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Transfer of Radiocaesium to Barley, Rye Grass and Pea

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Risø National Laboratory, DK-4000 Roskilde, Denmark
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Mette Øhlenschlæger and Gunnar Gissel-Nielsen

In areas with intensive farming, as in Denmark, it is of great interest to identify possible countermeasures to be taken in order to reduce the long-term effects of radioactive contamination of arable land. The most important long-lived radionuclides from the Chernobyl were ^{137}Cs and ^{134}Cs. The aim of the present project was to identify crops with relatively low or high root uptake of these two isotopes. Although such differences may be small, a shift in varieties might be a cost-effective way to reduce collective doses.

The experiment was carried out at Risø National Laboratory in the summer of 1988. The species used were: spring barley (Hordeum vulgare L) varieties: Golf, Apex, Anker, Sila; Perennial rye grass (Lolium perenne L.) varieties: Darbo (early) and Patoro (late); Italian rye grass (Lolium multiflorum) variety: Prego; and pea (Pisum arvense L.) variety: Bodil. Each crop was grown in two types of soil, a clay-loam and an organic soil. ^{137}Cs was added to the clay-loam. The organic soil, which was contaminated with ^{137}Cs from the Chernobyl accident, was supplied with ^{134}Cs.

Sila barley and Italian rye grass were identified among the species tested as plants with a relative high uptake of radiocaesium.

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TABLE OF CONTENTS

1. INTRODUCTION

The contamination of vegetation with nuclear debris in connection with accidents in nuclear facilities takes place in two ways:

1) directly, i.e. adsorption of the debris on the aerial parts of the vegetation often followed by an absorption, and

2) indirectly, i.e. absorption through the root system of radionuclides that have entered the soil.

While all radionuclides in nuclear debris play a role in direct contamination, it is among the long-lived nuclides, that absorption via the roots occurs.

In areas with intensive farming, as in Denmark, it is of great interest to identify possible countermeasures to be taken in order to reduce the long-term effects of radioactive contamination of arable land.

The most important long-lived radionuclides from the Chernobyl accident were Cs-137 and Cs-134. The aim of the present project was to identify crops with relatively low or high root uptake of these two isotopes. Although such differences may be small, a shift in varieties might be a cost-effective way to reduce collective doses.

Because a part of this project was carried out in a soil contaminated with radiocaesium from the Chernobyl accident, it was possible to investigate differences in experimentally added caesium (exp-Cs) and Chernobyl-produced caesium (Ch-Cs).

2. EXPERIMENTAL METHODS

The experiment was carried out at Risø Nat. Lab. in the summer of 1988. 68 pots were seeded on 10 May. The species used were: spring barley (Hordeum vulgare L) varieties: Golf, Apex, Anker, Sila; Perennial rye grass (Lolium perenne L.) varieties: Darbo (early) and Patoro (late); Italian rye grass (Lolium multiflorum) variety: Prego; and pea (Pisum arvense L.) variety: Bodil.

Each crop was grown in two types of soil, a Danish clay-loam and a Swedish organic soil. The clay-loam was a typical Danish agricultural soil from Risø. The organic soil originates from Gävle in Sweden, north-west of Stockholm, site of the largest deposition of radio-caesium in Sweden following the Chernobyl accident. Characteristics of the two soils are given in Table 1.

Table 1

Soil type	Content of organic matter %	Particle size in %				pH	mg K pr. 100 g soil
		0.002 mm<	0.002-0.02 mm	0.02-0.2mm	0.2-2.0 mm		
Clay-loam	2.8	6.7	10.5	37.9	42.1	7.0	10.7
Organic	66	4.4	7.7	15.9	6.0	5.2	8.0

Four replicates were systematically placed within the experiment, that is 64 pots containing the eight varieties in both types of soil. Four border-pots were placed at the end of the set-up.

Cs-137 (exp-Cs) was experimentally added to the clay-loam. The organic soil that was contaminated with Cs-137 (Ch-Cs) from the Chernobyl accident was supplied with Cs-134 (exp-Cs). The concentration of caesium in each pot at the beginning of the project is shown in Table 2.

