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Effect of K-fertilization, liming and placement, on crop uptake of cesium and strontium

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Abstract

Remedial measures to reduce crop uptake of cesium and strontium under Swedish field conditions were investigated in micro plot experiments. For cesium the effect of K-fertilization was studied on three soils with oats, peas and mustard and, in combination with placement, on two other soils with wheat, barley and rape. For strontium the effect of liming was studied on three soils with oats, barley and peas and, in combination with placement, on two other soils with wheat, oats, barley and peas. In this paper results are summarized for the grain product .

K-fertilization reduced the uptake of cesium considerably and to a greater extent than liming reduced the uptake of strontium. Placement of 134-Cs at a depth of 27-29 cm compared to 0-25 cm reduced the uptake by a factor of two or more, as also did placement of 90-Sr at a depth of 20-25 cm compared to 0-20 cm, while placement of 90-Sr at a depth of 0-5 or 0-10 cm increased the uptake compared to 0-20 cm. The deeper placement of the nuclides in combination with K-fertilization and liming may reduce the crop uptake of cesium and strontium by a factor of 10 and 4 respectively. On the basis of the experimental results the practical values of K-fertilization and liming as well as deep ploughing of surface contaminated land are discussed.

Introduction

Accidental release of radionuclides from nuclear power plants or nuclear war may cause a severe contamination of the environment. If the radionuclides are deposited on agricultural land it may not be possible to use the growing crops, nor the land for cultivating a new crop in the same or the next year. Later, however, when short-lived radionuclides have decayed and soil-plant transfer will be the sole entry of radionuclides into the food chain, it may be necessary to use the land again. It will then be of potential value to predict the soil-plant transfer or crop uptake of long-lived radionuclides like 137-Cs and 90-Sr, and also to consider whether remedial measures can be taken in practical agriculture to reduce the uptake.

If the current Swedish soil management practices, with more or less deep harrowing and autumn ploughing, are continued after the radioactive deposition, the surface soil initially contaminated will soon be mixed with the whole plough layer. The soil-plant transfer of 137-Cs and 90-Sr will then to a large extent be governed by the potassium and lime status of the plough layer but also by the root distribution with depth. A practial measure to reduce uptake would be to place the contaminated surface layer deeper in the soil profile with lower accessibility to nutrient uptake by roots. The objective of this paper is to discuss some results of such placements and also effects of fertilization with potassium and liming.

Methods

The microplot technique as described by Fredriksson (1963) was applied in order to simulate field conditions. At the start of an investigation the technique consists of removing the plough layer, of driving down metal frames 5 cm in the subsoil, and of filling the frames with contaminated and uncontaminated soil layers according to the experimental plan. The microplots thus comprise the plough layer and the subsoil beneath it as deep as is used by plant roots. Crops are then grown year by year as in the field and the harvested plant material radioassayed for determination of nuclide uptake or soil-plant transfer.

In this paper four investigations are referred to. Two of them, or those with K-fertilization and liming only, were carried out at a special experimental station and with constructed soil profiles. Three plough layer soils, 23 cm thick, were homogeneously contaminated with the nuclides and placed on a sandy subsoil with only 5 per cent clay. In the two other investigations, where deeper placement of the nuclides in the soil profile was also studied, the plough layers as well as the subsoils were the soil in situ.

Results and discussion

Results are only given for the grain products of the crops grown. They are presented in Tables 1-4 as relative numbers of nuclide uptake with the uptake in the control or reference treatment set at 100 and as transfer coefficients in Table 5.

Cesium, K-fertilization

The plough layers contaminated with 137-Cs were Soil 1, a loam, Soil 2, a clay loam, and Soil 3, a silty clay, with 5.4, 5.3 and 6.6 per cent organic matter respectively. In the first year K-fertilizer was mixed in with the plough layer in two treatments, 156 and 624 kg K per hectare. In the following year a fifth of this amount of K was mixed with a 5 cm thick top layer of soil. Oats, peas and mustard were grown in seven 3-year crop rotations during 1961-81. Results in detail were given for the first crop rotation by Fredriksson et al. (1966).

In Table 1 the effect of K-fertilization is averaged for soils and crops over the whole experimental period 1961-82. As seen, the 137-Cs-uptake decreased with the K-rate for all the crop-soil combinations. Compared to the control, or soil unfertilized with potassium, it decreased to 46-62 per cent at the low K-rate and to 3-15 per cent at the high K-rate. While it decreased more for mustard than for oats and more for oats than for peas, at both K-rates it decreased more on Soil 1, with 18 per cent clay, than on Soil 2 and Soil 3, with 33 and 48 per cent clay respectively.

