all the sites investigated in this study.[5,6,14] The soils were dried at 110 ºC and passed through a 2 mm sieve. A set of data on several soil properties (pH, humidity and loss on ignition) was obtained using standard methods.[5] Leaching experiments were conducted for several soil samples in which definite amounts of individual samples were suspended in aqueous solutions containing several chemical reagents of different concentrations, i.e. nitric acid (10^{-1}, 10^{-3} M), ammonium nitrate (10^{-1}, 10^{-3} M), potassium nitrate (10^{-1} M) and caesium nitrate (10^{-1} M) for 24 hrs. The residues collected by filtration were rinsed with water and dried at 110 ºC for further analyses.

Gamma spectrometry

Activity of ^{40}K was measured by gamma spectrometry using two types of high purity Ge detector (GEM-25185P and GMX10P, EG&G ORTEC, USA). Standard reference materials were purchased from the International Atomic Energy Agency (IAEA Soil-6, IAEA-312 and IAEA-327) to evaluate the activity concentration of individual samples from counting data obtained with the same geometry under identical operating conditions. Both energy and efficiency calibrations were carried out periodically as well as background check. Precision of the measurement was estimated by considering a photo-peak area of ^{40}K for both samples and the standards. The minimum detectable activity (MDA, Bq) and uncertainty (± %) of ^{40}K counting rates were 0.63 Bq and ±1.9-6.0 %, respectively for a sample (~100 g) in a container (100 cm3) for 48 hr counting time by using a HPGe detector (GEMX10P).

Elemental analysis

Major and minor elements contained in soil were determined by X-ray fluorescence spectrometry (JSX 3220, JEOL, Japan). Calibration curves were prepared for several elements including potassium which was carefully determined by considering overlapping effect on the potassium spectrum and matrix effects by soil organic matter.[15] Accuracy of a calibration curve using IAEA Soil-6 as a reference material was obtained to be 0.003409 %. Standard deviation of repeated measurements was obtained to be ±1.38 % for the IAEA Soil-6 reference material.

Results and discussion

Basic soil properties

Table 1 summarizes the results of some basic properties of soils (dry density, humidity, soil organic matter, soil pH and major components as oxides) investigated in this study. Their properties reflect geological, meteorological and stand properties at each site. Generally, pH values of the surface portion of coniferous stands in the Czech Republic were quite low (3.5 ~ 4), which would be caused by acid rain, one of the serious environmental problems.[16] Among the sites in the Czech Republic the bed rock in Pluhuv Bor is surpentinite, quite different with those in other places.[12] Soil sampling under semi-arid stands in El Angolo of northern Peru was carried out in March, 2006. It was a rainy season there, and humidity of the soils was relatively high in all the sites. Three points (P1-0, P1-1 and P1-2) around a big ceiba tree were selected to compare soil properties in the same geological background.[6] In the observation site in Sapporo soil sampling was carried out in different seasons to investigate seasonal variation of the soil properties including environmental radionuclides (^{226}Ra, ^{137}Cs and ^{210}Pb) other than ^{40}K. Radon (^{222}Rn) and CO_2 (and its carbon isotopes, δ^{13}C and Δ^{14}C) have also been monitored in this site since 2002.[5,10,11,17] It is interested to note in Table 1 that the amount of soil organic matter varied in winter-high and summer-low under a deciduous stand in Sapporo.

Potassium and radio-potassium (^{40}K) in soil

Potassium in soil varies its amount and chemical form depending on the "in situ" environment. Table 2 summarizes analytical data on potassium content (mg kg^{-1}) and activity concentration of ^{40}K (Bq kg^{-1}) in soils investigated in this study. The potassium content varies with different soils and with different depths at the same site. The table also includes calculated values of ^{40}K isotope ratio (^{40}K/K) (%) in these soils. The ^{40}K/K molar ratio is known to be constant, 0.0117 % in common chemical reagents used in the laboratory and also in natural substances. Soil is a mixture of organic and mineral components of different structural and chemical properties, and there is little data on determining ^{40}K/K ratio in soil. As shown in Table 2, ^{40}K/K values were not constant to be 0.0117 %, but varied in the range from 0.0085 to 0.0167 % for soils collected at different places. Taking certain uncertainty of our results into account, deviation of observed ^{40}K/K values, $(^{40}\mathrm{K/K})_{obs}$ from the certified value of 0.0117% is used to investigate possible factors affecting its variability. The deviation, $\Delta(^{40}$K/K) is obtained from the following equation:

$$\Delta(^{40}K/K) = \frac{(^{40}K/K)_{obs} - 0.0117}{0.0117} \times 100\,(\%)$$

where $\Delta(^{40}K/K)$ is expressed with per cent.

In Table 2, $\Delta(^{40}K/K)$ values are also summarized for individual soils obtained at different depths of the sites in Peru, in the Czech Republic and in Sapporo, Japan. There appear various patterns in these profiles with a common property of lower $\Delta(^{40}K/K)$ values in the surface portion of individual soils. The potassium isotopic ratios are rather constant and positively shifted to ~25 % with depth at three points around a Ceiba tree in El Angolo, Peru. The soil in this site formed from Tertiary and Quaternary sediments was shallow but rather homogeneous in composition down to a depth of 40 cm.[6] However, it should be noted that absolute values of the potassium content (and also ^{40}K activity concentration) were different at individual points of similar geological background. This is probably due to biological activities like root uptake and local population of micro (and macro) organisms.