Table 2 Cs-concentration in the soil at the beginning of the project. Bq kg^{-1}, dry weight. Means of thirty-two replicates ± 1SE.

Soil:	
A: Clay-loam, experimentally added Cs-137	343,000 ± 1%
B: Organic soil, experimentally added Cs-134	24,700 ± 2%
C: Organic soil, Chernobyl Cs-137	2,120 ± 2%

The Cs-137 solution was placed on sand, which was dried and mixed up in 32 kg clay-loam. This was divided into 32 portions, each of which was mixed with 19.5 kg clay-loam. A total of 20.5 kg clay-loam was then added to each pot. The Cs-134 solution was added to the organic soil in a similar way; however, because of the lower density of the organic soil, only 11 kg were placed in each pot. Each pot had a diameter of 25 cm and a volume of 20 l.

The barley was harvested on 30 August. The samples were cut 5 cm above the soil surface, divided into grain and straw, and dried at 80°C for 24 hours. The pea-plants were also harvested on 30 August. The samples were cut 5 cm above the soil surface, divided into peas and haulm, and then dried at 80°C for 24 hours. For the grass, six successive cuts were taken at appropriate stages of the development: 14 June, 28 June, 19 July, 8 September, and 21 October. The samples were cut 4 cm above the soil surface and dried at 80°C for 24 hours.

The dry weights of the samples were determined and the caesium concentrations measured with gamma-spectrometric equipment using germanium detectors.

All pots received a basic fertilization of 20 g of a formula fertilizer (16-5-12). After each harvest of grass, these pots were fertilized with 4g N as a solution of NH_4NO_2.

3. DATA TREATMENT

Data for the radio-caesium concentrations in soil and vegetation and concentration ratios (CR) are expressed as arithmetic means of the four replicates +/- one standard error in percent of the mean. The concentration ratio (CR) is defined as the ratio of the plant to the soil concentration, Bq per g plant/Bq per g soil, on dry weight basis.

To identify differences between the two isotopes in the organic soil, the ratio Ch-Cs/exp-Cs (Bq 134-Cs per g dry weight/Bq 137-Cs per g dry weight) is studied for the grass at each harvest. For barley and pea the differences in this ratio were investigated for the various parts of the plant.

The statistical analyses are performed on the log-transformed concentration ratios and the log-transformed caesium ratios, as the data had a log-normal rather than normal distribution. Comparisons are made with two- or three-sided analyses of variance, including two or three of the following factors: species, varieties, plant part, time of harvest, soil types and isotopes.

The results were corrected for the decay of the isotopes. Calculations showed that during the period of growth, the Italian rye grass removed 10 percent of the activity from the organic soil. For this particular combination of variety, soil and isotope, corrections were made in order to account for the activity removed from the soil during the period of growth. The other varieties grown in organic soil removed less than 4 percent. For the clay-loam less than one percent of the activity was removed from the soil; consequently, no corrections were made.

4. RESULTS AND DISCUSSION

4.1. BARLEY

Table 3 shows the root uptake of radio-caesium for the four varieties of barley. Analyses of variance show a significant difference in the root uptake for the four varieties in all three experiments A, B and C, confirming a higher root uptake for Sila as indicated in Table 3.

Table 3 Barley

Concentration ratios, Bq per g plant/Bq per g soil, dry weight. Means of four replicates ±1SE.

