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INVESTIGATIONS ON THE EFFECT OF GRAZING INTENSITY ON THE TRANSFER OF RADIONUCLIDES TO COW'S MILK

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CONTENTS

1. SUMMARY

Field experiments to determine radiocaesium transfer from vegetation to milk under different grazing conditions

For these investigations two farms were chosen where already measurements have been performed in the consequence of the Chernobyl accident. Farm A (Arnhofen) carries out a rotational grazing regime with 4 grazed pastures which is the more commonly used farm practice in Bavaria, farm B (Kleinhöhenkirchen) practises a continuous grazing regime with one grazed pasture only. In farm B a tenfold lower Cs-137 activity concentration was observed in milk though activity concentrations in soil and pasture grass were the same as that at farm A, indicating the same transfer rate soil-plant at both locations.

Grazing intensity in combination with grazing regime may influence Cs-137 milk concentrations, but not vegetation concentrations. Reasons for this finding may be uptake with more soil particles under a higher grazing pressure preventing soluble radiocaesium from uptake through the GUT and consequent milk transfer. It could be shown under normal agricultural conditions that with a higher grazing pressure lower activity concentrations in milk (in this case a factor of about 2 to 3) were obtained. Therefore changing stock density in combination with a continuous grazing regime on a given pasture after a major nuclear accident can be considered as a possible countermeasure which can be easily applied.

Simulation of grazing intensity in field plot studies

The experiments performed on farms are usful for realistic predictions of radiocaesium concentrations in feed of animals under farm conditions. However due to rather high variations of activities in soils, vegetation, and the inhomogenousity in heigths of the grazed sward over a given pasture, these results are difficult to use for models such as the RUINS model. Mainly to get more synchronised growth rates and a homogenous distribution of radiocontamination plot experiments were performed to simulate the influence of grazing intensity. Under the experimental design used here no effect of grazing intensity on the transfer of radionuclides to vegetation could be found. Effects of grazing intensity as found for the farm experiment, therefore must be due to other sources than vegetation activities, and are presumably due to soil ingestion preventing uptake of soluble plant incorporated radiocaesium in the animal rumen.

Conclusions

- In farm experiments a 10 fold reduction in milk activities for two different grazing regimes was found. However this effect was not caused by a lower transfer to vegetation due to grazing intensity, but presumably to the higher soil uptake by animals preventing GUT uptake under a higher grazing pressure.

- No influence of grazing intensity could be demonstrated in experiments simulating grazing intensity for three different sward heights over two vegetation periods and two different soil types.

2. INTRODUCTION

After the event of a nuclear accident the contamination of the environment and the consequent contamination of nutrition provided for humans, ingestion is an important radiation exposure pathway for the population. The most important radionuclides which have to be considered in most cases are radiocaesium, radioiodine and radiostrontium. Following the Chernobyl accident extensive studies on radiocaesium behaviour have considerably improved the knowledge and understanding of a range of factors influencing its migration in soil, as well as transfer to plants and animals. Also countermeasures which are practical and effective had been developed and applied. The understanding of the mechanisms governing the radionuclide behaviour is essential for the development of dynamic models describing and predicting the radionuclide concentrations in food products, and thus radiation dose to the population.

In a previous CEC programme [1] concerning the transfer of radiocaesium to animal products such as milk and meat, lacks have been identified where further information is needed. Additionally, it has been shown, that a better understanding of the behaviour of radioiodine and radiostrontium in animals is urgently needed. Suitable methods for reducing uptake of radiostrontium, or simultaneously radiostrontium and radiocaesium in farm animal were proposed to be investigated. Therefore the new CEC programme TRANSFER OF RADIONUCLIDES IN ANIMAL PRODUCTION SYSTEMS [2] was started to cover these areas, and to improve current knowledge.

One of the objectives of this programme was the influence of the grazing intensity and grazing regime on the transfer of radiocaesium described in the present report. It has been shown in field experiments that grazing intensity could influence the radiocaesium intake by sheep, as lower grazing intensity resulted in higher plant concentrations due to the different composition of the swards [3,4]. To date this was the only experimental evidence of the effect of grazing intensity. Furthermore, the RUINS model [5] predicts that higher grazing pressure will lower radionuclide concentrations in pasture and thus grazing ruminants. Therefore more controlled and detailed studies were needed to explain and quantify these findings. For this purpose in this study two different assays were chosen:

a) investigations at two farms with normal German agricultural practices (rotational and continuous grazing regime), and

b) investigations simulating grazing intensity in field plot exeriments with ryegrass *Lolium perenne* representative for agricultural conditions. This part of the project is linked to similar investigations performed in Scotland with *Agrostis capillaris* which is representative for semi-natural environments [6].

3. INVESTIGATIONS ON GRAZING INTENSITY

3.1. FARM STUDIES

3.1.1. MATERIALS AND METHODS

For these investigations two farms, located in South-East direction of Munich, were chosen where already measurements have been performed in the consequence of the Chernobyl accident [7, 8], and where the farmers were prepared to cooperate.

Farm A (Arnhofen) carries out a rotational grazing regime with 4 grazed pastures which is the more commonly used farm practice in Bavaria, farm B (Kleinhöhenkirchen) practises a continuous grazing regime with one grazed pasture only. The different pastures used for grazing dairy cows are marked in the map (A-D and E) of Fig 1. The additional informations such as number of animals, areas of the grazed pastures, and deposition densities are given in Table 1. In farm A each dairy cow has a grazing area of almost 2000 m^2, in farm B only about half of this area is grazed by each. Therefore additional feed is supplied by farmer B originating from another pasture (activities below detection limits of 0.01 Bq).

Table 1 Grazing conditions for dairy cows of farm A and B

	Farm A	**Farm B**
Number of animals	45	36
Area of pastures (m^2)	26 150 (A) 29 120 (B) 24 620 (C) 23 080 (D)	36 750(E)
Cs-137 activities in soil (Bq kg^{-1})	27 - 100	45 - 89
Cs-137 act. in vegetation (Bq kg^{-1})	0.1 - 30	0.1 - 20

The mean soil activity concentrations of Cs-137 pointed out to be very similar for the two farms, however there was considerable variation between the different pasture areas of farm A with values ranging from 27 to 100 Bq kg^{-1} fresh weight with a mean value of 61.1 ± 18.0 Bq kg^{-1}, and for farm B with values ranging from 45 to 89 Bq kg^{-1} over the whole area with a mean of 67.3 ± 21.9 Bq kg^{-1} (all soil samples taken into a depth of 30 cm). The majority of the Cs-137 soil activity (75 %) is still present in the first 10 cm. Soil characteristics of the two farms were generally similar and are given in Table 2.

Table 2 Characteristics of soils in farm A and B

	Farm A	**Farm B**
Org. Substance (%)	10.2	10.5
pH	7.2	5.6
Chalk status	high	average
Phosphate (mg 100 g^{-1})	31	13
Potassium (mg 100 g^{-1})	38	17
Clay (%)	15	22
Silt (%)	41	43
Sand (%)	44	35
CEC (mVal 100 g^{-1})*	27.9	32.0

*Cation exchange capacity

The higher chalk, phospate and potassium content in soil is due to a more intensive fertilization regime practiced at farm A.

In 1993 at farm B bulk milk samples (4 times 0.25 L) and vegetation samples (5 replicas, areas of 0.0491 m^2 each) were taken once a week as soon as the animals were driven outdoors (June). Bulk milk samples were taken in farm A in a two day rythm (4 times 0.25 L probes resulting in one Liter milk samples to be measured); equally two replicas of vegetation samples over the pasture grazed at the moment with areas of 0.2332 m^2 were clipped by hand. Fresh weight of all grass samples was determined immediately after cutting, samples were ovendried in the laboratory (70 ^{0}C) and weighted; all samples were measured by gamma-spectrometry.

The γ-spectrometric measurements were performed with pure Germanium detectors (25 % efficiency, typical energy resolution 1.9 keV) of 63.5 mm height and 63.5 mm diameter, and with a γ-spectrometry system*. Energy and efficiencies were calibrated with standard solutions (PTB, Braunschweig, FRG), the spectra were evaluated by the system installed SPECTRAN F software programme*. Samples were counted in either 1 L Marinelli beakers or 100 g or 30 g PE boxes until the statistical counting errors were less than 5 %.

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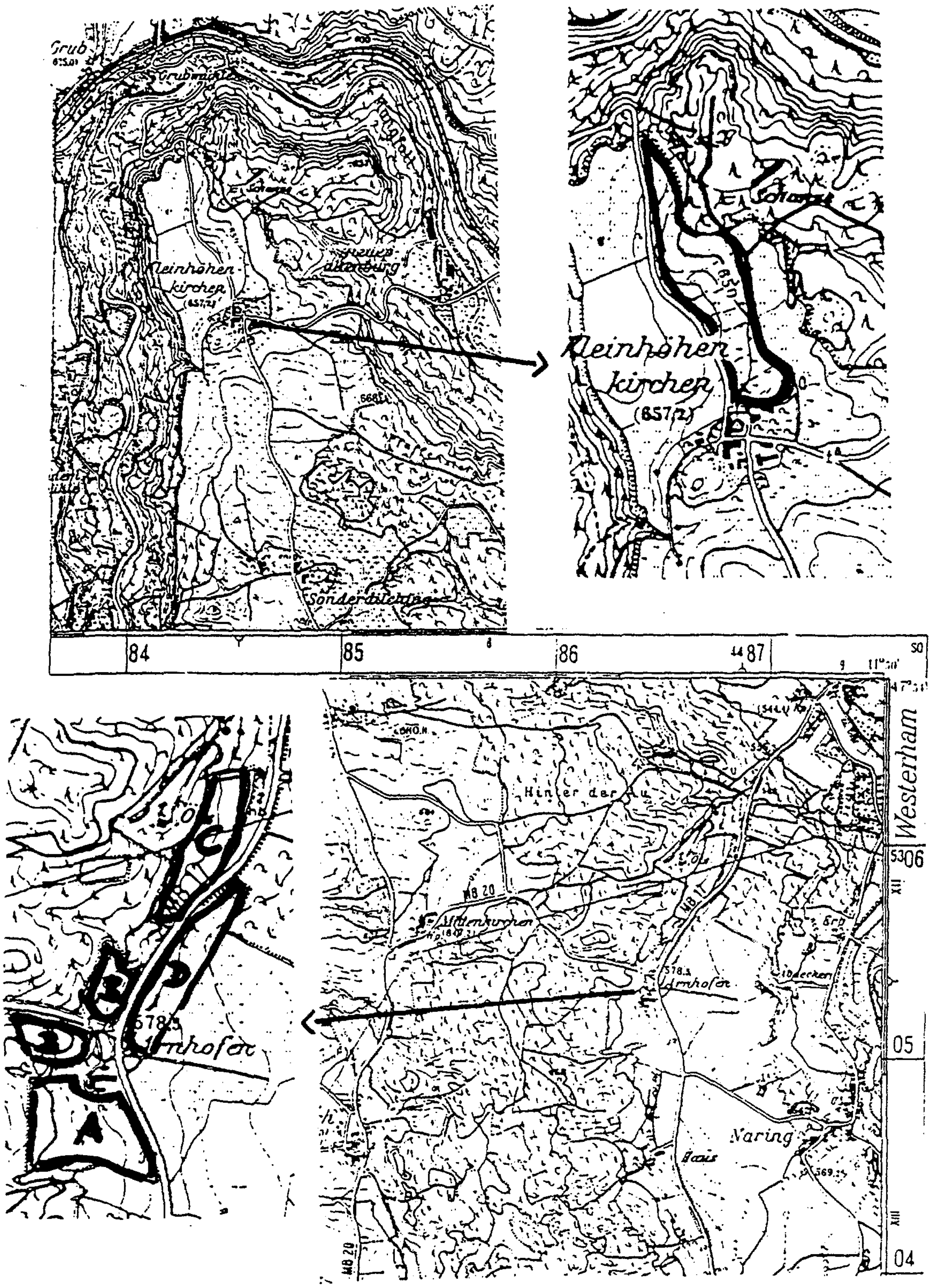
*Canberra Series 90 Spectrometer System, Canberra-Packard GmbH, Hahnstr. 70
D-6000 Frankfurt 71, FRG