Among the soils in the Czech Republic, $\Delta(^{40}K/K)$ values are negative and rather constant with depth under a coniferous stand in Pluhuv Bor where the bed rock is known to be geologically peculiar serpentinite of high magnesium and low potassium contents.[13] Under a thin (a few cm) organic layer, the soil shows clayey texture of grey in color down to a certain depth (~50 cm), and below this depth fragile dark green fragments appeared as a predominant phase. In contrast, the soils from Lysina and Nacetin showed highest value of $\Delta(^{40}K/K)$ at 10~12 and 12~15 cm in depth, respectively. It may result from podzolized layers with abundant Fe(III) around these depths. Quite low $\Delta(^{40}K/K)$ value in the upper-most soil layer at Nacetin may be related with quite high content of soil organic matter (58 %).

Seasonable variability of $\Delta(^{40}K/K)$ in soil was investigated under a cool-temperate deciduous stand in Sapporo. Except for the results in April when the site had been flooded by melting snow, $\Delta(^{40}K/K)$ values have a good positive correlation (r>0.9) with depth in

May and also in July.

It is now speculated that there might be potential factors influencing variability of ^{40}K isotope ratio in soil. Methods of multivariate analysis have been used to identify pollution sources, and then to evaluate natural and anthropogenic contribution.[18] Radio-potassium has often been regarded as a lithogenic origin as well as ^{238}U and ^{232}Th. A factor analysis was carried out on the $\Delta(^{40}K/K)$ values obtained in this study using several soil properties (Table 1) as potential variables. In the analytical process each variable was evaluated for its correlation with other variables.[19] They were then mingled to two or more factors of composite composition of each one to a varying degree. Table 3 summarizes loadings of individual variables on two factors (F1 and F2) in the case of a deciduous stand in Sapporo. As shown in the table, F1 may be roughly oriented by soil pH, humidity and SOM with positive values of 0.934, 0.744 and 0.415, respectively, and by both aluminum oxide (-0.923) and density (-0.732) negatively. In contrast, major loadings are weighted positively on Fe_2O_3 (0.995) and negatively on SiO_2 (-0.975) for F2. Such a specific property of each factor enables to estimate its contribution to $\Delta(^{40}K/K)$ values obtained for different soils.

Figure 1a show the relationships of F1 with $\Delta(^{40}K/K)$ values of the soil collected in different months (April, May and July) in 2006 at a test site in Sapporo, Japan. Values of $\Delta(^{40}K/K)$ have negative correlations ($r \geq 0.8$) with F1 values in May and in July. With respect to F2, positive relationships were obtained in May ($r=0.81$) and also in July ($r=0.96$) as shown in Fig. 1b. In April, however, there are no clear correlations between these factors and $\Delta(^{40}K/K)$ values as shown in Figs. 1a and 1b. As already mentioned, the result in April may be due to flooding by melting snow in early spring which caused dissolution of soluble components of the soil.

Figure 2 shows the relations of these factors with soil depth in the cases of May and July samples. Values of F1 are negatively correlated with soil depth ($r \geq 0.9$), while those of F2 correlated positively ($r \geq 0.9$). It suggests that aqueous variables (humidity and pH) may be controlling factors at the uppermost portion of the soil, while variables concerning with mineral components would be predominant at deeper portions of the surface soil. The amount of iron oxide may be a controlling factor of the soil at deeper portion, since F2 values increase with soil depth deeper than 10 cm. Values of F2 seemed rather constant (F2 ~ -1) in the surface portion between 5 to 10 cm in depth, which has little physicochemical background to interpret such an appearance at this moment.

The factor analysis indicates that isotopic ratio of $^{40}K/K$ may not be constant (0.0117 %) in soil, but it may be changed by certain processes in soil environment like dissolution of mineral components due to heavy rain and snow melting, redox reactions of organic and mineral components as well as biological activities not to have been concerned in this study. In order to know possible consequences of chemical treatments on the isotopic ratio of radio-potassium in soil, dissolution experiments were carried out with several chemical reagents, nitric acid (10^{-1}, 10^{-3} M), ammonium nitrate (10^{-1}, 10^{-3} M), potassium nitrate (10^{-1} M) and caesium nitrate (10^{-1} M) aqueous solutions. Figure 3 shows the results of dissolution experiments in which ($^{40}K/K$) values before and after the treatments are plotted at different depths. It was clear that the values approached to be the certified one (0.0117 %) in surface portion (< 20 cm in depth) of the soil by most leaching experiments. It indicates that certain equilibrium may exist in ion exchange reactions of potassium between aqueous and solid phases in surface soil. In contrast, the values did not change appreciably in deeper portions of the soil after individual chemical treatments.[20] The facts may be reflected by different chemical forms of potassium which would be labile (ionic and/or ion exchangeable) to be easily dissolved by acid or salt solutions in the surface portion. It is known that among several forms of potassium in soil, soluble form (K^+) in soil solution and exchangeable potassium are regarded primarily as plant-available. There are equilibria among plant-available, non-exchangeable and mineral form depending on various natural and artificial conditions.[21]

The result of dissolution experiments thus supports an estimation derived from the factor analysis (Fig. 2), in which aqueous parameters (humidity and pH) would influence the isotope ratio of radio-potassium in surface soil. Mobility of ^{40}K in aqueous solution is well known in natural environment

It should be noted that the treatment with 1M $CsNO_3$ results in increasing $^{40}K/K$ value at any depth. This could be explained by higher ion exchangeable ability of Cs^+ that predominantly occupies exchangeable sites of soil components prior to potassium uptake. The result is supported by the fact that potassium and caesium competes for the same sorption sites and both are primarily associated with clay minerals.[22]

Further investigation is to be carried out to ascertain and evaluate our findings on isotopic ratio of radio-potassium in soil by considering speciation of potassium.