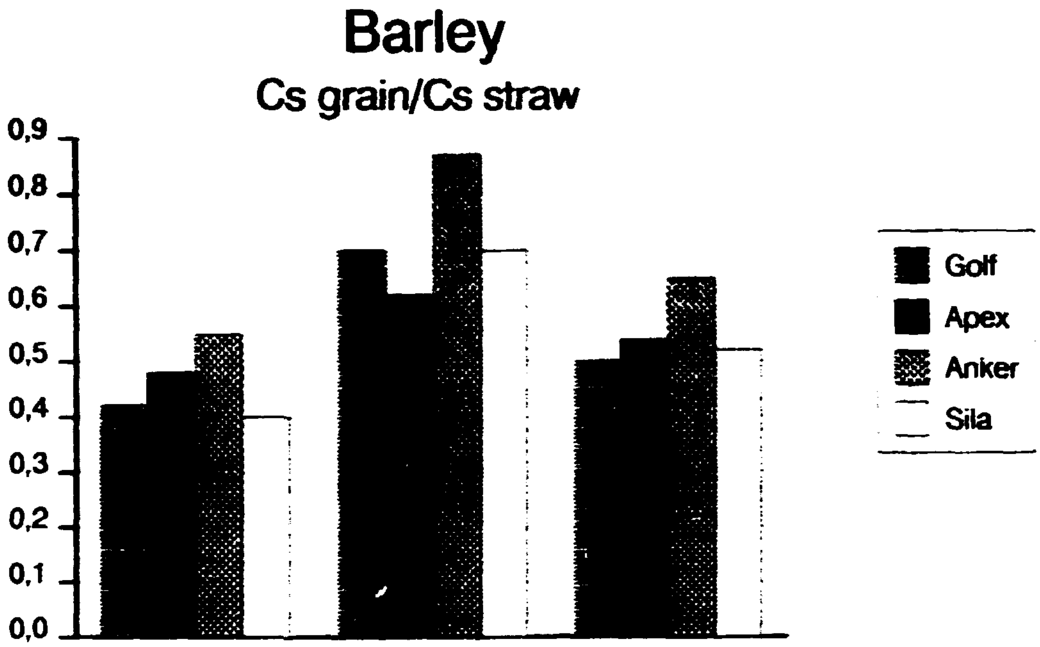
Soil and isotope	Variety	Grain	Straw
A:			
Clay-loam	Golf	0.034±5%	0.083±5%
experimentally	Apex	0.031±9%	0.065±8%
added Cs-137	Anker	0.036±7%	0.066±10%
	Sila	0.042±4%	0.105±7%
B:			
Organic soil	Golf	0.476±10%	0.679±12%
experimentally	Apex	0.471±7%	0.764±9%
added Cs-134	Anker	0.602±7%	0.700±9%
	Sila	0.640±7%	0.921±9%
C:			
Organic soil	Golf	0.119±10%	0.239±12%
Chernobyl	Apex	0.117±7%	0.219±11%
Cs-137	Anker	0.154±6%	0.240±8%
	Sila	0.179±9%	0.342±9%

Differences in the uptake from the two types of soil can be viewed from A and B in Table 3. The uptake of exp-Cs from the organic soil is about a factor of 15 higher than of exp-Cs in the clay-loam. This is in agreement with previous results which show that the uptake of Cs decreases with increasing clay content (Andersen 1967), (Baber 1964), (Fredriksson and Ericsson 1966), (Gillham et al. 1980), (Kühn et al. 1984), (Schuller et al. 1988) and (Steffens et al. 1988).

Differences in distribution in the plants between experimentally added Cs and Chernobyl Cs can be viewed from B and C. The uptake from exp-Cs is about a factor of 4 higher than for Ch-Cs. This might be caused by the fact that Ch-Cs is "older" than exp-Cs and therefore firmer fixed to soil-particles, and consequently less available for the plants. The difference might also be due to chemical differences between the two isotopes in the soil. This will be further investigated in the continuation of this project in 1989.

In agreement with earlier experiments (Gissel-Nielsen and Andersen 1967), (Steffens et al. 1988), (Grogan 1984), the uptake in the straw is greater than in the grain. Analyses of variance carried out for each type of soil showed a significant interaction between the different varieties and parts of the plants, which means that the translocation of caesium in the four varieties takes place in different ways. Figure 1 shows that Anker in particular translocates a greater part of the Cs to the grain than the other varieties.

Figure 1



A:	B:	C:
Clay-loam experimentally added Cs-137	Organic soil experimentally added Cs-134	Organic soil Chernobyl Cs-137

The Cs level in the plants from the border pots indicated some direct contamination from neighboring pots. This might be due to resuspension and rain-splash. According to H.A.Grogan et al. (Grogan 1984), the main part of the direct contamination arises from windblown soil particles. In 1988, the "natural" levels in Danish straw and husks contaminated with Cs-134 from Chernobyl were about 1Bq/kg, dry weight. Table 4 shows the Cs-134 levels in the straw from the border pots with clay-loam.