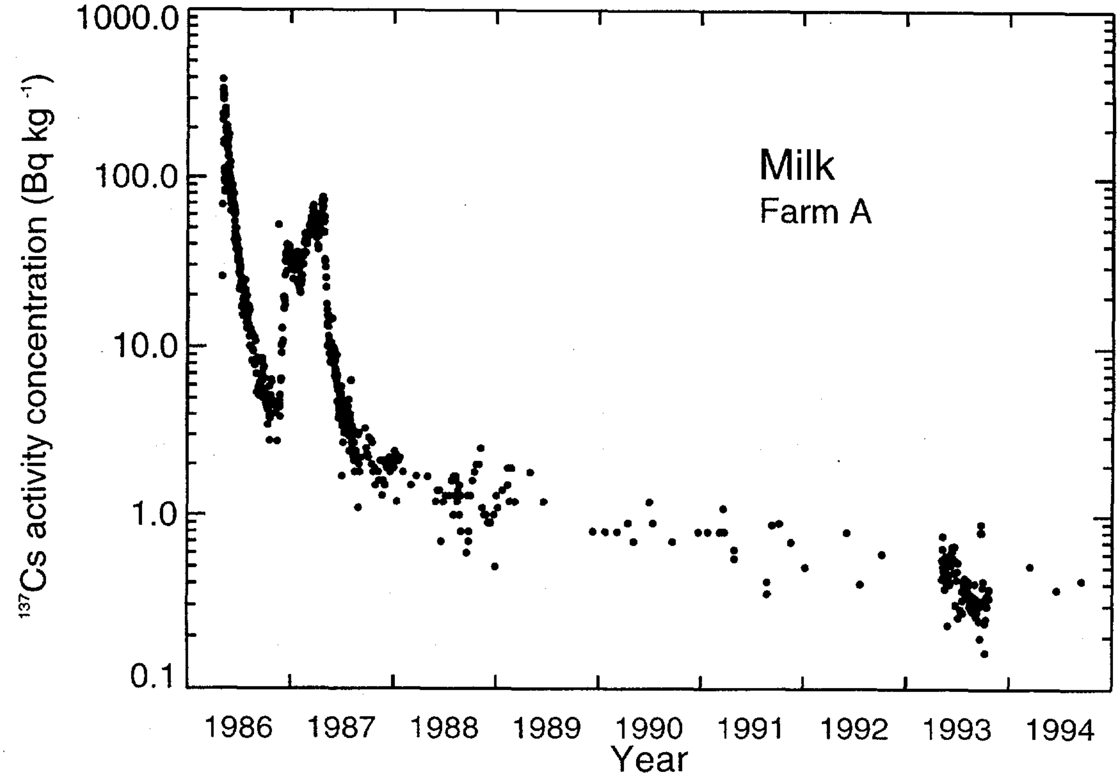
Fig. 1 Map of the sampling locations of farm A and B with marked pastures A-D and E



3.1.2. RESULTS AND DISCUSSION

Because farm A has been monitored for several years from the Chernobyl accident on, for completeness of data the changes in Cs-137 activity concentrations in milk with time since the Chernobyl accident is given for farm A in Fig. 2. In summary, the decrease of activity concentration can be described by two exponentials with a very rapidly half-life of about 4 days (99.2 %) and a long half-life of 1950 d (0.8 %). The increase of activity concentrations in winter 86/87 was caused by the feeding of hay produced from the first cut (May 86) which received directly deposited radionuclides. From 1989 it can be assumed that transfer was mainly by root-uptake into vegetation . Though there are some limitations [9] the transfer feed-animal product is commonly expressed by the transfer coefficient defined as the ration of the activity concentrations in milk or animal product and the mean daily activity intake (assumed value here is 65 kg fresh pasture grass multiplied with the corresponding activity concentration plus daily added feed) at equilibrium conditions.

Fig. 2 Time dependent ^{137}Cs activity concentrations in milk of farm A (1986 - 1994)



On the basis of the measurements the transfer coefficients for the different years given in Table 3 were estimated.

Table 3 Changes in Cs-137 milk transfer coefficients (T_m) of farm A with time after the Chernobyl accident

Year	1986	1987	1988	1989	1991	1993
T_m (d kg^{-1})	0.0035 ± 0.001	0.0040 ± 0.001	0.0021 ±0.001	0.0072 ± 0.002	0.010 ± 0.003	0.0095 ± 0.003

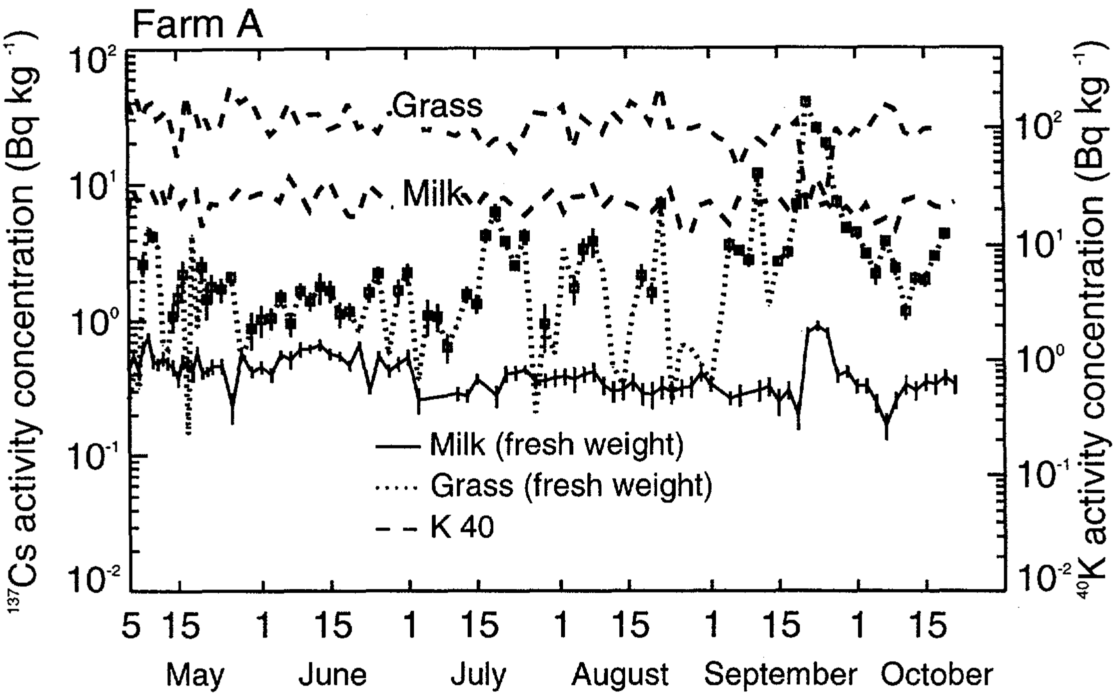
Transfer coefficients feed-milk for radiocaesium originating from the Chernobyl accident have been determined by different groups [10; 11; 12] and bioavailability has been reported to increase with time after deposition. This observation could be confirmed by our results, but occurred 4 years after the accident and has been constant since 91 with a value of about 0.01 d kg^{-1}. This value is also consistent with those determined for weapons' fallout-Cs [10]. The transfer soil to plant via root uptake has been described to be identical for weapons' fallout-Cs and Chernobyl-Cs by [13]. This would imply that in this case there have been other mechanisms for contamination of pasture grass in the first three years after the accident (direct contamination, rain splash, resuspension), but that from 1989 on root-uptake with radiocaesium in a more bioavailable form for animal uptake was the predominant pathway.

In order to compare different grazing regimes vegetation and milk activities of farm A and B shown in Figs. 3 and 4 in 1993 have been determined more frequently. K-40 activities in milk of both farms were in the same range of 20 to 30 Bq kg^{-1} and in vegetation around 100 ± 10 Bq kg^{-1}, both values rather stable, and independent of season and of the different locations. The movement of animals to the different pastures of farm A applying the rotational grazing regime was not reflected in the milk radiocaesium activity concentration (Fig 3) which was also rather stable except for a small increase at the end of September due to an unexplainable increase in activity concentration in pasture grass by a factor of 10. No influence of the oscillating grass activities over time in the grazed pasture mainly due to the movement to the different pastures is reflected by the milk activities.

In farm B a tenfold lower Cs-137 activity concentration was observed in milk though activity concentrations in soil and pasture grass were the same as that at farm A, indicating the same transfer rate soil-plant at both locations. Because the cows are forced to graze the limited area more intensively, activity concentrations may be decreased by a factor of about 2 to 3 in the grazed plant parts according to the RUINS model by Crout [5]. Cs-137 uptake with soil can be neglected because the absorption from soil particles through the GUT is usually much lower than that from vegetation [12, 14], however, binding of soluble (plant incorporated) Cs-137 in the rumen and consequent prevention of absorption by ingested soil particles has to be considered as the main contributor for reduced milk acitivities of farm B. The additional feeding with uncontaminated feed, however in unknown exact amounts (but estimated to be maximum half of the daily intake, since additional feeding of fresh grass was provided in the evening only i.e. 0.1 % of the daily Cs-137 intake), may explain a futher slight reduction in milk activities but not to that extent as obseved. In contrast cows of farm A have enough space and material for grazing, therefore grazing intensity is much lower compared to farm B resulting in higher activity concentrations in milk.

Evidently, it was not possible to see any difference in the vegetation activities and the composition of the grazed swards, except that in the continuous grazed pasture there was a more homogeneous and lower sward height over the whole area. In the rotational grazed pastures sward heights were rather inhomogeneous, however, with generally larger sward heights.