Conclusion

Isotopic ratio of radio-potassium was found to be varied depending on soil properties. Aqueous parameters like humidity and pH may be a controlling factor on $^{40}K/K$ values in the surface portion of the soil, whereas redox parameters including the amount (and chemical form) of iron may control the ratio in the deeper portions.

Acknowledgements

The present authors would thank Dr. Tomas Paces (Czech Geological Survey) for helping soil sampling in the Czech Republic and for giving them valuable comments. They also thank Dr. Reiner Zimmermann (Hohenheim University, Germany) and Dr. Johannes Dietz (ICRAF, Kenya) for helping soil sampling in Peru.

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Figure caption

Table 1 Summary of soil properties (humidity, dry density, soil organic matter, soil pH and major components as oxides) investigated in this study (Lysina, Pluhuv Bor and Nacetin in the Czech Republic, El Angolo in Peru, Sapporo in Japan)

Table 2 Analytical data on potassium content (mg kg^{-1}), ^{40}K activity concentration (Bq kg^{-1}), $^{40}K/K$ (%) and $\Delta(^{40}K/K)$ (%) in the forest soils

Table 3 Loading of individual variables (humidity, density, SOM, SiO_2, Al_2O_3, Fe_2O_3 and pH) on two factors (F1 and F2) in the case of a cool-temperate deciduous stand in Sapporo, Japan

Figure 1a Correlation plots between F1 and $\Delta(^{40}K/K)$ values of the forest soil collected in different months (April, May and July) in 2006 at a test site in Sapporo, Japan. Linear regression lines were obtained in May and in July with correlation coefficients of 0.90 and 0.78, respectively.

Figure 1b Correlation plots between F2 and $\Delta(^{40}K/K)$ values of the forest soil collected in different months (April, May and July) in 2006 at a test site in Sapporo, Japan. Linear regression lines were obtained in May and in July with correlation coefficients of 0.81and 0.96, respectively.

Figure 2 Relationships between two factors (F1 and F2) and soil depth in the cases of May and July samples. Values of F1 correlate negatively with soil depth, while positive correlations exist between F2 and soil depth.

Figure 3 Results of dissolution experiments in which 40K/K values before and after individual treatments are plotted at different depths. The chemical reagents used were nitric acid (10^{-1}, $!0^{-3}$ M), ammonium nitrate (10^{-1}, $!0^{-3}$ M), potassium nitrate (10^{-1} M) and caesium nitrate (10^{-1} M) aqueous solutions.

Table 1 Summary of soil properties (humidity, dry density, soil organic matter, soil pH and major components as oxides) investigated in this study (Lysina, Nacetin and Pluhuv Bor in the Czech Republic, El Angolo in Peru and Sapporo in Japan)