The presence of Cs-134 indicates a direct contamination from the pots with organic soil with experimentally added Cs-134. The large variation (SD) supports this conclusion. The mean activity indicates that the equivalent amount of soil on the straw is about 1 g organic soil, dry weight. This indicates a resuspension factor of 0.014 g soil, d.w./g plant d.w., which is in good agreement with previous results. (Grogan et al. 1984) The Cs-134 levels in the grain were below the detection limit, which agrees with the prediction that most of the direct contamination will be at the straw and husks.

Table 4 Clay-loam. Direct contamination of straw with Cs-134. Dry weight. Means of replicates ± 1SD.

Variety	Bq/kg	Bq/pot	Replicates*
Golf	301±46%	21±46%	3
Apex	145±40%	12±40%	3
Anker	208±54%	17±54%	3
Sila	235	20	1

*Results are missing, below detection limit.

Assuming similar translocation for the two isotopes, the difference in the Cs grain/Cs straw ratio between B and C in Figure 1 is explained by direct contamination at the straw with Cs-137 both from Ch-Cs in the pots with organic soil and from experimentally added Cs-137 in the pots with clay-loam.

The reason that the direct contamination is detectable when measuring Ch-Cs in straw from the organic soil, but not detectable for exp-Cs, is that the root uptake from exp-Cs is much more pronounced and suppresses the effect of direct contamination. A similar conclusion can be drawn from A and B. Because the root uptake of exp-Cs from the clay-loam is small, the direct contamination will become detectable. In addition, analyses of variance showed a significant difference between the Ch-Cs/exp-Cs ratio for grain and for straw and husks in the organic soil.

Within each variety of barley no significant difference in the yield of dry matter occurred. Consequently the yield was not considered in the discussion.

4.2. PEA

Table 5 shows that root uptake in pea follows the same pattern as in barley. There is a higher root uptake of exp-Cs from organic soil than from clay-loam, and in the organic soil a higher root-uptake of exp-Cs occurs than that of Ch-Cs. The reasons are the same as discussed for barley. However, there are differences in the translocation of Cs, Table 6. The CR value for the seed grown in the organic soil is of the same order of magnitude as the CR value for the straw, while in the clay-loam the translocation to the straw is a factor of two higher than the translocation to the seed.

Table 5 Pea

Concentration ratios, Bq per g plant/Bq per g soil, dry weight. Means of four replicates ± 1SE.

Soil and isotopes	Pea	Haulm
A: Clay-loam experimentally added Cs-137	0.036±8%	0.073±7%
B: Organic soil experimentally added Cs-134	0.75±13%	0.80±10%
C: Organic soil Chernobyl Cs-137	0.33±14%	0.37±10%

Table 6 Pea

Cs seed/Cs straw and husks, Bq per g peas/Bq per g haulm. Means of four replicates ± 1 SE.

Soil and isotopes	Cs peas/Cs haulm
A: Clay-loam experimentally added Cs-137	0.50±7%
B: Organic soil experimentally added Cs-134	0.93±8%
C: Organic soil Chernobyl Cs-137	0.89±8%

4.3. GRASS

Table 7 shows the differences in the root uptake for the three varieties of grass.