Fig. 3 Time dependent ^{137}Cs and ^{40}K activity concentrations in milk and vegetation (fresh weight) of farm A and B in 1993



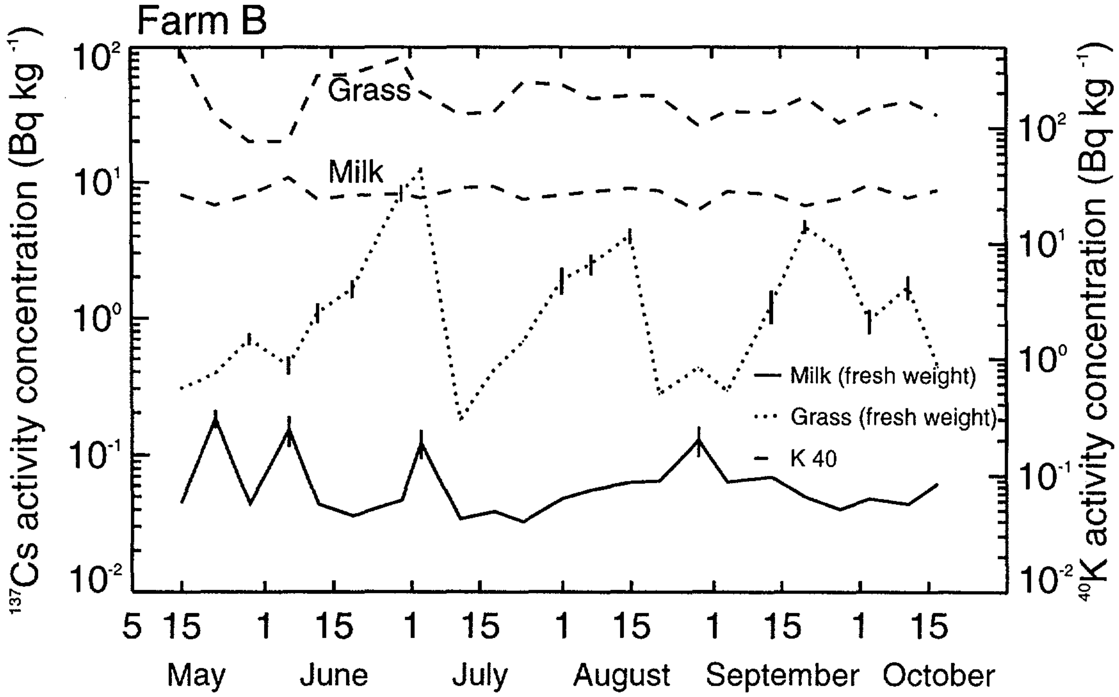
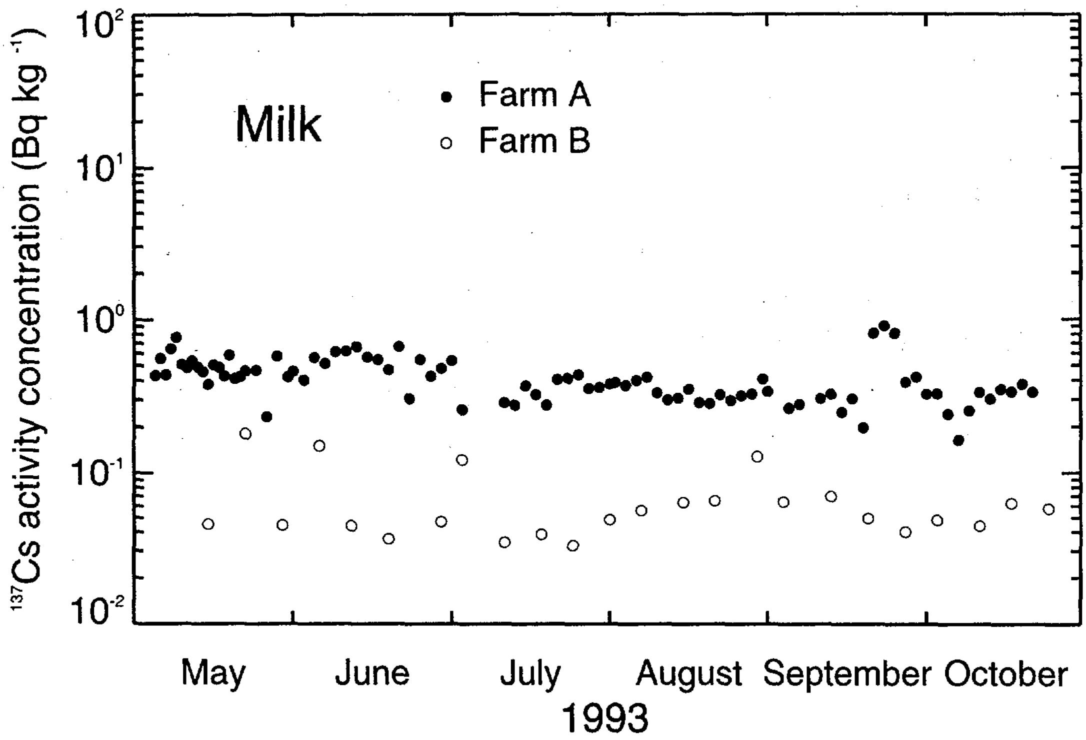
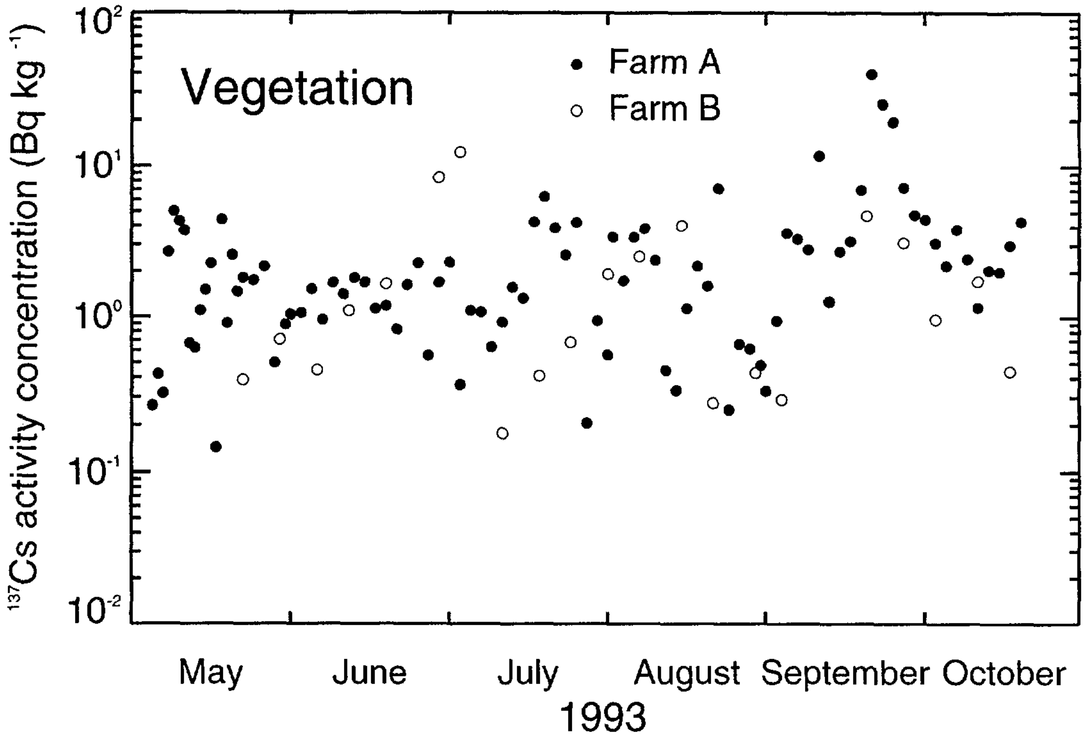


Fig. 4 Comparison of ^{137}Cs and ^{40}K activity concentrations in milk and vegetation (fresh weight) of farm A and B in 1993





3.1.3. CONCLUSIONS

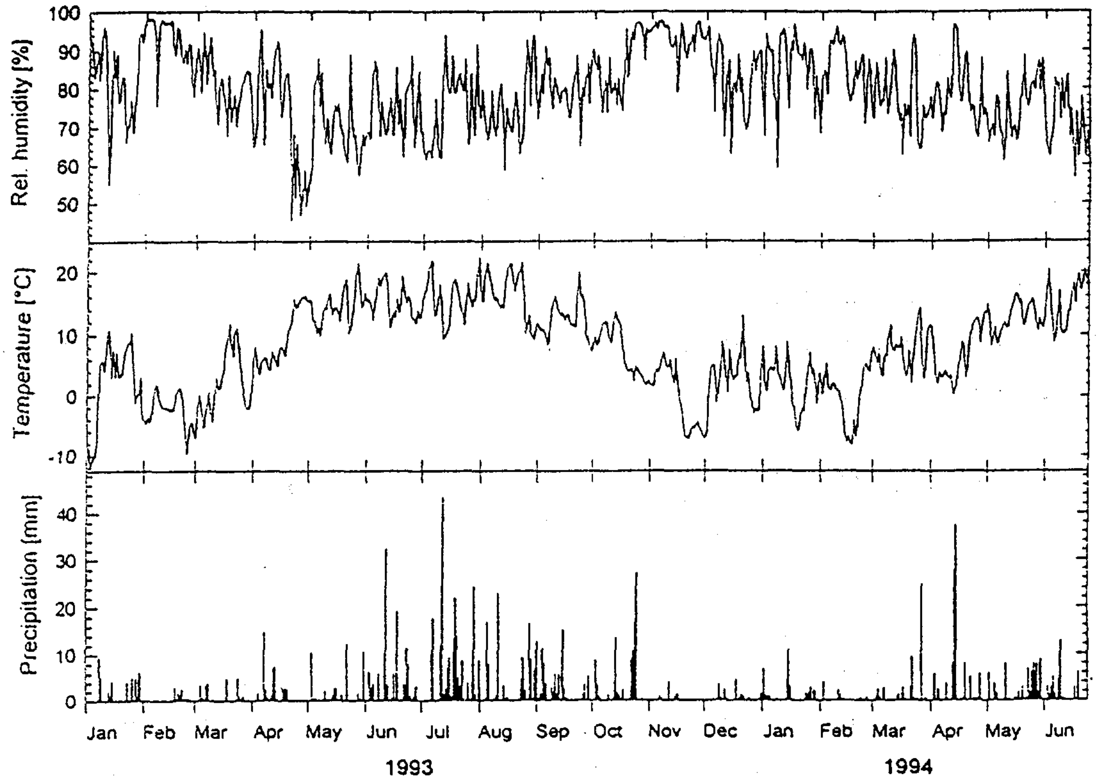
The mobility of Chernobyl released radiocaesium has changed over the years. Now radiocaesium is transferred into vegetation by root-uptake only and is in a more available form for uptake by animals (incorporated in vegetation) compared to plant adhered forms. The Cs-137 transfer coefficients feed-milk had, by 1992, reached values identical to the ones determined after the weapon's fallout. Grazing intensity can influence Cs-137 milk concentrations. It could be shown under normal agricultural conditions that the higher the grazing pressure is the lower activity concentrations in milk (in this case a factor of 2 to 3) will be. However this effect is not caused by a reduced soil-plant transfer in more heavily grazed swards but other influences. Therefore changing stock density in combination with a continuous grazing regime on a given pasture after a major nuclear accident can be considered as an effective countermeasure which can be easily applied without any additional effort and costs.