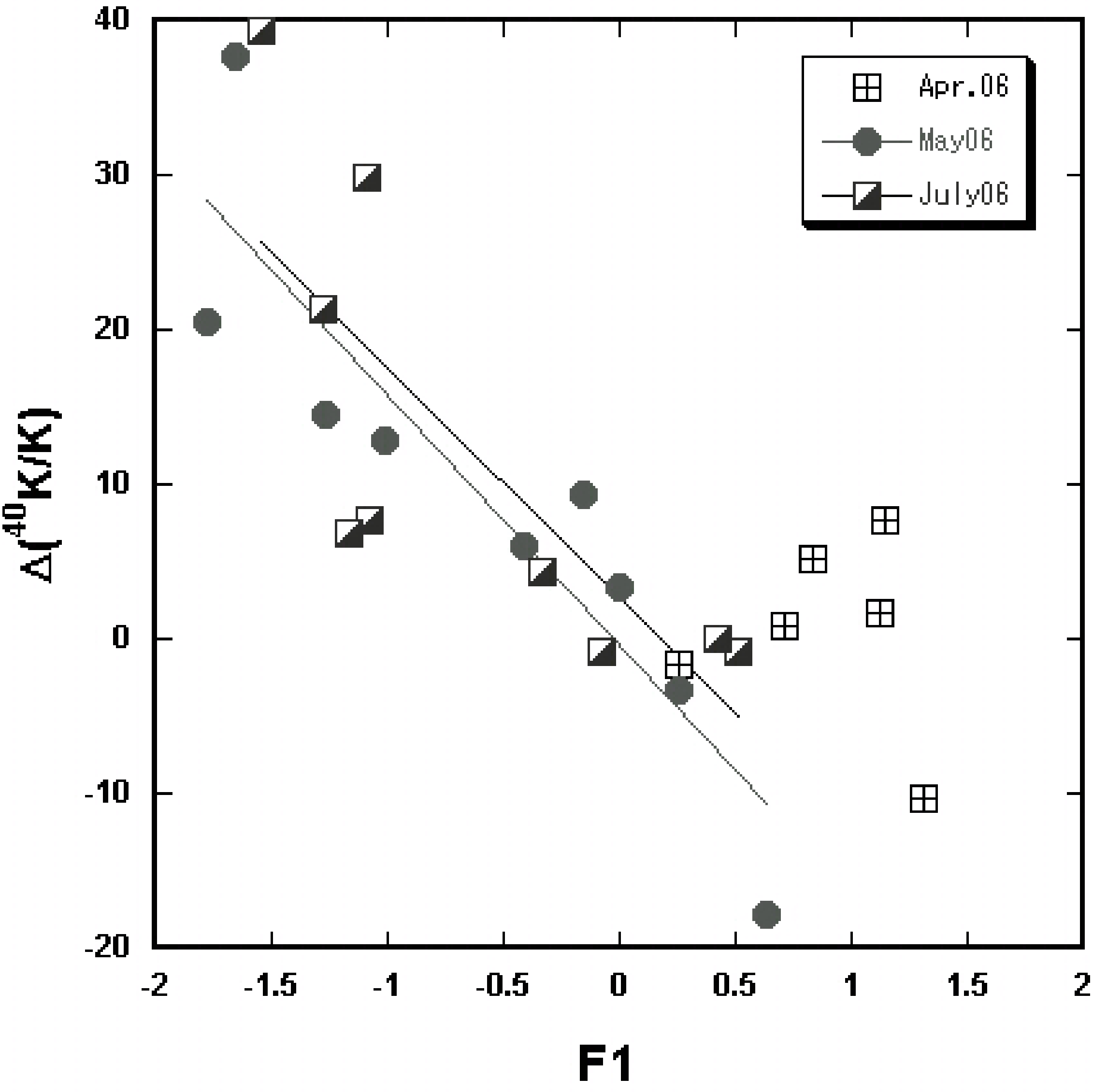
Country	Site	Depth (cm)	Humidity (%)	Density (g cm^{-3})	SOM (%)	SiO_2	Al_2O_3	Fe_2O_3	pH
Czech Republic	Lysina	2.5	19.00	0.77	21.1	68.69	15.02	4.59	3.56
		7.5	6.68	1.31	5.91	72.51	17.41	2.68	3.64
		12.5	8.95	1.24	7.71	70.05	17.46	4.88	3.64
		17.5	12.04	1.24	0.03	64.75	18.20	8.63	3.70
		22.5	6.23	1.48	7.73	73.55	16.00	2.68	3.90
	Nacetin	2.5	34.65	0.5	57.26	60.95	11.09	13.38	3.39
		7.5	19.41	0.9	18.41	62.94	13.78	14.92	3.49
		12.5	19.12	0.97	13.54	57.52	12.55	22.76	3.57
		17.5	18.85	1	11.41	58.99	14.83	18.93	3.67
		22.5	17.33	1.23	7.11	61.67	16.47	14.39	3.89
	Pluhuv Bor	2.5	8.97	1.17	8.63	61.68	8.66	12.95	3.88
		7.5	7.13	1.42	4.06	60.98	9.45	12.61	4.08
		12.5	8.02	1.45	3.97	60.59	9.31	12.89	4.20
		17.5	6.92	1.51	2.73	61.59	9.65	12.23	4.63
		22.5	5.71	1.62	2.11	59.80	9.37	13.56	4.53
Peru	P1-0	2.5	18.70	1.45	8.46	62.60	15.35	13.63	6.93
		7.5	17.50	1.51	8.42	61.62	15.98	14.45	7.02
		12.5	17.43	1.58	8.91	60.47	16.22	15.43	6.74
		17.5	16.76	1.7	8.56	60.25	16.28	15.51	6.76
		22.5	15.19	1.62	8.29	60.09	16.32	15.64	6.59
		27.5	15.01	1.58	8.25	60.47	15.79	15.56	6.69
	P1-1	2.5	15.42	1.48	8.49	59.47	16.31	15.44	7.14
		7.5	17.66	1.51	9.44	59.88	16.23	15.43	6.89
		12.5	16.97	1.55	9.1	59.28	16.36	15.77	6.89
		17.5	14.98	1.58	8.65	59.68	16.01	15.71	6.80
		22.5	14.36	1.58	8.2	59.56	15.92	15.70	6.88
		27.5	14.69	1.58	7.98	60.40	15.87	15.08	6.85
	P1-2	2.5	16.10	1.39	10.02	58.45	16.63	16.08	7.01
		7.5	18.12	1.42	9.65	57.18	17.27	16.98	7.01
		12.5	17.49	1.45	9.72	56.43	16.90	17.22	6.62
		17.5	14.39	1.45	9.65	57.94	16.93	16.91	6.65
		22.5	16.80	1.48	9.36	57.49	17.04	17.02	6.35
		27.5	9.86	1.55	8.48	57.53	16.92	17.05	6.47
	P2	1.25	13.84	1.48	7.49	60.96	14.62	14.28	6.50
		3.75	10.83	1.48	7.98	61.40	14.51	14.30	6.28
		6.25	13.15	1.55	7.63	61.71	14.69	14.03	6.11
		8.75	7.03	1.55	7.26	62.82	14.66	13.86	5.81
		11.25	12.21	1.58	6.61	63.17	14.71	13.59	5.92