134-Cs, placement and K-fertilization

The two experiments in this investigation were located at Tierp, 60 km northeast of Uppsala, and at Bjärsjölagård in the south of Sweden; Soil 4, a loam, and Soil 5, a silty clay loam, with 4.5 and 7.8 per cent organic matter respectively. Four combinations of placement and K-fertilization were employed. In two treatments the plough layer, 0-25 cm, was contaminated, and unfertilized or fertilized with potassium. In the two other treatments a soil layer 2 cm thick was contaminated and placed at a depth of 27-29 cm, likewise unfertilized or fertilized with potassium. The nuclide used on these sites was 134-Cs and the K-rate was 250 kg per hectare.

In Table 2 results are presented for barley and rape in 1982, for barley and winter wheat in 1983 and for winter wheat and rape in 1984. As is evident, the effects varied with soil, crop and year. Compared to the control and averaged over crops and years, the 134-Cs-uptake on Soil 4 and Soil 5 was reduced by placement to 56 and 48, by K-fertilization to 43 and 45, and by both placement and K-fertilization to 43 and 45 per cent respectively.

90-Sr, liming

In this investigation the plough layers contaminated with 90-Sr were Soil 6, a loamy sand, with 4.0 per cent organic matter and Soil 2 and Soil 3 as in the investigation with 137-Cs. In the first year lime as $CaCO_3$ was mixed in with the plough layer in two treatments, 5 and 25 tonnes per hectare. Oats, barley and peas were grown in two 3-year crop rotations during 1961-66. Results were given in detail by Lönsjö and Haak (1975).

In Table 3 the effect of liming is averaged for crops and soils over the years 1961-66. As seen, the 90-Sr uptake decreased with liming rate but differently with crop and soil. It decreased more for peas, where the 90-Sr-uptake at the high lime rate was about half of that in the control. The reason may be that cereals usually have a deeper root system and therefore take up more calcium from the subsoil than peas.

The effect of liming was about 10 per cent higher for oats and barley on Soil 6 and Soil 2 at both the lime rates. On Soil 3 it was very low at the low liming rate for oats and barley but higher for barley than oats at the high liming rate.

90-Sr, placement and liming

The two experiments of this investigation were located at Skarhults Nygård in the south of Sweden and at Lanna in the west of Sweden; Soil 7, a sandy loam, and Soil 8, a silty clay loam, with 6.8 and 3.7 per cent organic matter respectively. Eight combinations of placement and liming were employed. The soil layers 0-5, 0-10, 0-20 and 20-25 cm were contaminated with 90-Sr of unlimed and limed soil. In the three first placements the soil layer 0-20 cm was limed and in the fourth placement also the layer 20-25 cm, in all cases with 10 tonnes Ca CO_3 per hectare. Detailed results of these two experiments and two others, unlimed only, were given by Fredriksson et al. (1969).

In Table 4 results are presented for four crops as relative numbers with placement of 90-Sr at 0-20 cm of unlimed soil as the control; set to 100. The numbers given are mean effects of the period 1960-65.

The effect of placement at 20-25 cm compared to placement at 0-20 cm, varied with soil and crop. Usually it was larger on Soil 7 than on Soil 8. Placements at 0-5 and 0-10 cm usually resulted in higher 90-Sr uptake than placement at 0-20 cm.

The effect of liming at placements 0-5, 0-10 and 0-20 cm was larger on Soil 7 than on Soil 8, a result to be expected as liming increased the pH from 5.0-6.8 and from 5.8 to 6.4 on the two soils respectively. Thus liming on average decreased the 90-Sr-uptake at these three placements, on Soil 7 to 44 per cent in cereals and to 20 per cent in peas, on Soil 8 to 78 per cent in cereals and to 85 per cent in peas. On Soil 7 the effect of liming at placement 20-25 cm was about the same while on Soil 8 it was smaller compared to the shallower placements.

Transfer coefficients

In order to compare the plant uptake of nuclides on the 8 soils investigated, TC_{sp} or transfer coefficients soil/plant have been calculated for the control or reference treatment in Table 5 as follows.

$$TC_{sp} = Bq(kg\ dry\ matter)^{-1} / Bq\ m^{-2} = m^{2}(kg\ dry\ matter)^{-1}$$

where TC_{sp} is the fraction of activity per unit dry matter of that deposited per unit soil surface area. As to be expected, TC_{sp}, or in this case the transfer from soil to grain, was higher for strontium than for cesium, and varied with soil and crop. For cesium it was higher on Soil 1 than on Soil 2 and Soil 3 and higher on Soil 4 than on Soil 5. For strontium it was higher on Soil 6 than on Soil 2 and Soil 3 and higher on Soil 7 than on Soil 8.

Conclusions and practical considerations

In a situation after an accidental release of fission products many pertinent problems must be solved if contaminated agricultural land should be used again for production of food items. Provided that enough time has been allowed for short-lived radionuclides to decay, we are especially concerned with the availability of 137-Cs and 90-Sr initially present in a surface layer of arable soils. As can be deduced from the last field investigation referred to, the availability will be lowered to some extent by mixing this contaminated soil layer with the whole plough layer, as would be the case if the present Swedish soil management practices are continued. From Table 5 we see that the availability and thereby the crop uptake, or more specifically TC_{sp}, will vary with soil characteristics but will always be many times higher for 90-Sr than for 137-Cs.