3.2. FIELD PLOT EXPERIMENTS

3.2.1. MATERIALS AND METHODS

At GSF premises close to the experimental field a weatherstation is located, and therefore weatherdata such as rainfall, radiation etc. are easily available, and were recorded over the whole experimental procedure (Fig. 5).

Fig. 5 Weather profiles at GSF premises in 1993 and 1994



For the simulation experiments the field was subdivided into 30 field plots (aluminum frames) with an area of 1 m² each. Two different types of soils (one mineral and one organic soil) with relatively high Chernobyl-^{137}Cs contamination (mineral soil: 144 ± 5.0 Bq/kg dry weight, organic soil: 300 ± 10.5 Bq/kg dry weight) were received via G. Lindner (Fachhochschule Ravensburg-Weingarten) in January 1993, and filled after mixing for obtaining a homogeneous distribution into 15 aluminum frames each resulting in a volume of about 70 Liter soil per area. This soil was chosen because of its activities, and because both soils were undisturbed and unfertilized since the Chernobyl accident; therefore the first 15 cms without vegetation were scratched off and transported to Neuherberg. The soil characteristics were determined and are given in Table 4.

Table 4 Characteristics of the soil used in the grazing intensity simulation experiments

	Mineral soil	**Organic soil**
Org. Substance (%)	4.1	24.4
pH	6.0	6.3
Chalk status	average	high
Phospate (mg 100 g^{-1})	2	19
Potassium (mg 100 g^{-1})	6	6
Clay (%)	14	11
Silt (%)	33	44
Sand (%)	53	45
CEC (mVal 100 g^{-1})*	15.2	54.2

*Cation exchange capacity

The soil plots were additionally contaminated with an artificial radionuclide mixture. The radionuclides were chosen in regard of their radioecological importance, commercial availability, their g-energies (no interference with each other), and because of their short physical half-lives for radiation contamination limitation purposes. About 1 Liter of the radionuclide mixture containing

^{57}Co (63.7 kBq L^{-1}), ^{51}Cr (19.7 kBq L^{-1}), ^{134}Cs (65.0 kBq L^{-1}),
^{59}Fe (7.1 kBq L^{-1}), and ^{85}Sr (55.0 kBq L^{-1})

was sprayed on the plane soil in each plot two days before seeding *Lolium perenne* (28.5.93), a pasture grass representative for Germany and agricultural used landscape. Radionuclide activites were calculated on the basis of the sprayed volume/weight and measurement for each individual plot, and were recorded; the distribution of all radionuclides was rather uniform for the different plots. When the grass has grown to give a closed vegetation cover, it was clipped manually in time intervals (generally 2 week intervals depending on weather and growth condition) to obtain three different sward heights (3, 6, and 9 cm) in five replicas each for the two soil types.

Fresh weight of all clipped grass samples was determined immediately after cutting, samples were ovendried in the laboratory (70 ^{0}C) until there was no weight loss, and weighted. All samples were measured by g-spectrometry already described under 3.1.1.. Samples were counted in either 1 L Marinelli beakers or 100 g or 30 g PE boxes until the statistical counting errors were less than 5 %. For ^{137}Cs long measuring times were necessary; often the detection limit was reached even after counting for more than 250 000 sec, therefore data for ^{137}Cs are rather uncertain and with high statistical errors.

Table 5 Activities (kBq/m^2) of the different plots after contamination

	Mineral soil			Organic soil		
	A1	A2	A3	A4	A5	A6
^{137}Cs	7.0	7.5	8.5	7.2	7.0	7.0
^{57}Co	66.9	66.2	65.3	65.1	63.0	66.0
^{51}Cr	83.7	82.3	81.7	81.5	78.8	82.6
^{134}Cs	68.3	67.5	66.6	66.4	64.3	67.4
^{59}Fe	7.5	7.4	7.3	7.3	7.0	7.4
^{85}Sr	58.0	57.2	56.4	56.2	54.4	57.0
	B1	B2	B3	B4	B5	B6
^{137}Cs	8.0	7.9	7.6	6.3	7.5	7.4
^{57}Co	64.3	59.4	66.4	66.6	66.4	60.3
^{51}Cr	80.4	74.4	83.0	83.4	83.0	75.4
^{134}Cs	65.6	60.6	67.7	68.0	67.7	61.5
^{59}Fe	7.2	7.6	7.4	7.4	7.4	6.7
^{85}Sr	55.5	51.3	57.3	57.5	57.3	52.0
	C1	C2	C3	C4	C5	C6
^{137}Cs	7.8	7.9	6.9	7.0	7.1	6.3
^{57}Co	65.4	67.3	66.8	67.1	67.5	67.1
^{51}Cr	81.8	84.2	83.6	84.0	84.5	84.0
^{134}Cs	66.7	68.7	68.2	68.5	68.9	68.5
^{59}Fe	7.3	7.5	7.4	7.5	7.5	7.5
^{85}Sr	56.4	58.1	57.7	58.0	58.3	58.0
	D1	D2	D3	D4	D5	D6
^{137}Cs	8.8	9.3	8.8	5.3	6.6	5.1
^{57}Co	63.2	65.2	66.2	65.9	68.2	70.4
^{51}Cr	79.1	81.6	82.8	82.5	85.3	88.1
^{134}Cs	64.5	66.6	67.5	67.3	69.6	71.8
^{59}Fe	7.0	7.3	7.4	7.3	7.6	7.8
^{85}Sr	54.6	56.3	57.1	56.9	58.8	60.8
	E1	E2	E3	E4	E5	E6
^{137}Cs	6.8	8.9	9.2	5.1	7.2	8.4
^{57}Co	65.0	65.3	62.2	68.0	68.5	63.5
^{51}Cr	81.3	81.7	77.9	85.1	85.8	79.5
^{134}Cs	663.3	66.6	63.5	69.4	69.9	64.8
^{59}Fe	7.2	7.3	7.9	7.6	7.6	7.1
^{85}Sr	56.1	56.4	53.7	58.7	59.2	54.8

3.2.2. RESULTS AND DISCUSSION

Because plots were not protected against weather influences (wind, rain, dryness), a weekly clipping of vegetation, which normally is considered to guarantee a constant sward height [15], could not be performed to obtain regular sward heights. Additionally growth of vegetation was not generally constant not only due to season but mainly due to weather conditions. Therefore clippings were performed when possible and vegetation was clipped to the according sward height. The time dependent $^{134/137}$Cs, ^{57}Co, ^{51}Cr, ^{85}Sr, and ^{59}Fe activity concentrations for the different sward heights and the two soil types on a dry weight basis are demonstrated in Figs. 6,7,8 (means), the individual values (mean values with standard deviations) are included in Table 6-11. Additionally, activity concentrations in the tissue water of the clipped grass swards (wet weight minus dry weight = tissue water) are shown for all nuclides in Figs. 9,10,11, which was proposed to show less variability dependent on seasonal influences. However this could not be confirmed for these cases.

A comparison of the two radiocaesium isotopes is given in Figs.12,13 for the organic and mineral soil. It can be seen that freshly deposited ^{134}Cs is first transferred to a higher extent (factor of about 10) to plant tissues than aged ^{137}Cs into vegetation with decreasing transfer rates in dependence of time, reaching the same transfer as aged ^{137}Cs after a couple of months, and behaving then identically. No statistically significant difference in transfer behaviour for the two soils could be determined.

The ratio (percentage) in the total clipped vegetation (1 m^2) to the deposited activity (1 m^2) are given in Figs. 14-19, and in Figs. 20-22 on an activity concentration basis (dry weight) related to the deposited activity. The individual mean values with standard deviations are also included in Table 6-11.

In general the results obtained in these experiments are consistent with the results by Salt in *Agrostis capillaris*. No statistically significant changes in activity concentrations by applying different cutting regimes could be observed, indicating that there was little or no influence of grazing intensity on the soil-plant transfer.

Figs. 6-8 Time dependent radionuclide activity concentrations (dry weight) for a sward height of 3 cm, 6 cm and 9 cm on mineral and organic soil