		13.75	11.25	1.62	6.45	62.82	14.87	13.70	5.63
		17.5	14.05	1.62	6.54	62.39	15.09	14.27	5.96
		22.5	10.28	1.62	7.00	61.94	15.59	14.37	6.05
	P4	0.50	32.70	1.33	15.48	60.74	13.98	13.78	7.27
		2.00	24.28	1.51	10.78	61.49	15.00	14.06	7.31
		4.00	20.17	1.51	8.07	62.64	15.21	13.77	7.07
		6.00	17.52	1.48	8.39	63.29	15.39	13.30	7.23
		8.50	19.11	1.51	8.32	63.38	14.90	13.21	7.03
		11.00	18.00	1.58	7.35	63.94	14.96	12.99	7.20
		13.50	17.82	1.62	7.43	64.40	14.95	12.66	6.86
		17.50	17.25	1.62	7.46	64.56	14.55	12.86	7.10
		22.50	17.57	1.62	7.75	65.19	14.76	12.20	7.00
		27.50	14.90	1.62	7.29	66.54	14.42	11.70	7.33
Japan	Sapporo(April)	1.00	50.38	0.78	25.29	54.19	11.93	24.99	5.25
		3.00	48.76	0.95	22.81	54.52	12.11	24.48	5.22
		5.00	47.14	0.97	22.27	54.12	11.99	25.38	5.27
		7.00	39.97	0.89	21.38	53.74	12.09	26.03	5.26
		9.00	37.43	0.89	18.14	51.63	12.03	29.01	5.11
		11.00	34.89	0.89	20.18	53.76	12.02	26.29	5.22
	Sapporo(May)	1.00	33.73	0.85	23.09	56.13	12.40	22.41	5.02
		3.00	34.86	0.95	20.49	57.26	12.12	22.26	4.99
		5.00	36.00	0.95	20.01	55.95	12.21	23.23	4.98
		7.00	33.01	0.97	19.24	55.94	12.64	23.05	4.93
		9.00	31.59	0.99	18.14	56.28	12.85	22.98	4.94
		11.00	33.43	1.01	17.76	56.37	12.94	22.89	4.76
		13.50	32.68	1.03	17.16	55.92	13.11	23.59	4.76
		17.50	32.29	1.03	16.04	54.91	13.57	24.80	4.70
		22.50	34.23	1.09	15.56	52.39	13.04	28.46	4.79
	Sapporo(July)	1.00	37.88	0.94	21.03	56.71	12.33	21.98	5.10
		3.00	36.51	0.97	18.56	56.17	12.44	22.69	5.09
		5.00	35.13	0.97	18.15	56.52	12.50	22.50	5.00
		7.00	34.76	0.97	16.74	56.25	12.66	22.89	4.86
		9.00	34.89	0.95	15.32	56.69	12.88	22.64	4.67
		11.00	34.75	1.03	14.61	56.27	13.22	23.08	4.72
		13.50	34.89	0.99	14.55	55.55	13.47	24.08	4.80
		17.50	35.29	1.01	13.62	53.30	13.56	26.92	4.82
		22.50	37.21	1.03	13.00	53.43	13.44	27.09	4.74
		27.50	35.07	1.03	12.06	52.98	13.48	28.32	4.77
		35.00	32.73	1.07	10.23	54.36	13.77	24.39	4.71
		45.00	28.34	1.07	7.11	61.11	15.75	15.36	4.72

