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Relevance of Radiocaesium Interception Potential (RIP) on a worldwide scale to assess soil vulnerability to ^{137}Cs contamination

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ABSTRACT

The extent of radiocaesium retention in soil is important to quantify the risk of further foodchain contamination. The Radiocaesium Interception Potential (RIP – Cremers et al., 1988, Nature 335, 247–249) is an intrinsic soil parameter which can be used to categorize soils or minerals in terms of their capacity to selectively adsorb radiocaesium. In this study, we measured RIP for a large soil collection (88 soil samples) representative of major FAO soil reference groups on a worldwide scale and tested the possibility to predict the RIP on the basis of other easily accessible or measurable soil data. We also compared RIP values with those obtained from separate chemical extraction experiments. The range of measured RIP values (1.8–13300 mmol kg^{-1}) was shown to include nearly all possible cases of agricultural soil contamination. Only Podzols, Andosols and Ferralsols were clearly characterized by a very low RIP (<2000 mmol kg^{-1}). On a worldwide scale, RIP was in fact slightly related to soil reference type or other simple major physicochemical parameters such as clay percentage or organic matter. Conversely our results indicated a link between the RIP and radiocaesium extractability across very different soils. We showed that, with the proposed scale of RIP values, a simple acid extraction method can provide an operational result highly predictive of potential RIP despite very contrasting soil properties. The RIP could be estimated from the empirical equation: $RIP = (-31.701 * \log(AER) + 58.886)^2$ where AER is the fraction of acid-extractable radiocaesium.

1. Introduction

Following an accidental atmospheric release, radiocaesium is of great environmental and public health concern, due to its possible long transport, its long half-live, its high solubility in water and its biogeochemical behavior similar to that of K, a major nutrient for plants and animals. After deposition, radiocaesium is retained in the topsoil because of its selective adsorption on soil particles, largely ruled by weathered micaceous clays (Maes et al., 1998). Vertical migration rates are usually very low in agricultural mineral soils (Almgren and Isaksson, 2006). Even in soils of semi-natural areas, with low clay and high organic matter content, the net ^{137}Cs export from the rooting zone was determined to be less than 0.007% per year (Tikhomirov et al., 1993). In organic-rich forest soils in particular, ^{137}Cs persistence in the surface layers can be a source of long-lasting recycling by the vegetation (Kruyts et al., 2000; Goor and Thiry, 2004; Thiry et al., 2000). In general, the extent of ^{137}Cs retention in agricultural and forest soils plays a key role in understanding the risk of foodchain contamination. Various experimental approaches were used to quantify such retention, yielding a variety of conceptual coefficients. One of them, the Radiocaesium Interception Potential (RIP – Cremers et al., 1988) has the particularity to be an intrinsic soil parameter but it must be determined under standardized experimental conditions. The measurement procedure involves soil chemical equilibration and its labeling with a sufficient amount of radiocaesium and thus necessitates adapted facilities to manipulate artificial radioactivity, which can discourage the use of RIP as a standard indicator at international level.

Only a few European laboratories have produced most RIP values. Moreover, while the RIP method was frequently used to characterize the ^{137}Cs adsorption capacity of various temperate soils containing micas (Waegeneers et al., 1999; Delvaux et al., 2000; Gil-García et al., 2008), tropical and sub-tropical soils were largely overlooked. However, Joussein et al. (2004) have shown that

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Table 1
Selected characteristics of the 88 soils including mean RIP values ($n = 3$) and mean fraction of total radiocaesium that is extractable in 0.1 M HCl and 1 M NH_4OAc ($n = 3$).