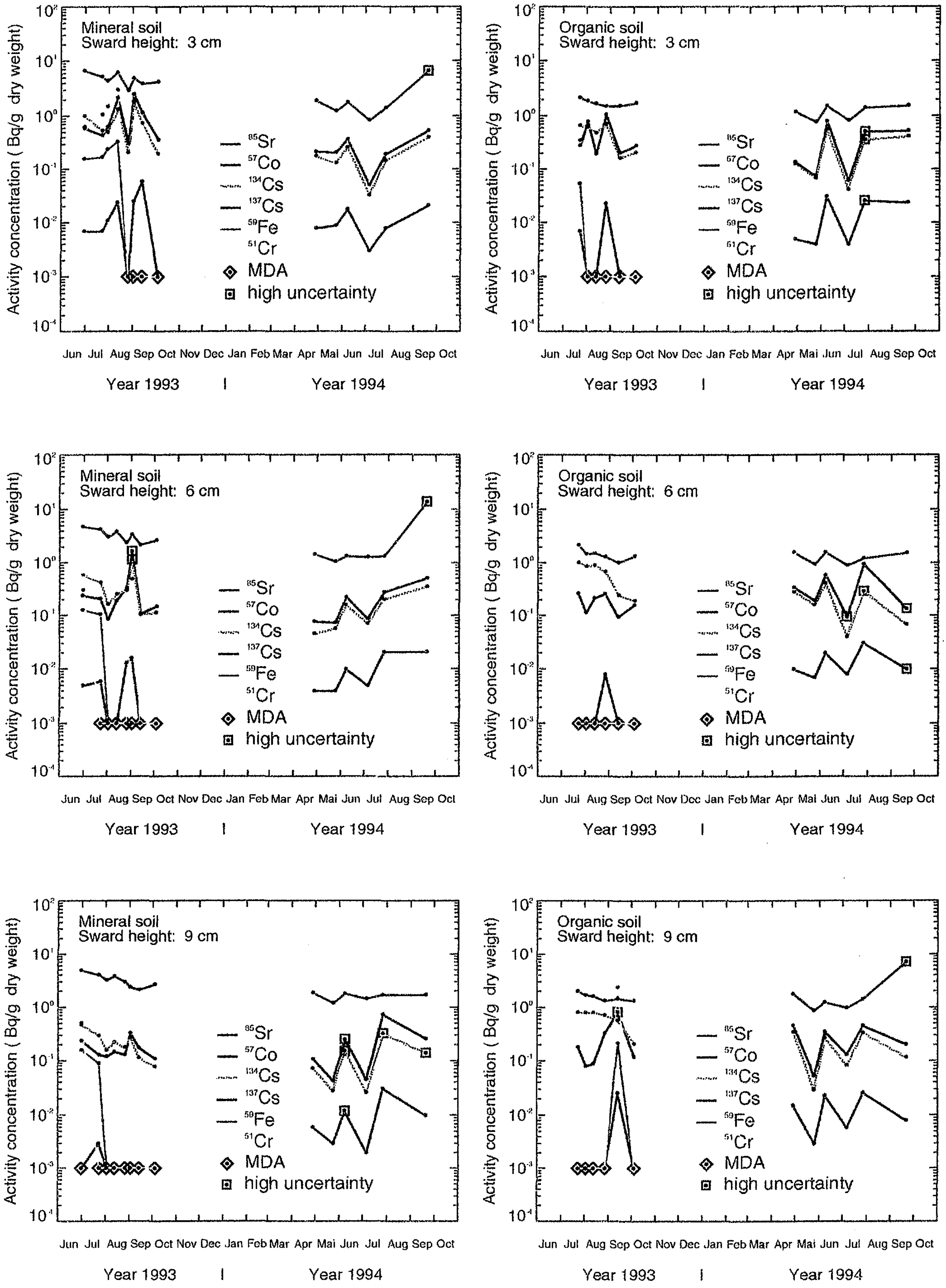


Table 6 Time dependent activities of ^{134}Cs nuclide for different sward heights and two soil types in a grazing intensity simulation experiment

^{134}Cesium

decay corrected	date	d.a.c.*	activity per area (Bq/m²)	activity concentration (Bq/g dry weight)	activity per area / deposited activity [%]	activity concentration / deposited activity [m²/kg]	
Sward height 3 cm	23.07.93	58	60,449 ± 28,526	0,670 ± 0,127	8,90 E-02 ± 4,20 E-02	9,86 E-03 ± 1,87 E-03	Organic soil
	02.08.93	68	9,509 ± 2,717	0,626 ± 0,353	1,40 E-02 ± 4,00 E-03	9,22 E-03 ± 5,20 E-03	
	13.08.93	79	20,376 ± 5,434	0,485 ± 0,124	3,00 E-02 ± 8,00 E-03	7,14 E-03 ± 1,83 E-03	
	27.08.93	93	12,905 ± 8,830	0,714 ± 0,573	1,90 E-02 ± 1,30 E-02	1,05 E-02 ± 8,44 E-03	
	13.09.93	110	2,038 ± 0,679	0,165 ± 0,020	3,00 E-03 ± 1,00 E-03	2,43 E-03 ± 2,94 E-04	
	04.10.93	131	2,038 ± 0,679	0,209 ± 0,058	3,00 E-03 ± 1,00 E-03	3,08 E-03 ± 8,54 E-04	
	28.04.94	337	8,150 ± 4,075	0,128 ± 0,057	1,20 E-02 ± 6,00 E-03	1,88 E-03 ± 8,39 E-04	
	25.05.94	364	6,792 ± 2,038	0,068 ± 0,022	1,00 E-02 ± 3,00 E-03	1,00 E-03 ± 3,24 E-04	
	08.06.94	378	8,830 ± 2,717	0,558 ± 0,147	1,30 E-02 ± 4,00 E-03	8,22 E-03 ± 2,16 E-03	
	06.07.94	406	2,038 ± 0,679	0,042 ± 0,013	3,00 E-03 ± 1,00 E-03	6,18 E-04 ± 1,91 E-04	
	27.07.94	427	9,509 ± 0,679	0,363 ± 0,001	1,40 E-02 ± 1,00 E-03	5,34 E-03 ± 1,47 E-05	
	21.09.94	483	43,469 ± 29,885	0,419 ± 0,235	6,40 E-02 ± 4,40 E-02	6,17 E-03 ± 3,46 E-03	
Sward height 6 cm	23.07.93	58	25,870 ± 6,808	1,018 ± 0,209	3,80 E-02 ± 1,00 E-02	1,50 E-02 ± 3,07 E-03	
	02.08.93	68	8,170 ± 6,808	0,869 ± 0,156	1,20 E-02 ± 1,00 E-02	1,28 E-02 ± 2,29 E-03	
	13.08.93	79	17,020 ± 0,681	0,904 ± 0,194	2,50 E-02 ± 1,00 E-03	1,33 E-02 ± 2,85 E-03	
	27.08.93	93	23,147 ± 4,085	0,689 ± 0,094	3,40 E-02 ± 6,00 E-03	1,01 E-02 ± 1,38 E-03	
	13.09.93	110	4,085 ± 1,362	0,247 ± 0,055	6,00 E-03 ± 2,00 E-03	3,63 E-03 ± 8,08 E-04	
	04.10.93	131	2,042 ± 1,362	0,193 ± 0,030	3,00 E-03 ± 2,00 E-03	2,83 E-03 ± 4,41 E-04	
	28.04.94	337	19,743 ± 6,127	0,281 ± 0,093	2,90 E-02 ± 9,00 E-03	4,13 E-03 ± 1,37 E-03	
	25.05.94	364	10,212 ± 5,446	0,162 ± 0,091	1,50 E-02 ± 8,00 E-03	2,38 E-03 ± 1,34 E-03	
	08.06.94	378	5,446 ± 2,042	0,406 ± 0,143	8,00 E-03 ± 3,00 E-03	5,96 E-03 ± 2,10 E-03	
	06.07.94	406	1,362 ± 0,681	0,041 ± 0,028	2,00 E-03 ± 1,00 E-03	6,02 E-04 ± 4,11 E-04	
	27.07.94	427	7,489 ± 0,681	0,290 ± 0,001	1,10 E-02 ± 1,00 E-03	4,26 E-03 ± 1,47 E-05	
	21.09.94	483	0,681 ± 0,681	0,069 ± 0,028	1,00 E-03 ± 1,00 E-03	1,01 E-03 ± 4,11 E-04	
Sward height 9 cm	23.07.93	58	4,008 ± 1,336	0,813 ± 0,153	6,00 E-03 ± 2,00 E-03	1,22 E-02 ± 2,29 E-03	
	02.08.93	68	0,668 ± 0,000	0,801 ± 0,135	1,00 E-03 ± 0,00 E+00	1,20 E-02 ± 2,02 E-03	
	13.08.93	79	8,016 ± 0,000	0,807 ± 0,232	1,20 E-02 ± 0,00 E+00	1,21 E-02 ± 3,47 E-03	
	27.08.93	93	11,356 ± 7,348	0,718 ± 0,223	1,70 E-02 ± 1,10 E-02	1,07 E-02 ± 3,34 E-03	
	13.09.93	110	10,020 ± 8,684	0,582 ± 0,529	1,50 E-02 ± 1,30 E-02	8,71 E-03 ± 7,92 E-03	
	04.10.93	131	2,004 ± 0,668	0,211 ± 0,061	3,00 E-03 ± 1,00 E-03	3,16 E-03 ± 9,13 E-04	
	28.04.94	337	26,720 ± 9,352	0,345 ± 0,090	4,00 E-02 ± 1,40 E-02	5,16 E-03 ± 1,35 E-03	
	25.05.94	364	0,668 ± 0,668	0,029 ± 0,008	1,00 E-03 ± 1,00 E-03	4,34 E-04 ± 1,20 E-04	
	08.06.94	378	4,676 ± 2,672	0,266 ± 0,156	7,00 E-03 ± 4,00 E-03	3,98 E-03 ± 2,34 E-03	
	06.07.94	406	3,340 ± 0,668	0,083 ± 0,060	5,00 E-03 ± 1,00 E-03	1,24 E-03 ± 8,98 E-04	
	27.07.94	427	4,676 ± 0,668	0,338 ± 0,295	7,00 E-03 ± 1,00 E-03	5,06 E-03 ± 4,42 E-03	
	21.09.94	483	6,012 ± 5,344	0,117 ± 0,094	9,00 E-03 ± 8,00 E-03	1,75 E-03 ± 1,41 E-03	

* *days after comtamination (26.05.1993)*

Table 7 Time dependent activities of ^{137}Cs nuclide for different sward heights and two soil types in a grazing intensity simulation experiment