Table 7

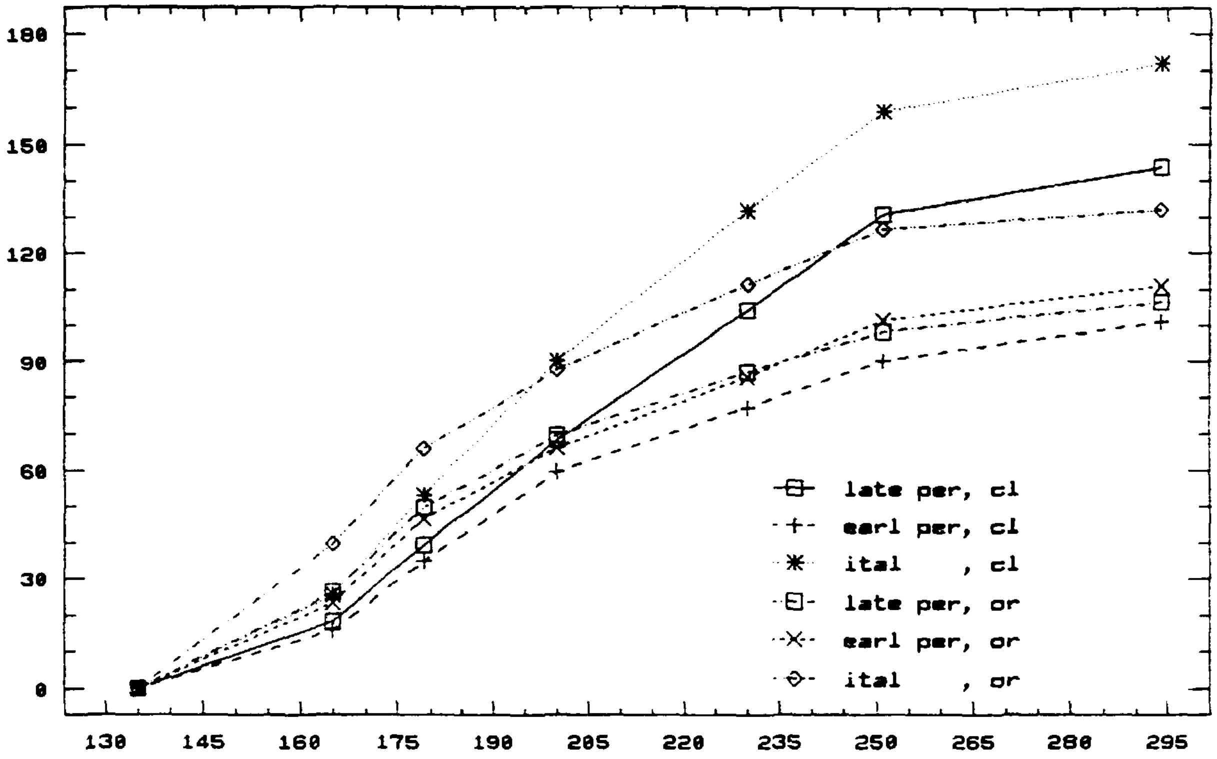
Grass: Concentration ratios, Bq per g plant/Bq per g soil, dry weight.
Means of four replicates ±1SE.

Soil and isotopes	Variety	Date of harvest (1988) 14/6	28/6	19/7	18/8	8/9	21/9
A: Clay-loam experimentally added Cs-137	Italian	0.111±5%	0.163±5%	0.141±6%	0.417±6%	0.313±6%	0.393±9%
	Early Perennial	0.046±9%	0.063±6%	0.053±7%	0.123±16%	0.121±16%	0.148±11%
	Late Perennial	0.045±5%	0.055±8%	0.050±8%	0.199±7%	0.166±5%	0.168±7%
B: Organic soil experimentally added Cs-134	Italian	1.75±7%	4.69±6%	2.79±8%	2.96±7%	4.50±7%	3.65±9%
	Early Perennial	0.85±7%	1.51±8%	1.33±10%	1.67±10%	2.34±16%	3.66±13%
	Late Perennial	0.72±8%	1.49±8%	1.40±10%	1.71±8%	2.12±17%	2.73±13%
C: Organic soil Chernobyl Cs-137	Italian	0.455±9%	1.26±6%	1.00±8%	1.38±6%	2.09±6%	2.03±12%
	Early Perennial	0.237±8%	0.467±9%	0.534±13%	0.860±8%	1.20±11%	1.98±11%
	Late Perennial	0.190±9%	0.444±6%	0.540±7%	0.877±8%	1.12±10%	1.59±9%

On comparing the results from A and B, and B and C in Table 7, no differences are seen from the pattern in the results achieved with barley and pea, which means a higher root uptake of exp-Cs in organic soil than in clay-loam, and in organic soil a higher root uptake of exp-Cs than of Ch-Cs.