Ref. Group	Land	Texture fractions			pH		C[a] %	Exchangeable cations			CEC[b]	RIP[c] mmol kg^{-1}	^{137}Cs extractions	
		Sand	Silt	Clay	Water	KCl		Ca	Mg	K			HCl	NH_4OAc
		%						cmol$_c$ kg^{-1}					% of total activity	
Andosol	C. Rica	13.2	10.4	76.5	4.9	4.3	6.88	0.2	0.4	0.2	23.3	177	22.8	50.3
Andosol	Ecuador	61.4	29.4	9.3	5.7	4.8	1.11	3.8	1.3	0.1	5.9	938	6.19	44.4
Andosol	Ecuador	58.6	34.6	6.8	6.7	5.4	2.48	5.8	1.0	0.7	10.0	1020	19.8	41.8
Andosol	Ecuador	50.6	34.7	14.7	6.4	4.3	0.43	4.8	2.8	1.1	10.2	484	3.95	24.4
Andosol	Ecuador	57.2	38.9	4.0	6.6	5.7	1.00	4.1	1.9	0.4	6.7	94	55.7	74.2
Andosol	Ecuador	31.0	52.6	16.4	5.2	4.6	3.40	4.9	0.6	0.3	12.4	97	51.4	52.6
Andosol	Indonesia	29.5	46.4	24.2	5.6	5.2	7.72	20.4	4.2	2.7	36.7	450	16.2	68.7
Andosol	Indonesia	41.2	33.6	25.2	5.0	4.5	4.15	3.1	0.2	0.2	20.7	208	31.4	80.1
Andosol	Japan	31.0	38.8	30.2	5.5	4.6	5.80	8.5	1.8	0.8	48.6	1630	2.02	55.1
Andosol	Kenya	19.2	54.8	26.1	6.7	6.1	9.99	33.0	4.1	1.5	70.7	1320	10.1	70.5
Arenosol	China	95.9	1.4	2.6	8.9	8.2	0.03	20.0	1.0	0.2	2.1	1680	1.21	34.0
Calcisol	Spain	25.7	21.3	53.0	7.9	7.1	0.88	16.7	1.3	0.9	20.0	4340	0.12	14.9
Calcisol	Turkey	34.4	26.1	39.5	8.2	7.3	0.67	29.5	3.7	2.6	25.3	12100	0.07	15.9
Calcisol	Turkey	27.6	27.5	44.9	8.1	7.3	0.77	19.7	3.1	0.9	27.5	4220	0.16	13.3
Calcisol	Turkey	6.7	29.7	63.6	8.1	7.0	0.67	35.4	3.1	0.7	29.9	9630	0.05	11.0
Calcisol	Turkey	10.4	33.3	56.3	8.0	7.3	1.06	24.3	2.2	1.8	17.2	9090	0.21	36.3
Calcisol	Turkey	ND	ND	65.7	7.5	6.6	2.97	ND	ND	ND	50.5	9220	0.43	21.1
Cambisol	China	21.0	53.0	26.0	8.3	7.1	0.32	49.8	1.0	0.3	22.2	10500	0.05	5.32
Cambisol	China	12.3	43.1	44.5	8.2	7.1	1.04	49.0	2.4	0.5	23.0	12900	0.04	4.59
Cambisol	China	15.7	54.9	29.5	7.4	6.5	0.68	20.3	2.4	0.6	19.2	5310	0.15	5.28
Cambisol	China	32.5	23.4	44.2	4.8	4.1	0.53	0.8	0.3	0.1	5.1	945	9.87	61.2
Cambisol	China	45.7	17.9	36.2	4.3	3.8	2.91	0.8	0.3	0.3	10.5	1290	6.21	37.7
Cambisol	China	36.1	30.5	33.5	3.9	3.6	1.57	0.0	0.0	0.1	8.0	1370	1.49	15.7
Cambisol	China	31.8	16.8	51.3	6.2	4.8	1.41	10.2	2.7	0.7	13.2	4410	0.57	25.3
Cambisol	China	0.8	24.6	74.9	4.7	4.0	1.74	2.3	0.3	0.3	10.0	1680	2.88	39.1
Cambisol	Italy	12.2	30.7	57.1	6.8	5.9	1.70	20.9	1.3	0.4	25.6	6770	0.46	18.7
Cambisol	Italy	ND	ND	75.5	6.3	5.6	4.15	ND	ND	ND	30.5	8860	0.47	19.5
Chernozem	China	18.1	46.3	35.5	8.0	7.3	2.01	43.0	2.8	0.2	30.2	5770	0.15	3.66
Chernozem	Germany	8.3	75.0	16.7	8.1	7.1	1.32	12.2	0.7	0.3	16.4	5820	0.36	10.3
Chernozem	Peru	38.9	36.2	24.9	8.1	7.8	3.95	41.0	21.3	0.9	24.9	5100	0.26	5.87
Chernozem	Peru	15.6	52.5	31.9	8.3	7.4	2.11	47.2	13.2	1.7	39.1	8590	0.12	7.21
Chernozem	Romania	15.0	56.3	28.7	7.7	7.0	2.51	20.0	2.9	0.3	28.9	6790	0.11	4.47
Chernozem	USA	ND	ND	24.6	5.9	4.8	2.11	ND	ND	ND	20.0	4510	0.41	15.1
Ferralsol	Brazil	16.0	27.0	57.0	4.5	4.2	3.33	0.6	0.4	0.3	6.7	26	48.9	62.0