^{137} Cesium

decay corrected		date	d.a.c.*	activity per area (Bq/m²)	activity concentration (Bq/g dry weight)	activity per area / deposited activity [%]	activity concentration / deposited activity $\left[\mathrm{m^2/kg}\right]$	
Sward height	3 cm	23.07.93	58	0,314 ± 0,063	0,007 ± 0,004	5,00 E-03 ± 1,00 E-03	1,11 E-03 ± 6,37 E-04	Organic soil
		02.08.93	68	0,063 ± 0,000	0,001 ± 0,000	1,00 E-03 ± 0,00 E+00	1,59 E-04 ± 0,00 E+00	
		13.08.93	79	0,063 ± 0,000	0,001 ± 0,000	1,00 E-03 ± 0,00 E+00	1,59 E-04 ± 0,00 E+00	
		27.08.93	93	0,377 ± 0,000	0,023 ± 0,000	6,00 E-03 ± 0,00 E+00	3,66 E-03 ± 0,00 E+00	
		13.09.93	110	0,063 ± 0,000	0,001 ± 0,000	1,00 E-03 ± 0,00 E+00	1,59 E-04 ± 0,00 E+00	
		04.10.93	131	0,063 ± 0,000	0,001 ± 0,000	1,00 E-03 ± 0,00 E+00	1,59 E-04 ± 0,00 E+00	
		28.04.94	337	0,314 ± 0,126	0,005 ± 0,002	5,00 E-03 ± 2,00 E-03	7,96 E-04 ± 3,18 E-04	
		25.05.94	364	0,377 ± 0,063	0,004 ± 0,001	6,00 E-03 ± 1,00 E-03	6,37 E-04 ± 1,59 E-04	
		08.06.94	378	0,502 ± 0,126	0,031 ± 0,007	8,00 E-03 ± 2,00 E-03	4,94 E-03 ± 1,11 E-03	
		06.07.94	406	0,188 ± 0,063	0,004 ± 0,001	3,00 E-03 ± 1,00 E-03	6,37 E-04 ± 1,59 E-04	
		27.07.94	427	0,754 ± 0,063	0,026 ± 0,001	1,20 E-02 ± 1,00 E-03	4,14 E-03 ± 1,59 E-04	
		21.09.94	483	2,449 ± 1,633	0,024 ± 0,010	3,90 E-02 ± 2,60 E-02	3,82 E-03 ± 1,59 E-03	
	6 cm	23.07.93	58	0,071 ± 0,000	0,001 ± 0,000	1,00 E-03 ± 0,00 E+00	1,41 E-04 ± 0,00 E+00	
		02.08.93	68	0,071 ± 0,000	0,001 ± 0,000	1,00 E-03 ± 0,00 E+00	1,41 E-04 ± 0,00 E+00	
		13.08.93	79	0,071 ± 0,000	0,001 ± 0,000	1,00 E-03 ± 0,00 E+00	1,41 E-04 ± 0,00 E+00	
		27.08.93	93	0,212 ± 0,071	0,008 ± 0,000	3,00 E-03 ± 1,00 E-03	1,13 E-03 ± 0,00 E+00	
		13.09.93	110	0,071 ± 0,000	0,001 ± 0,000	1,00 E-03 ± 0,00 E+00	1,41 E-04 ± 0,00 E+00	
		04.10.93	131	0,071 ± 0,000	0,001 ± 0,000	1,00 E-03 ± 0,00 E+00	1,41 E-04 ± 0,00 E+00	
		28.04.94	337	0,708 ± 0,212	0,010 ± 0,003	1,00 E-02 ± 3,00 E-03	1,41 E-03 ± 4,24 E-04	
		25.05.94	364	0,425 ± 0,283	0,007 ± 0,004	6,00 E-03 ± 4,00 E-03	9,89 E-04 ± 5,65 E-04	
		08.06.94	378	0,283 ± 0,142	0,020 ± 0,010	4,00 E-03 ± 2,00 E-03	2,82 E-03 ± 1,41 E-03	
		06.07.94	406	0,212 ± 0,071	0,008 ± 0,001	3,00 E-03 ± 1,00 E-03	1,13 E-03 ± 1,41 E-04	
		27.07.94	427	0,779 ± 0,496	0,031 ± 0,014	1,10 E-02 ± 7,00 E-03	4,38 E-03 ± 1,98 E-03	
		21.09.94	483	0,142 ± 0,071	0,010 ± 0,001	2,00 E-03 ± 1,00 E-03	1,41 E-03 ± 1,41 E-04	
	9 cm	23.07.93	58	0,068 ± 0,000	0,001 ± 0,000	1,00 E-03 ± 0,00 E+00	1,46 E-04 ± 0,00 E+00	
		02.08.93	68	0,068 ± 0,000	0,001 ± 0,000	1,00 E-03 ± 0,00 E+00	1,46 E-04 ± 0,00 E+00	
		13.08.93	79	0,068 ± 0,000	0,001 ± 0,000	1,00 E-03 ± 0,00 E+00	1,46 E-04 ± 0,00 E+00	
		27.08.93	93	0,068 ± 0,000	0,001 ± 0,000	1,00 E-03 ± 0,00 E+00	1,46 E-04 ± 0,00 E+00	
		13.09.93	110	0,274 ± 0,000	0,026 ± 0,000	4,00 E-03 ± 0,00 E+00	3,80 E-03 ± 0,00 E+00	
		04.10.93	131	0,068 ± 0,000	0,001 ± 0,000	1,00 E-03 ± 0,00 E+00	1,46 E-04 ± 0,00 E+00	
		28.04.94	337	1,163 ± 0,410	0,015 ± 0,005	1,70 E-02 ± 6,00 E-03	2,19 E-03 ± 7,31 E-04	
		25.05.94	364	0,137 ± 0,068	0,003 ± 0,001	2,00 E-03 ± 1,00 E-03	4,39 E-04 ± 1,46 E-04	
		08.06.94	378	0,342 ± 0,068	0,023 ± 0,010	5,00 E-03 ± 1,00 E-03	3,36 E-03 ± 1,46 E-03	
		06.07.94	406	0,274 ± 0,205	0,006 ± 0,003	4,00 E-03 ± 3,00 E-03	8,77 E-04 ± 4,39 E-04	
		27.07.94	427	0,342 ± 0,137	0,026 ± 0,015	5,00 E-03 ± 2,00 E-03	3,80 E-03 ± 2,19 E-03	
		21.09.94	483	0,479 ± 0,274	0,008 ± 0,003	7,00 E-03 ± 4,00 E-03	1,17 E-03 ± 4,39 E-04	

* *days after comtamination (26.05.1993)*

Table 8 Time dependent activities of ^{85}Sr nuclide for different sward heights and two soil types in a grazing intensity simulation experiment

^{85}Strontium

decay corrected		date	d.a.c.*	activity per area (Bq/m²)	activity concentration (Bq/g dry weight)	$\frac{\text{activity per area}}{\text{deposited activity}}$ [%]	$\frac{\text{activity concentration}}{\text{deposited activity}}$ $\left[\text{m}^2/\text{kg}\right]$	
Sward height	3 cm	23.07.93	58	176,977 ± 75,273	2,179 ± 0,254	3,08 E-01 ± 1,31 E-01	3,79 E-02 ± 4,42 E-03	Organic soil
		02.08.93	68	17,813 ± 4,022	1,907 ± 0,640	3,10 E-02 ± 7,00 E-03	3,32 E-02 ± 1,11 E-02	
		13.08.93	79	73,549 ± 14,365	1,731 ± 0,253	1,28 E-01 ± 2,50 E-02	3,01 E-02 ± 4,40 E-03	
		27.08.93	93	27,006 ± 13,216	1,555 ± 0,765	4,70 E-02 ± 2,30 E-02	2,71 E-02 ± 1,33 E-02	
		13.09.93	110	18,962 ± 5,171	1,558 ± 0,197	3,30 E-02 ± 9,00 E-03	2,71 E-02 ± 3,43 E-03	
		04.10.93	131	18,387 ± 6,895	1,747 ± 0,154	3,20 E-02 ± 1,20 E-02	3,04 E-02 ± 2,68 E-03	
		28.04.94	337	75,273 ± 27,006	1,205 ± 0,146	1,31 E-01 ± 4,70 E-02	2,10 E-02 ± 2,54 E-03	
		25.05.94	364	75,273 ± 9,194	0,780 ± 0,097	1,31 E-01 ± 1,60 E-02	1,36 E-02 ± 1,69 E-03	
		08.06.94	378	25,857 ± 6,321	1,528 ± 0,170	4,50 E-02 ± 1,10 E-02	2,66 E-02 ± 2,96 E-03	
		06.07.94	406	33,901 ± 11,492	0,839 ± 0,153	5,90 E-02 ± 2,00 E-02	1,46 E-02 ± 2,66 E-03	
		27.07.94	427	38,498 ± 16,663	1,432 ± 0,668	6,70 E-02 ± 2,90 E-02	2,49 E-02 ± 1,16 E-02	
		21.09.94	483	167,209 ± 21,835	1,563 ± 0,174	2,91 E-01 ± 3,80 E-02	2,72 E-02 ± 3,03 E-03	
	6 cm	23.07.93	58	57,024 ± 13,248	2,200 ± 0,197	9,90 E-02 ± 2,30 E-02	3,82 E-02 ± 3,42 E-03	
		02.08.93	68	17,280 ± 2,880	1,490 ± 0,149	3,00 E-02 ± 5,00 E-03	2,59 E-02 ± 2,59 E-03	
		13.08.93	79	29,376 ± 5,760	1,532 ± 0,225	5,10 E-02 ± 1,00 E-02	2,66 E-02 ± 3,91 E-03	
		27.08.93	93	44,352 ± 12,096	1,323 ± 0,102	7,70 E-02 ± 2,10 E-02	2,30 E-02 ± 1,77 E-03	
		13.09.93	110	16,704 ± 2,880	1,012 ± 0,084	2,90 E-02 ± 5,00 E-03	1,76 E-02 ± 1,46 E-03	
		04.10.93	131	16,128 ± 4,032	1,335 ± 0,113	2,80 E-02 ± 7,00 E-03	2,32 E-02 ± 1,96 E-03	
		28.04.94	337	111,744 ± 5,760	1,607 ± 0,073	1,94 E-01 ± 1,00 E-02	2,79 E-02 ± 1,27 E-03	
		25.05.94	364	62,208 ± 6,336	0,974 ± 0,097	1,08 E-01 ± 1,10 E-02	1,69 E-02 ± 1,68 E-03	
		08.06.94	378	23,040 ± 2,304	1,641 ± 0,113	4,00 E-02 ± 4,00 E-03	2,85 E-02 ± 1,96 E-03	
		06.07.94	406	33,984 ± 12,096	0,916 ± 0,153	5,90 E-02 ± 2,10 E-02	1,59 E-02 ± 2,66 E-03	
		27.07.94	427	28,800 ± 21,888	1,241 ± 0,668	5,00 E-02 ± 3,80 E-02	2,15 E-02 ± 1,16 E-02	
		21.09.94	483	19,584 ± 2,304	1,563 ± 0,521	3,40 E-02 ± 4,00 E-03	2,71 E-02 ± 9,05 E-03	
	9 cm	23.07.93	58	14,695 ± 7,348	2,020 ± 0,147	2,60 E-02 ± 1,30 E-02	3,57 E-02 ± 2,60 E-03	
		02.08.93	68	7,348 ± 3,391	1,696 ± 0,208	1,30 E-02 ± 6,00 E-03	3,00 E-02 ± 3,68 E-03	
		13.08.93	79	10,174 ± 7,348	1,619 ± 0,225	1,80 E-02 ± 1,30 E-02	2,86 E-02 ± 3,98 E-03	
		27.08.93	93	19,782 ± 7,348	1,340 ± 0,245	3,50 E-02 ± 1,30 E-02	2,37 E-02 ± 4,33 E-03	
		13.09.93	110	21,478 ± 11,304	1,442 ± 0,608	3,80 E-02 ± 2,00 E-02	2,55 E-02 ± 1,08 E-02	
		04.10.93	131	11,304 ± 2,261	1,319 ± 0,113	2,00 E-02 ± 4,00 E-03	2,33 E-02 ± 2,00 E-03	
		28.04.94	337	134,518 ± 11,304	1,789 ± 0,110	2,38 E-01 ± 2,00 E-02	3,17 E-02 ± 1,95 E-03	
		25.05.94	364	24,304 ± 6,217	0,877 ± 0,097	4,30 E-02 ± 1,10 E-02	1,55 E-02 ± 1,72 E-03	
		08.06.94	378	17,521 ± 6,217	1,245 ± 0,113	3,10 E-02 ± 1,10 E-02	2,20 E-02 ± 2,00 E-03	
		06.07.94	406	38,434 ± 13,000	0,992 ± 0,076	6,80 E-02 ± 2,30 E-02	1,76 E-02 ± 1,34 E-03	
		27.07.94	427	16,956 ± 0,565	1,432 ± 0,191	3,00 E-02 ± 1,00 E-03	2,53 E-02 ± 3,38 E-03	
		21.09.94	483	70,650 ± 13,000	7,120 ± 0,174	1,25 E-01 ± 2,30 E-02	1,26 E-01 ± 3,08 E-03	