Italian rye grass has a significantly higher CR value in the three experiments A, B and C. This might be partly due to the greater vigour of Italian rye grass, which means that it has a greater part of connective tissue than the other varieties and a higher yield, Figure 2.

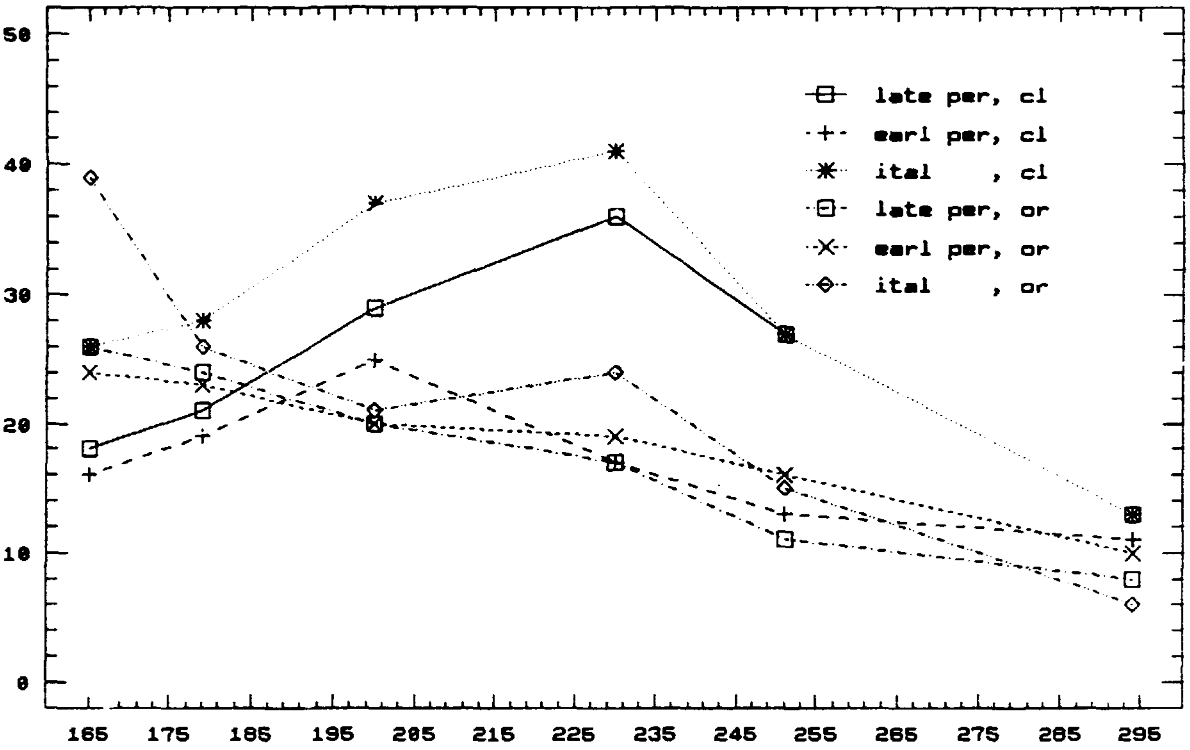
Figure 2 Accumulated yield of rye grass, 1988



Growth period, days

To build this connective tissue, the plants use K. Because of the chemical similarity between Cs and K, the Cs uptake from contaminated soil is related to the uptake of K, e.g. (Andersen 1967), (Kühn et al. 1984), (Schuller et al. 1988), (Nielsen and Strandberg 1988). This might explain the difference in the uptake of Cs between Italian rye grass and other varieties. Analyses of variance show for all three experiments A, B and C: a significant difference between the varieties, a significant effect of the time of harvest and a significant interaction between varieties and time of harvest. This significant interaction is due to the different growth patterns for the three varieties during the growth season, Figure 3.