Table 2 Analytical data on potassium content (mg kg^{-1}), ^{40}K activity concentration (Bq kg^{-1}), $^{40}K/K$ (%) and D(40K/K) (%) in the forest soils

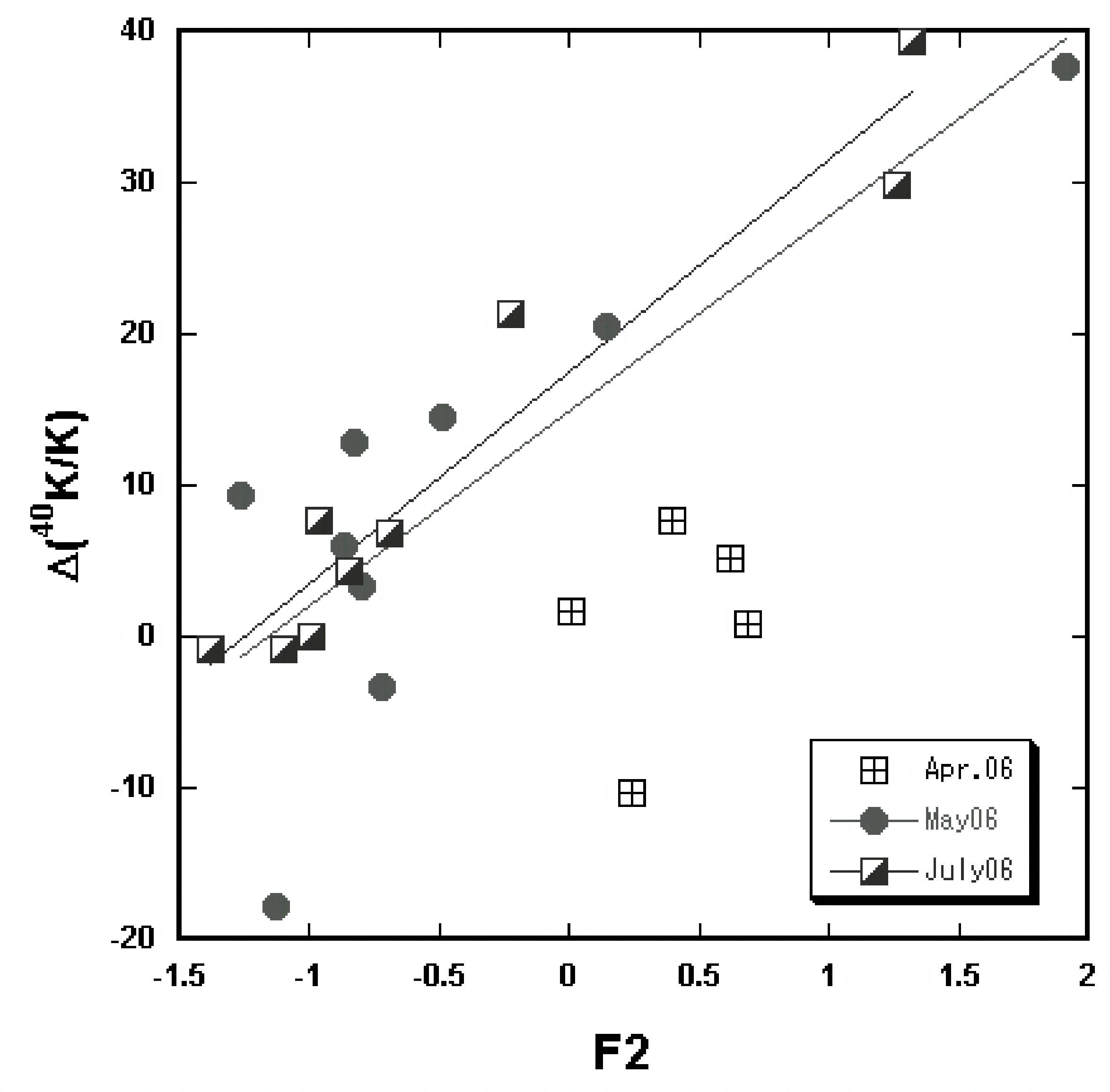
Country	Site	Depth (cm)	K (mg kg^{-1})	K uncertainty (± mg kg^{-1})	^{40}K (Bq kg^{-1})	^{40}K uncertainty (± Bq kg−1)	$^{40}K/K$ (10^{-2} %)	$\Delta(^{40}K/K)$ (%)
Czech Republic	Lysina	2.5	45765	1006	1009.0	11.8	0.85	−27.4
		7.5	55668	1217	1237.7	12.7	0.86	−26.5
		12.5	40636	893	1152.6	12.6	1.09	−6.8
		17.5	31936	706	1098.2	12.4	1.33	13.7
		22.5	56551	1236	1336.7	12.4	0.91	−22.2
	Nacetin	2.5	22706	518	334.7	13.9	0.57	−51.3
		7.5	24647	550	636.2	12.2	1.00	−14.5
		12.5	18925	426	673.3	11.7	1.37	17.1
		17.5	23813	531	729.2	11.5	1.18	0.9
		22.5	27943	619	760.8	12.7	1.05	−10.3
	Pluhuv Bor	2.5	8436	206	211.8	4.7	1.11	−5.1
		7.5	7361	179	256.1	4.2	1.12	−4.3
		12.5	8790	209	260.5	5.1	1.07	−8.6
		17.5	9367	221	264.1	5.1	0.94	−19.7
		22.5	10802	251	277.2	5.1	1.01	−13.7
Peru	P1−0	2.5	15316	348	529.9	7.6	1.33	13.7
		7.5	14332	327	521.0	7.5	1.40	19.7
		12.5	13020	299	480.9	7.1	1.42	21.4
		17.5	11754	272	470.2	7.1	1.54	31.6
		22.5	11429	265	477.2	7.2	1.61	37.6
		27.5	11385	264	432.2	6.7	1.46	24.8
	P1−1	2.5	15436	351	529.4	7.6	1.32	12.8
		7.5	13984	320	549.2	7.7	1.51	29.1
		12.5	13854	317	542.0	7.6	1.51	29.1
		17.5	13284	305	525.4	7.5	1.53	30.8
		22.5	13375	307	515.9	7.4	1.49	27.4
		27.5	13747	315	530.3	7.6	1.49	27.4
	P1−2	2.5	14758	336	475.9	7.1	1.24	6.0
		7.5	13068	300	459.4	6.9	1.36	16.2
		12.5	11442	266	416.0	6.6	1.40	19.7
		17.5	10948	255	404.4	6.4	1.42	21.4
		22.5	11175	260	400.9	6.4	1.38	17.9
		27.5	10920	254	404.9	6.4	1.43	22.2
	P2	1.25	16083	364	630.7	8.4	1.51	29.1
		3.75	16303	369	612.5	8.2	1.46	24.8
		6.25	15933	361	633.4	8.4	1.53	30.8
		8.75	15167	345	624.6	8.3	1.59	35.9
		11.25	14727	335	614.2	8.3	1.61	37.6
		13.75	14370	328	575.7	7.9	1.54	31.6
		17.5	13671	313	585.9	8.0	1.65	41.0
		22.5	13253	304	528.3	7.6	1.54	31.6
	P4	0.50	18758	423	559.2	8.0	1.15	−1.7
		2.00	18737	422	553.9	7.8	1.14	−2.6
		4.00	17113	387	637.0	8.4	1.44	23.1
		6.00	17497	395	586.3	8.2	1.29	10.3
		8.50	16893	382	580.0	8.0	1.32	12.8
		11.00	15775	358	472.6	7.1	1.16	−0.9
		13.50	14992	341	567.3	7.9	1.46	24.8
		17.50	14085	322	531.7	7.6	1.46	24.8
		22.50	13371	307	505.1	7.4	1.46	24.8
		27.50	12690	292	455.8	6.9	1.39	18.8
Japan	Sapporo(April	1.00	9555	227	260.0	4.2	1.05	−10.3
		3.00	9433	224	290.3	4.5	1.19	1.7
		5.00	9408	224	307.0	4.7	1.26	7.7
		7.00	9368	223	297.6	4.6	1.23	5.1
		9.00	9224	219	275.7	4.4	1.15	−1.7
		11.00	9315	221	285.7	4.5	1.18	0.9
	Sapporo(May	1.00	9844	233	245.5	5.1	0.96	−17.9
		3.00	9392	223	310.6	5.9	1.28	9.4
		5.00	9264	220	271.6	5.4	1.13	−3.4
		7.00	9485	225	297.1	5.8	1.21	3.4
		9.00	9217	219	296.3	5.8	1.24	6.0
		11.00	9266	220	316.6	6.0	1.32	12.8
		13.50	9156	218	318.5	6.3	1.34	14.5
		17.50	9396	223	343.8	6.5	1.41	20.5
		22.50	8684	208	362.1	6.7	1.61	37.6
	Sapporo(July	1.00	9762	231	294.0	5.7	1.16	−0.9
		3.00	9577	227	290.4	5.7	1.17	0.0
		5.00	9815	232	294.0	5.7	1.16	−0.9
		7.00	9440	224	298.3	5.8	1.22	4.3
		9.00	9270	220	302.1	5.8	1.26	7.7
		11.00	9134	217	296.5	6.2	1.25	6.8
		13.50	8916	212	328.8	6.3	1.42	21.4
		17.50	8648	207	341.7	6.5	1.52	29.9
		22.50	8442	202	357.3	6.5	1.63	39.3