* *days after comtamination (26.05.1993)*

Table 9 Time dependent activities of ^{57}Co nuclide for different sward heights and two soil types in a grazing intensity simulation experiment

^{57} Cobalt

decay corrected		date	d.a.c.*	activity per area (Bq/m²)	activity concentration (Bq/g dry weight)	activity per area / deposited activity [%]	activity concentration / deposited activity [m²/kg]	
Sward height	3 cm	23.07.93	58	19,297 ± 9,316	0,283 ± 0,133	2,90 E-02 ± 1,40 E-02	4,25 E-03 ± 2,00 E-03	Organic soil
		02.08.93	68	7,319 ± 5,989	0,791 ± 0,661	1,10 E-02 ± 9,00 E-03	1,19 E-02 ± 9,93 E-03	
		13.08.93	79	8,650 ± 2,662	0,196 ± 0,042	1,30 E-02 ± 4,00 E-03	2,95 E-03 ± 6,31 E-04	
		27.08.93	93	15,970 ± 15,304	1,092 ± 0,960	2,40 E-02 ± 2,30 E-02	1,64 E-02 ± 1,44 E-02	
		13.09.93	110	2,662 ± 0,665	0,207 ± 0,037	4,00 E-03 ± 1,00 E-03	3,11 E-03 ± 5,56 E-04	
		04.10.93	131	2,662 ± 0,665	0,283 ± 0,074	4,00 E-03 ± 1,00 E-03	4,25 E-03 ± 1,11 E-03	
		28.04.94	337	8,650 ± 4,658	0,138 ± 0,059	1,30 E-02 ± 7,00 E-03	2,07 E-03 ± 8,87 E-04	
		25.05.94	364	6,654 ± 1,996	0,074 ± 0,028	1,00 E-02 ± 3,00 E-03	1,11 E-03 ± 4,21 E-04	
		08.06.94	378	13,308 ± 3,992	0,802 ± 0,216	2,00 E-02 ± 6,00 E-03	1,21 E-02 ± 3,25 E-03	
		06.07.94	406	2,662 ± 0,665	0,062 ± 0,009	4,00 E-03 ± 1,00 E-03	9,32 E-04 ± 1,35 E-04	
		27.07.94	427	13,973 ± 0,665	0,517 ± 0,003	2,10 E-02 ± 1,00 E-03	7,77 E-03 ± 4,51 E-05	
		21.09.94	483	53,897 ± 37,928	0,532 ± 0,297	8,10 E-02 ± 5,70 E-02	8,00 E-03 ± 4,46 E-03	
	6 cm	23.07.93	58	7,339 ± 3,336	0,263 ± 0,109	1,10 E-02 ± 5,00 E-03	3,94 E-03 ± 1,63 E-03	
		02.08.93	68	1,334 ± 0,667	0,114 ± 0,112	2,00 E-03 ± 1,00 E-03	1,71 E-03 ± 1,68 E-03	
		13.08.93	79	3,336 ± 1,334	0,215 ± 0,132	5,00 E-03 ± 2,00 E-03	3,22 E-03 ± 1,98 E-03	
		27.08.93	93	8,006 ± 2,669	0,258 ± 0,135	1,20 E-02 ± 4,00 E-03	3,87 E-03 ± 2,02 E-03	
		13.09.93	110	1,334 ± 0,667	0,094 ± 0,032	2,00 E-03 ± 1,00 E-03	1,41 E-03 ± 4,80 E-04	
		04.10.93	131	2,002 ± 1,334	0,157 ± 0,052	3,00 E-03 ± 2,00 E-03	2,35 E-03 ± 7,79 E-04	
		28.04.94	337	24,019 ± 7,339	0,340 ± 0,116	3,60 E-02 ± 1,10 E-02	5,10 E-03 ± 1,74 E-03	
		25.05.94	364	12,010 ± 6,672	0,193 ± 0,104	1,80 E-02 ± 1,00 E-02	2,89 E-03 ± 1,56 E-03	
		08.06.94	378	8,006 ± 2,669	0,591 ± 0,214	1,20 E-02 ± 4,00 E-03	8,86 E-03 ± 3,21 E-03	
		06.07.94	406	3,336 ± 1,334	0,096 ± 0,003	5,00 E-03 ± 2,00 E-03	1,44 E-03 ± 4,50 E-05	
		27.07.94	427	24,019 ± 19,349	0,963 ± 0,613	3,60 E-02 ± 2,90 E-02	1,44 E-02 ± 9,19 E-03	
		21.09.94	483	2,002 ± 0,667	0,135 ± 0,003	3,00 E-03 ± 1,00 E-03	2,02 E-03 ± 4,50 E-05	
	9 cm	23.07.93	58	0,655 ± 0,655	0,180 ± 0,073	1,00 E-03 ± 1,00 E-03	2,75 E-03 ± 1,12 E-03	
		02.08.93	68	0,655 ± 0,000	0,001 ± 0,000	1,00 E-03 ± 0,00 E+00	1,53 E-05 ± 0,00 E+00	
		13.08.93	79	1,309 ± 0,655	0,089 ± 0,000	2,00 E-03 ± 1,00 E-03	1,36 E-03 ± 0,00 E+00	
		27.08.93	93	4,582 ± 2,618	0,331 ± 0,141	7,00 E-03 ± 4,00 E-03	5,06 E-03 ± 2,15 E-03	
		13.09.93	110	10,474 ± 1,309	0,827 ± 0,001	1,60 E-02 ± 2,00 E-03	1,26 E-02 ± 1,53 E-05	
		04.10.93	131	1,309 ± 0,655	0,119 ± 0,059	2,00 E-03 ± 1,00 E-03	1,82 E-03 ± 9,01 E-04	
		28.04.94	337	36,003 ± 11,783	0,461 ± 0,121	5,50 E-02 ± 1,80 E-02	7,04 E-03 ± 1,85 E-03	
		25.05.94	364	1,309 ± 0,655	0,053 ± 0,015	2,00 E-03 ± 1,00 E-03	8,10 E-04 ± 2,29 E-04	
		08.06.94	378	5,891 ± 3,928	0,351 ± 0,232	9,00 E-03 ± 6,00 E-03	5,36 E-03 ± 3,54 E-03	
		06.07.94	406	5,237 ± 3,928	0,133 ± 0,074	8,00 E-03 ± 6,00 E-03	2,03 E-03 ± 1,13 E-03	
		27.07.94	427	6,546 ± 5,891	0,458 ± 0,395	1,00 E-02 ± 9,00 E-03	7,00 E-03 ± 6,03 E-03	
		21.09.94	483	9,819 ± 7,201	0,204 ± 0,107	1,50 E-02 ± 1,10 E-02	3,12 E-03 ± 1,63 E-03	

* *days after comtamination (26.05.1993)*

Table 10 Time dependent activities of ^{59}Fe nuclide for different sward heights and two soil types in a grazing simulation experiment

^{59}Iron

decay corrected	date	d.a.c.*	activity per area (Bq/m^2)	activity concentration (Bq/g dry weight)	activity per area / deposited activity [%]	activity concentration / deposited activity [m^2/kg]	
Sward height 3 cm	23.07.93	58	1,929 ± 0,519	0,054 ± 0,020	2,60 E-02 ± 7,00 E-03	7,28 E-03 ± 2,70 E-03	Organic soil
	02.08.93	68	0,074 ± 0,000	0,003 ± 0,000	1,00 E-03 ± 0,00 E+00	4,04 E-04 ± 0,00 E+00	
	13.08.93	79	0,074 ± 0,000	0,003 ± 0,000	1,00 E-03 ± 0,00 E+00	4,04 E-04 ± 0,00 E+00	
	27.08.93	93	0,074 ± 0,000	0,004 ± 0,000	1,00 E-03 ± 0,00 E+00	5,39 E-04 ± 0,00 E+00	
	13.09.93	110	0,074 ± 0,000	0,006 ± 0,000	1,00 E-03 ± 0,00 E+00	8,09 E-04 ± 0,00 E+00	
	04.10.93	131	0,074 ± 0,000	0,008 ± 0,000	1,00 E-03 ± 0,00 E+00	1,08 E-03 ± 0,00 E+00	
	28.04.94	337					
	25.05.94	364					
	08.06.94	378					
	06.07.94	406					
	27.07.94	427					
	21.09.94	483					
6 cm	23.07.93	58	0,074 ± 0,000	0,002 ± 0,000	1,00 E-03 ± 0,00 E+00	2,70 E-04 ± 0,00 E+00	
	02.08.93	68	0,074 ± 0,000	0,003 ± 0,000	1,00 E-03 ± 0,00 E+00	4,04 E-04 ± 0,00 E+00	
	13.08.93	79	0,074 ± 0,000	0,003 ± 0,000	1,00 E-03 ± 0,00 E+00	4,04 E-04 ± 0,00 E+00	
	27.08.93	93	0,074 ± 0,000	0,004 ± 0,000	1,00 E-03 ± 0,00 E+00	5,39 E-04 ± 0,00 E+00	
	13.09.93	110	0,074 ± 0,000	0,006 ± 0,000	1,00 E-03 ± 0,00 E+00	8,09 E-04 ± 0,00 E+00	
	04.10.93	131	0,074 ± 0,000	0,008 ± 0,000	1,00 E-03 ± 0,00 E+00	1,08 E-03 ± 0,00 E+00	
	28.04.94	337					
	25.05.94	364					
	08.06.94	378					
	06.07.94	406					
	27.07.94	427					
	21.09.94	483					
9 cm	23.07.93	58	0,073 ± 0,000	0,002 ± 0,000	1,00 E-03 ± 0,00 E+00	2,74 E-04 ± 0,00 E+00	
	02.08.93	68	0,073 ± 0,000	0,003 ± 0,000	1,00 E-03 ± 0,00 E+00	4,11 E-04 ± 0,00 E+00	
	13.08.93	79	0,073 ± 0,000	0,003 ± 0,000	1,00 E-03 ± 0,00 E+00	4,11 E-04 ± 0,00 E+00	
	27.08.93	93	0,073 ± 0,000	0,004 ± 0,000	1,00 E-03 ± 0,00 E+00	5,48 E-04 ± 0,00 E+00	
	13.09.93	110	2,774 ± 0,073	0,216 ± 0,000	3,80 E-02 ± 1,00 E-03	2,96 E-02 ± 0,00 E+00	
	04.10.93	131	0,073 ± 0,000	0,008 ± 0,000	1,00 E-03 ± 0,00 E+00	1,10 E-03 ± 0,00 E+00	
	28.04.94	337					
	25.05.94	364					
	08.06.94	378					
	06.07.94	406					
	27.07.94	427					
	21.09.94	483					