Figure 3 Yield of rye grass, 1988

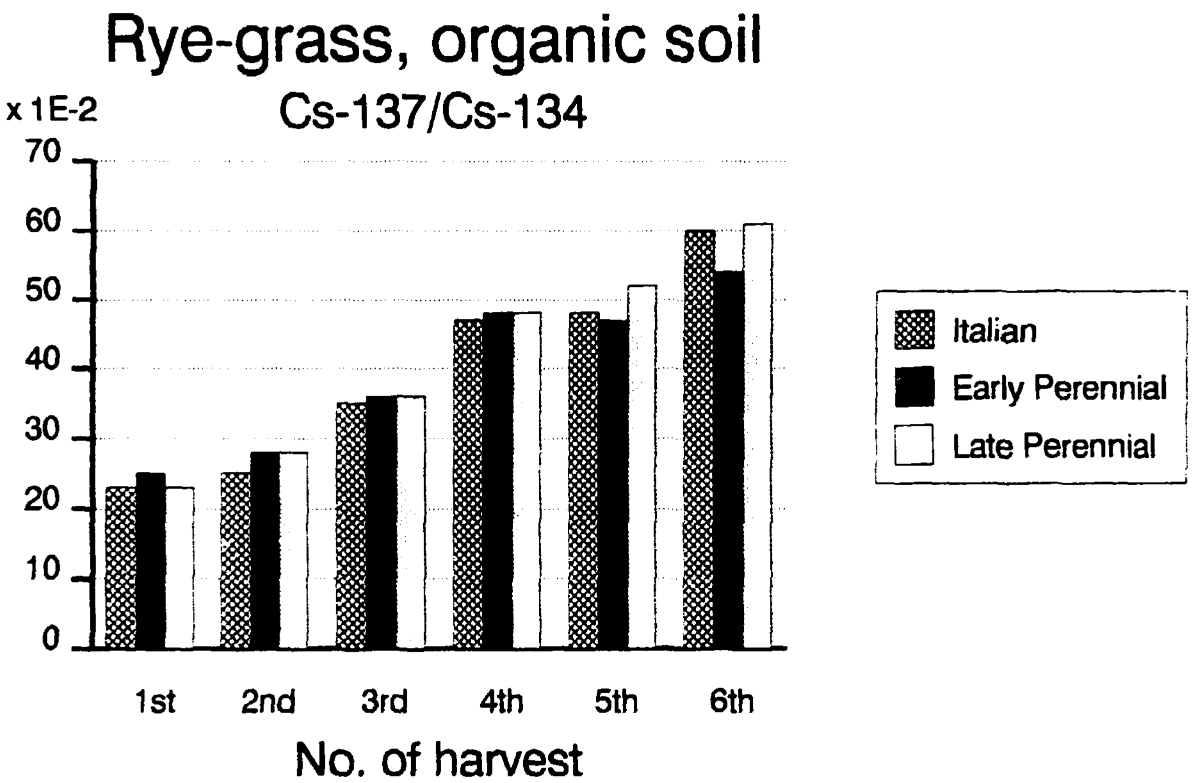


Growth period, days

Analyses of variance showed a significant interaction between time of harvest and isotopes in the organic soil. This means that the two isotopes behave differently during the growing season. In order to investigate this further, the ratio Ch-Cs/exp-Cs was found for each harvest. The results are shown in Figure 4.

The analysis of variance shows a significant effect of harvest time, no significant effect of varieties and no significant interaction. This agrees with the theory of direct contamination. Due to the weather, the amount of direct contamination is different throughout the growing season, but it shows the same effect on each variety. The effect of Ch-Cs is again much greater than that of exp-Cs, due to the lowered concentration of Ch-Cs in the organic soil, and in consequence a lowered absolute root uptake.

Figure 4



5. *ACTIVITY PER FODDER UNIT*

The aim of this project was to identify crops with a relatively low or high root uptake of caesium. In order to compare the uptake of the different species with different yields, the common unit activity per fodder unit, Bq/FU was introduced. The results for crops grown in the Danish clay-loam are shown in Table 8.

Table 8

Activity retained in the crops, grown in clay-loam, expressed per Fodder Units Bq/FU*. Average of four replicates ±1SE.