Table 3 Loading of individual variables (humidity, density, SOM, SiO_2, Al_2O_3, Fe_2O_3 and pH) on two factors (F1 and F2) in the case of a cool-temperate deciduous stand in Sapporo, Japan

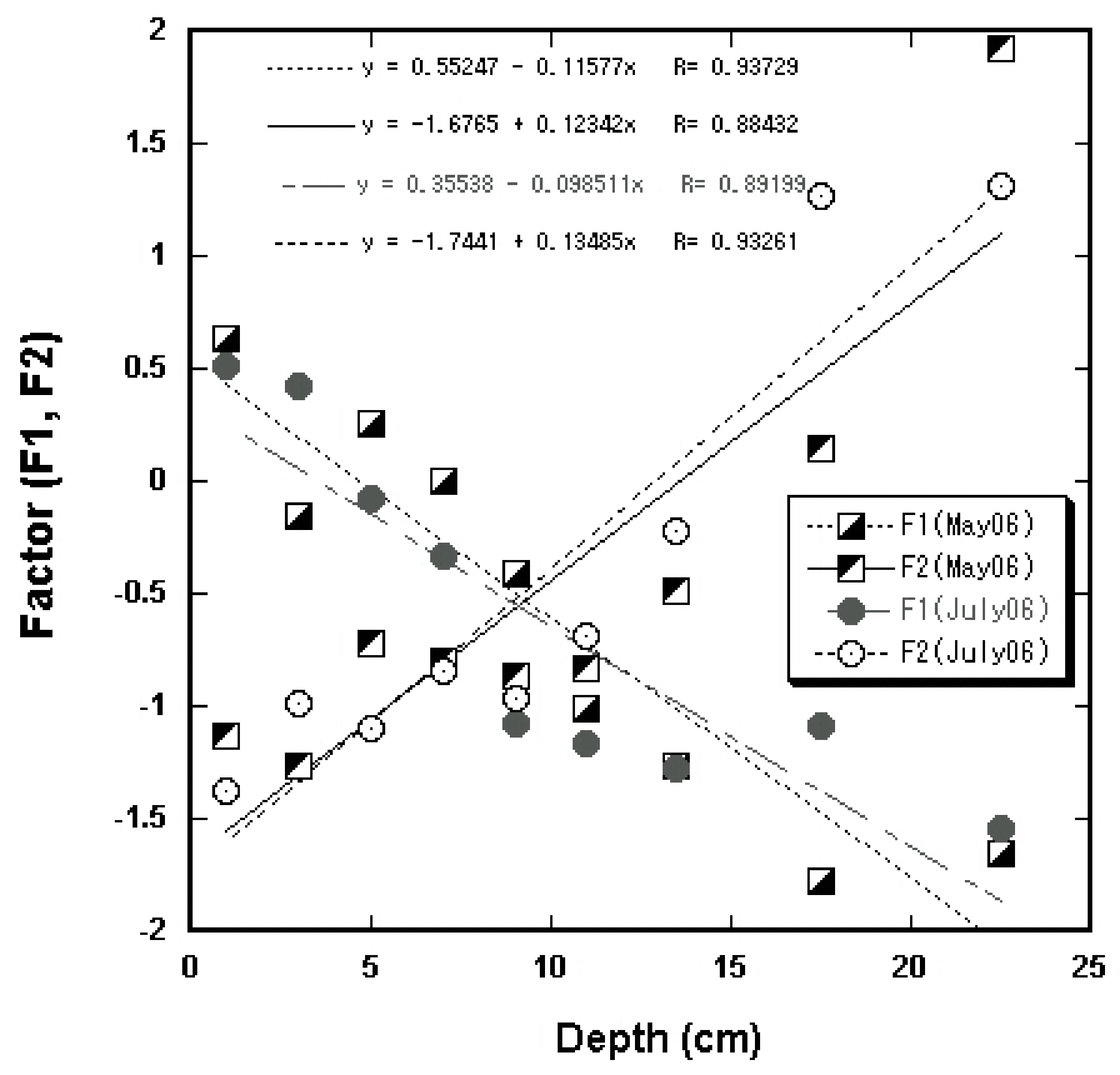
Variable	Loading	
	F1	F2
Humidity	0.7216	0.2481
Density	−0.8043	0.0144
SOM	0.4327	−0.0955
SiO_2	−0.1478	−0.9806
Al_2O_3	−0.9106	−0.1348
Fe_2O_3	0.0117	0.9949
pH	0.9417	0.2373