Ferralsol	Brazil	36.0	22.0	42.0	4.0	4.0	2.58	0.2	0.1	0.1	7.3	203	23.3	60.5
Ferralsol	China	10.5	12.4	77.0	4.3	4.1	1.48	0.2	0.3	0.0	5.9	217	22.2	63.2
Ferralsol	China	74.1	6.7	19.2	4.8	4.1	1.50	0.6	0.3	0.2	3.5	245	29.3	54.1
Ferralsol	Cuba	23.9	10.6	65.6	6.7	5.6	1.56	8.0	2.7	0.5	12.0	1410	3.28	66.8
Ferralsol	Cuba	10.3	9.5	80.1	5.2	4.2	1.49	5.8	1.5	0.3	13.2	835	3.03	55.6
Ferralsol	Indonesia	52.2	13.0	34.6	4.2	3.7	2.67	1.8	0.5	0.2	9.5	509	6.07	16.1
Ferralsol	Indonesia	28.6	9.0	62.3	4.7	4.2	3.52	3.0	0.7	0.2	11.8	87	16.0	48.7
Ferralsol	Indonesia	6.0	8.9	84.0	3.5	3.5	6.87	0.2	0.2	0.2	25.2	180	4.12	21.4
Fluvisol	Japan	56.1	34.9	9.0	6.6	5.7	1.11	7.1	2.7	0.9	14.9	2720	2.23	29.6
Fluvisol	Malaysia	98.2	0.7	1.1	8.3	8.1	0.16	7.3	0.8	0.0	2.2	150	13.6	38.5
Fluvisol	Nicaragua	37.6	38.6	23.8	7.3	6.7	1.72	37.9	2.4	1.1	33.8	9620	0.10	3.96
Fluvisol	Peru	52.1	38.0	10.0	6.0	5.5	2.08	14.9	0.0	0.4	12.1	1730	1.52	6.48
Fluvisol	Poland	41.7	38.6	19.7	5.1	4.6	1.26	12.7	3.1	0.3	16.2	6530	0.60	7.82
Gleysol	Cuba	6.3	29.1	64.7	7.7	6.8	1.02	28.9	12.4	0.2	38.3	2110	2.05	23.5
Gleysol	Cuba	5.0	20.4	74.4	6.6	5.1	1.43	29.9	12.2	0.2	46.3	504	5.05	30.0
Gleysol	Thailand	28.5	52.4	19.1	5.8	5.3	0.84	7.1	1.3	0.0	11.5	4460	0.89	13.1
Gleysol	Thailand	1.1	25.6	73.3	5.0	4.1	1.46	15.1	3.9	0.6	30.2	10100	0.28	11.7
Greyzem	China	7.8	66.6	25.6	6.7	6.3	1.77	20.8	2.4	0.1	20.4	4760	0.22	4.96
Kastanozem	USA	34.6	33.1	32.3	7.0	6.1	1.33	15.0	4.5	1.7	20.2	8390	0.39	18.0
Kastanozem	USA	ND	ND	23.1	8.1	ND	0.88	ND	ND	ND	14.0	5720	0.14	13.3
Luvisol	China	5.6	61.9	32.4	5.6	4.9	11.31	29.7	5.2	1.2	51.0	8050	1.52	17.2
Luvisol	China	19.3	59.2	21.6	6.5	5.8	1.29	16.0	2.7	0.2	16.1	5020	0.20	3.24
Luvisol	Italy	7.9	25.1	67.2	6.2	5.4	2.11	14.9	3.2	1.2	25.7	6750	0.54	23.5
Luvisol	Kenya	71.1	4.0	24.8	6.7	5.8	0.93	2.4	0.9	0.4	6.7	1470	2.80	53.8
Luvisol	Nicaragua	20.4	36.0	43.6	6.8	5.4	2.35	22.8	5.2	0.9	29.4	13 300	0.20	11.7
Luvisol	Spain	62.8	26.1	11.1	5.7	4.3	0.93	3.3	1.1	0.2	11.1	2270	0.74	12.5
Luvisol	Turkey	1.1	38.2	60.7	8.0	6.6	0.73	56.9	8.9	1.9	83.8	7970	0.15	8.80
Nitisol	Brazil	7.2	37.5	55.4	6.2	5.2	2.84	10.4	2.2	1.1	17.7	1550	14.8	56.0
Nitisol	Cameroon	18.1	28.3	53.6	6.4	5.8	3.00	9.3	4.0	0.4	22.7	539	6.15	32.5
Nitisol	Columbia	42.4	15.5	42.1	4.8	4.0	2.57	0.0	0.1	0.2	14.8	324	23.7	60.9
Nitisol	Italy	7.0	21.8	71.3	5.6	4.9	3.69	14.0	4.5	1.8	25.0	4920	0.98	30.0
Nitisol	Kenya	7.0	36.2	56.8	5.4	4.5	4.87	ND	ND	ND	ND	4370	3.26	57.4
Nitisol	Kenya	6.2	23.6	70.0	5.8	4.9	2.33	7.9	1.9	2.1	25.7	4430	1.09	46.2
Nitisol	Kenya	5.8	19.3	74.8	6.4	5.4	6.54	12.8	8.1	2.9	30.9	3510	2.21	43.4
Phaeozem	China	8.0	54.2	37.9	6.5	5.5	1.67	23.7	6.6	0.6	25.6	6080	0.12	3.83
Podzol	Belgium	68.0	16.4	15.6	6.2	5.7	2.49	ND	ND	ND	10.0	944	3.07	32.6
Podzol	Malaysia	97.2	2.6	0.2	4.9	3.6	1.34	0.8	0.3	0.0	5.2	1.8	87.6	94.7