Species	Variety	Grain	Straw	
Barley	Golf	9900±3%	95600±10%	
	Apex	9100±8%	75500±6%	
	Anker	10400±6%	76700±7%	
	Sila	12200±2%	121000±6%	
Peas	Bodil	10200±5%		
Grass	Italian			91800±3%
	Early perennial			33800±24%
	Late perennial			44800±6%

* 1FU is the fodder value of 1 kg of barley.

Regarding a possible way of reducing the long-term effects of radioactive contamination of arable land and thereby the collective doses, the results of this project show that farmers should prefer barley grain, apart from Sila, when feeding domestic animals. Because it might not be that easy to change species, one can look for differences in varieties, as these can be changed much more easily.

Concerning the barley grain, we have found significant differences in the levels of radioactivity per fodder unit between the four varieties for all three experiments. We identified Sila as the variety with the highest activity per fodder unit and Apex as the one with the lowest. In Denmark, the main part of the fodder for pigs consists of barley grain. A change of variety from Sila to Apex reduces the activity per fodder unit, and thereby the activity per kg pork used for human consumption, by at least 25% after a given contamination. In the context of long-term effects of radioactive contamination of arable land, it is feasible to include these aspects in the planning of crops for the growing seasons in the years after an accident.

An even more pronounced effect of varieties is seen for the fodder grass, where the activity per fodder unit in the Italian rye grass is a factor of two to three higher than for the other two varieties. This is found in all three experiments during the main part of the growing season. Italian rye grass is much used in Denmark as pasture grass. This variety has a high grass yield in the beginning of the growing season, and it is grown only for one year in each field. The qualities of this variety fits very well with the intensive farming in Denmark where rotation of crops is used as a normal agricultural practice. Reducing the activity per fodder unit by a factor two to three by choosing another rye grass variety, will reduce the activity in the animal produce similarly.

Only one variety of pea was tested. It showed a root-uptake similar to that of Sila. Research with additional varieties must be done in order to obtain a more comprehensive data set here.

In summary, we can state that an effective agricultural planning of countermeasures to reduce the radiological consequences after a nuclear accident, comprising changes of agricultural practices towards the use of plant species and varieties with low root uptake, can contribute to a significant reduction of the contaminations levels perhaps even below a critical level.

The differences between the species and varieties grown in the organic Swedish soil follow the same pattern as described for the Danish clay-loam.

6. SUMMARY AND CONCLUSIONS

Sila barley and Italian rye grass were identified among the species tested as plants with a relative high uptake of radiocaesium both in clay-loam and organic soil.

It seems that the root uptake for pea is similar to that for barley, but this has to be investigated further, because only one variety of pea was involved. More varieties will be considered in the follow-up of this project.

For all three species the CR values for the organic soil are significantly higher than those for the clay-loam.

The CR values reported above are in good agreement with other values published for well mixed Cs in clay-loamy soil and organic soil, e.g. (Andersen 1967). Any lack of agreement might be due to small differences in the soil used, in fertilizing, weather conditions, plant varieties etc.

The differences between the uptake of Chernobyl caesium and experimentally added caesium in the organic Swedish soil indicate an effect of ageing. This will be investigated further in the continuation of these studies.

During the project, certain signs of direct contamination appeared. Presumably these were due to resuspension, rainsplash etc. It was decided to continue the investigation in subsequent years in order to follow this phenomenon.

7. ACKNOWLEDGEMENTS

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Abstract (Max. 2000 char.)

In areas with intensive farming, as in Denmark, it is of great interest to identify possible countermeasures to be taken in order to reduce the long-term effects of radioactive contamination of arable land. The most important longer-lived radionuclides from the Chernobyl were ^{137}Cs and ^{134}Cs. The aim of the present project was to identify crops with relatively low or high root uptake of these two isotopes. Although such differences may be small, a shift in varieties might be a cost-effective way to reduce collective doses.

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Sila barley and Italian rye-grass were identified among the species tested as plants with a relative high uptake of radio-caesium.

Descriptors - INIS

BARLEY; CESIUM 134; CESIUM 137; CHERNOBYLSK-4 REACTOR; CLAYS; LOAM; PARTICLE RESUSPENSION; PEAS; REMEDIAL ACTION; RETENTION; ROOTS; RYE; UPTAKE

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