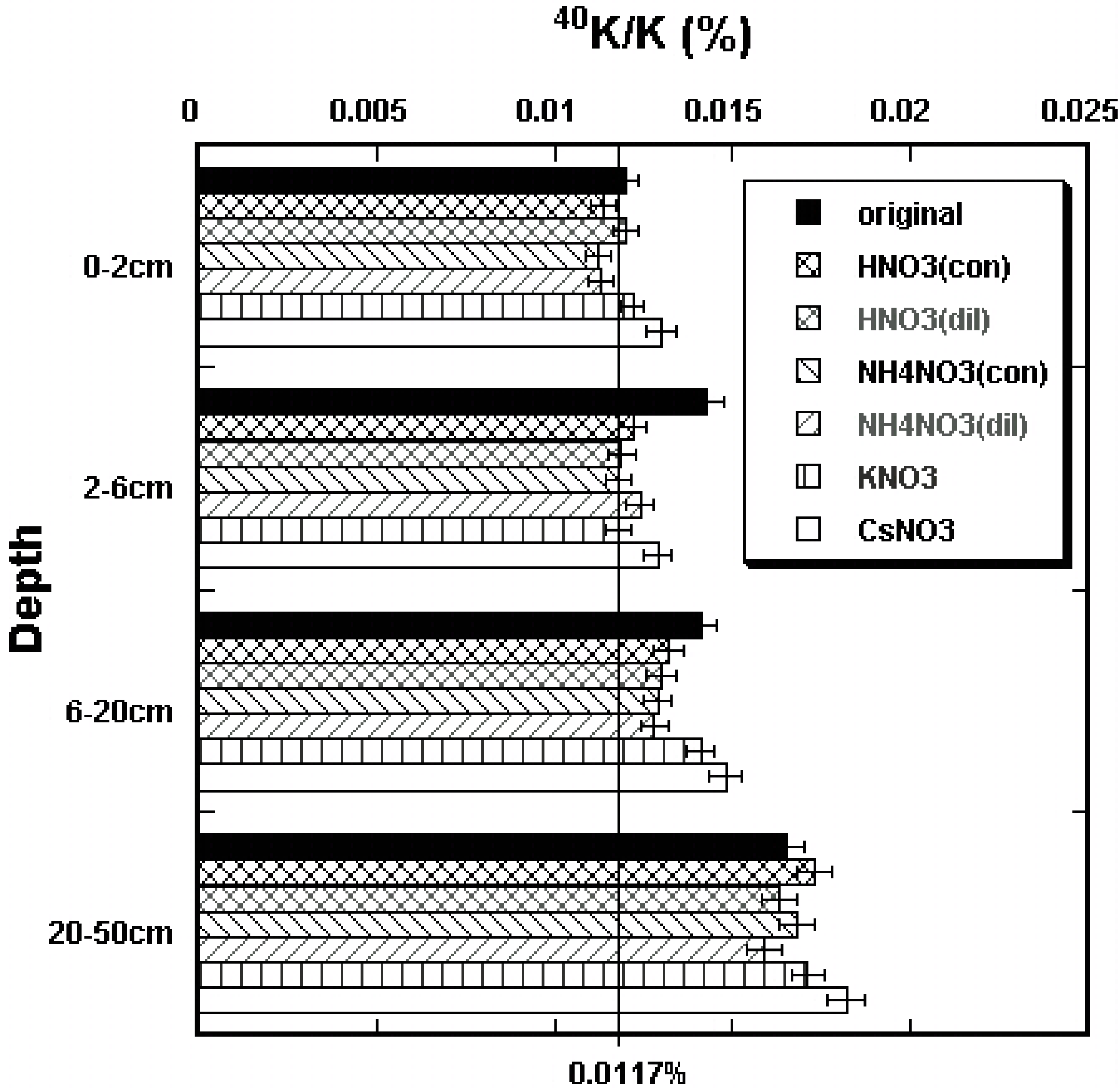
Apr.06
May06
July06
40
30
20
10
0
-10
-20
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
$\Delta(^{40}K/K)$
F1



40
30
20
10
0
-10
-20
-1.5
-1
-0.5
0
0.5
1
1.5
2
Δ(40K/K)
F2
Apr.06
May06
July06



y = 0.55247 - 0.11577x R= 0.93729
y = -1.6765 + 0.12342x R= 0.88432
y = 0.35538 - 0.098511x R= 0.89199
y = -1.7441 + 0.13485x R= 0.93261
F1(May06)
F2(May06)
F1(July06)
F2(July06)
Factor (F1, F2)
Depth (cm)



^{40}K/K (%)
0
0.005
0.01
0.015
0.02
0.025
Depth
0-2cm
2-6cm
6-20cm
20-50cm
original
HNO3(con)
HNO3(dil)
NH4NO3(con)
NH4NO3(dil)
KNO3
CsNO3
0.0117%