Compared to continued soil management and mixing of nuclides with the whole plough layer, placement of the contaminated surface layer deeper in the soil profile will to a much larger extent reduce the availability of cesium and strontium. Nutrient additions are also effective. The reduction will vary with soil and crop and also with year. To be considered as conservative estimates, placement and nutrient additions can reduce the transfer from soil to grain by a factor of 10 for cesium and by a factor of 4 for strontium.

At the practical farm level, safe placement of the surface contaminated soil layer by deep ploughing will be the critical measure to be taken prior to growing the first crop. It will also be critical to apply surface tillage in the following years in order to conserve the nuclides at the desired depth. Both field practices will be more difficult on stony till soils than on sedimentary clay soils. Nevertheless, in the long-term perspective these changes in soil management and nutrient practices imply an attractive approach to reduce the crop uptake of 137-Cs and 90-Sr.

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Table 1. Effect of K-fertilization on 137-Cs-uptake by oats, peas and mustard.

Soil (% clay)	K-fertilization kg ha^{-1} y^{-1}		137-Cs uptake relative numbers		
	1961	1962-81	Oats	Peas	Mustard
Soil 1	0	0	100	100	100
(18)	156	31	54	47	62
	624	125	5.9	8.4	3.0
Soil 2	0	0	100	100	100
(33)	156	131	60	52	54
	624	125	6.7	15	3.2
Soil 3	0	0	100	100	100
(48)	156	31	46	50	49
	624	125	8.1	14	5.0

Table 2. Effect of placement and K-fertilization on 134-Cs-uptake by barley, rape and wheat. Relative numbers.

Placement	Soil 4		Soil 5		Soil 4		Soil 5	
depth, cm	No K	K-fert.	No K	K-fert.	No K	K-fert.	No K	K-fert.
	Barley -82				Barley -83			
0-25	100	30	100	39	100	54	100	38
27-29	39	5	55	2	77	20	66	3
	Rape -82				Rape -84			
0-25	100	32	100	50	100	34	100	64
27-29	19	6	52	1	71	12	78	18
	Wheat - 83				Wheat - 84			
0-25	100	43	100	32	100	67	100	26
27-29	58	6	40	2	71	1	65	1

Table 3. Effect of liming on 90-Sr uptake by oats, barley and peas.

Soil (CEC)	Lime t ha^{-1} 1961	Ca-AL me(100 g soil)$^{-1}$ 1961	1966	90-Sr-uptake, relative numbers Oats	Barley	Peas
Soil 6	0	3.8	3.5	100	100	100
(4.2)	5	3.8	5.8	80	92	76
	25	3.8	18.1	62	69	47
Soil 2	0	10.2	8.1	100	100	100
(15.2)	5	10.2	10.7	83	90	62
	25	10.2	20.5	57	70	47
Soil 3	0	10.0	7.7	100	100	100
(20.1)	5	10.0	10.7	97	96	77
	25	10.0	21.3	78	58	46

Table 4. Effect of liming and placement on 90-Sr-uptake by wheat, oats, barley and peas. Relative numbers.

Placement depth, cm	Soil 7 Unlimed	Limed	Soil 8 Unlimed	Limed
	Wheat			
0-5	124	40	128	98
0-10	106	41	114	88
0-20	100	33	100	84
20-25	41	21	28	28
	Oats			
0-5	131	64	180	141
0-10	126	59	145	99
0-20	100	46	100	84
20-25	42	23	39	30
	Barley			
0-5	137	56	100	85
0-10	126	58	100	87
0-20	100	50	100	72
20-25	36	31	42	32
	Peas			
0-5	122	23	145	141
0-10	120	24	137	99
0-20	100	22	100	84
20-25	47	13	38	30

Table 5. Transfer coefficients, TC_{sp}, in the control treatment of Soils 1-8.

Nuclide Soil	TC_{sp}, m^2(kg dry grain)$^{-1}$ x 10^{-3}			
^{137}Cs	Oats	Peas	Mustard	
Soil 1	0.276	0.271	0.477	
Soil 2	0.162	0.161	0.260	
Soil 3	0.092	0.088	0.109	
^{137}Cs	Barley-82	Rape-82	Wheat-83	
Soil 4	0.083	0.054	0.025	
Soil 5	0.073	0.176	0.092	
^{137}Cs	Barley-83	Rape-84	Wheat-84	
Soil 4	0.046	0.059	0.049	
Soil 5	0.064	0.119	0.026	
^{90}Sr	Oats	Barley	Peas	
Soil 6	2.16	1.00	1.00	
Soil 2	1.28	0.68	0.68	
Soil 3	1.37	0.68	0.68	
^{90}Sr	Wheat	Oats	Barley	Peas
Soil 7	1.30	1.17	1.44	1.12
Soil 8	0.39	0.48	0.63	0.55