* *days after comtamination (26.05.1993)*

Table 11 Time dependent activities of ^{51}Cr nuclide for different sward heights and two soil types in a grazing intensity simulation experiment

^{51}Chromium

decay corrected	date	d.a.c.*	activity per area (Bq/m²)	activity concentration (Bq/g dry weight)	activity per area / deposited activity [%]	activity concentration / deposited activity [m²/kg]	
Sward height 3 cm	23.07.93	58	13,328 ± 0,833	0,353 ± 0,004	1,60 E-02 ± 1,00 E-03	4,24 E-03 ± 4,80 E-05	Organic soil
	02.08.93	68	0,833 ± 0,000	0,005 ± 0,000	1,00 E-03 ± 0,00 E+00	6,00 E-05 ± 0,00 E+00	
	13.08.93	79	0,833 ± 0,000	0,007 ± 0,000	1,00 E-03 ± 0,00 E+00	8,40 E-05 ± 0,00 E+00	
	27.08.93	93	0,833 ± 0,000	0,010 ± 0,000	1,00 E-03 ± 0,00 E+00	1,20 E-04 ± 0,00 E+00	
	13.09.93	110	0,833 ± 0,000	0,016 ± 0,000	1,00 E-03 ± 0,00 E+00	1,92 E-04 ± 0,00 E+00	
	04.10.93	131	0,833 ± 0,000	0,026 ± 0,000	1,00 E-03 ± 0,00 E+00	3,12 E-04 ± 0,00 E+00	
	28.04.94	337					
	25.05.94	364					
	08.06.94	378					
	06.07.94	406					
	27.07.94	427					
	21.09.94	483					
6 cm	23.07.93	58	0,835 ± 0,000	0,004 ± 0,000	1,00 E-03 ± 0,00 E+00	4,79 E-05 ± 0,00 E+00	
	02.08.93	68	0,835 ± 0,000	0,005 ± 0,000	1,00 E-03 ± 0,00 E+00	5,99 E-05 ± 0,00 E+00	
	13.08.93	79	0,835 ± 0,000	0,007 ± 0,000	1,00 E-03 ± 0,00 E+00	8,39 E-05 ± 0,00 E+00	
	27.08.93	93	0,835 ± 0,000	0,010 ± 0,000	1,00 E-03 ± 0,00 E+00	1,20 E-04 ± 0,00 E+00	
	13.09.93	110	0,835 ± 0,000	0,016 ± 0,000	1,00 E-03 ± 0,00 E+00	1,92 E-04 ± 0,00 E+00	
	04.10.93	131	0,835 ± 0,000	0,026 ± 0,000	1,00 E-03 ± 0,00 E+00	3,11 E-04 ± 0,00 E+00	
	28.04.94	337					
	25.05.94	364					
	08.06.94	378					
	06.07.94	406					
	27.07.94	427					
	21.09.94	483					
9 cm	23.07.93	58	0,819 ± 0,000	0,004 ± 0,000	1,00 E-03 ± 0,00 E+00	4,88 E-05 ± 0,00 E+00	
	02.08.93	68	0,819 ± 0,000	0,005 ± 0,000	1,00 E-03 ± 0,00 E+00	6,10 E-05 ± 0,00 E+00	
	13.08.93	79	0,819 ± 0,000	0,007 ± 0,000	1,00 E-03 ± 0,00 E+00	8,54 E-05 ± 0,00 E+00	
	27.08.93	93	0,819 ± 0,000	0,010 ± 0,000	1,00 E-03 ± 0,00 E+00	1,22 E-04 ± 0,00 E+00	
	13.09.93	110	31,949 ± 0,819	2,420 ± 0,000	3,90 E-02 ± 1,00 E-03	2,95 E-02 ± 0,00 E+00	
	04.10.93	131	0,819 ± 0,000	0,026 ± 0,000	1,00 E-03 ± 0,00 E+00	3,17 E-04 ± 0,00 E+00	
	28.04.94	337					
	25.05.94	364					
	08.06.94	378					
	06.07.94	406					
	27.07.94	427					
	21.09.94	483					

* *days after comtamination (26.05.1993)*

Figs. 9-11 Actvity concentrations in the tissue water of the clipped grass swards for a sward height of 3 cm, 6 cm and 9 cm on mineral and organic soil

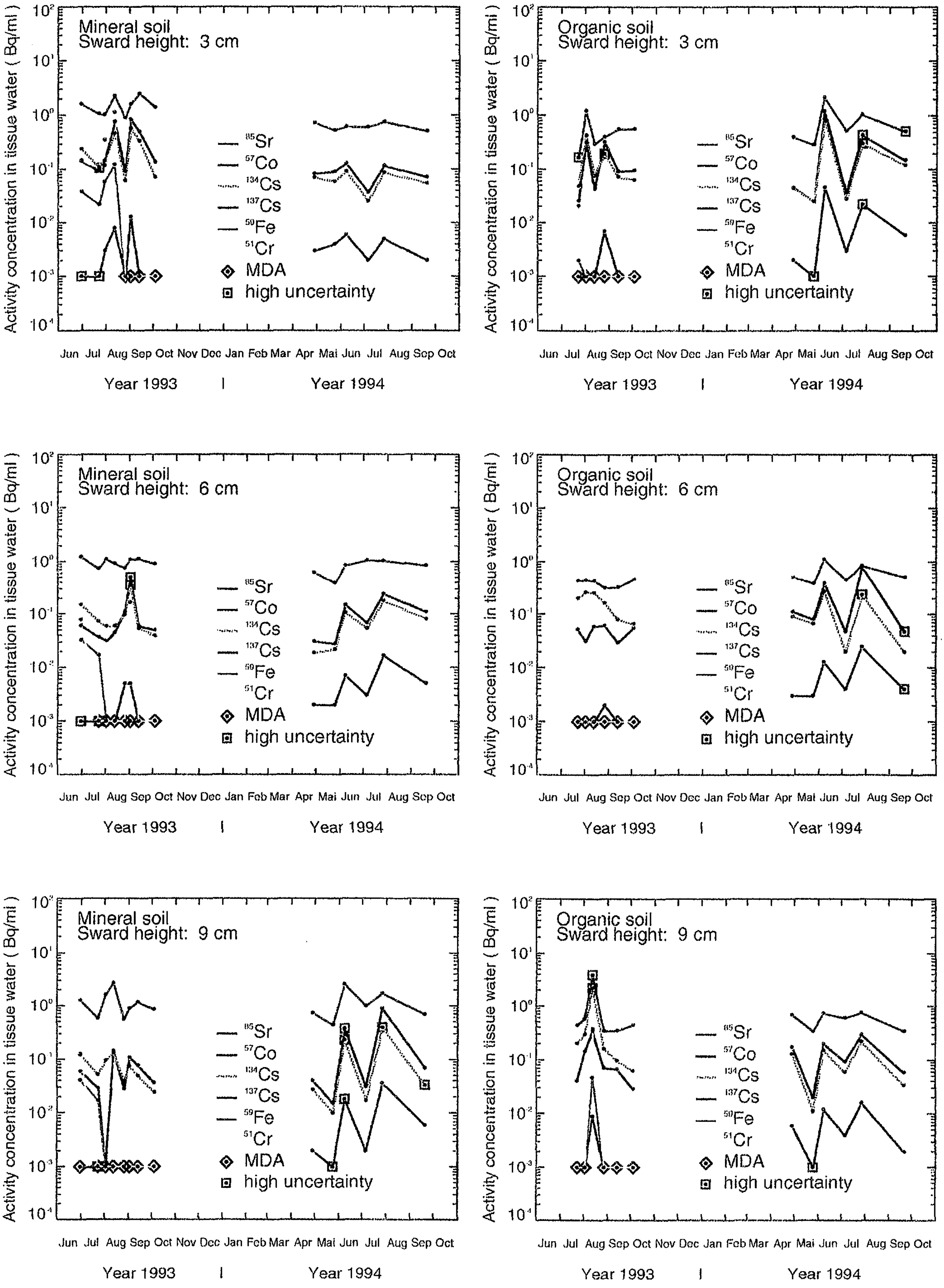
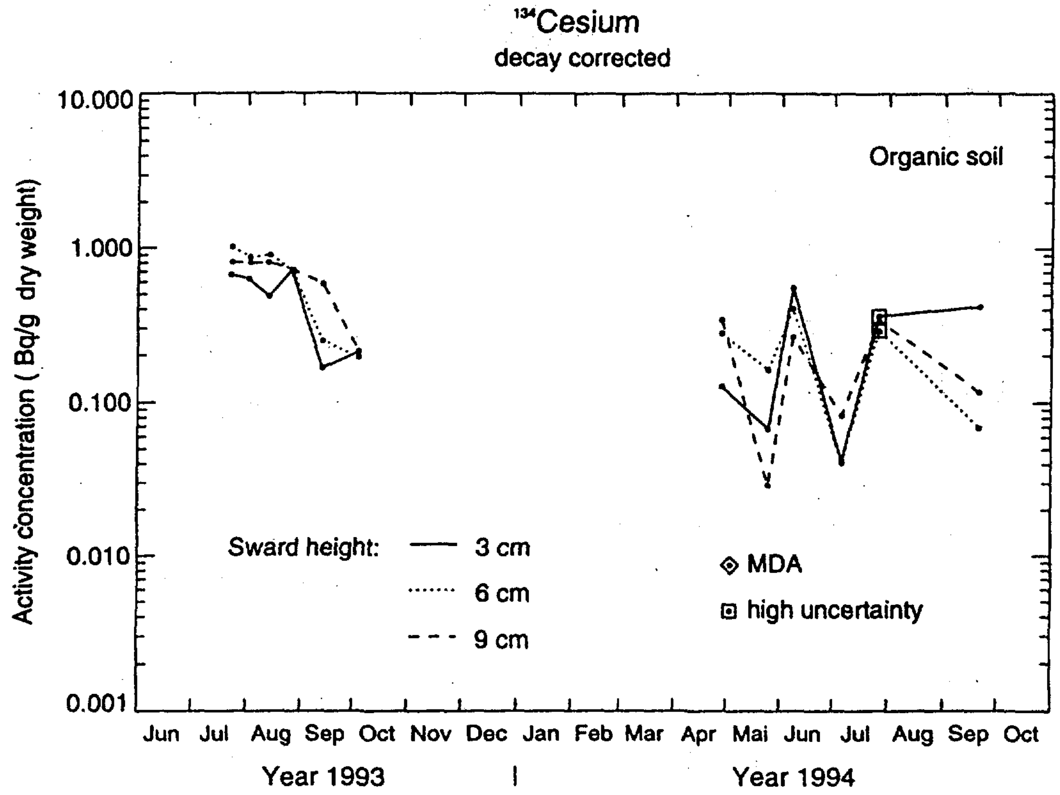


Fig. 12 Comparison of ^{134}Cs and ^{137}Cs for different sward heights on organic soil



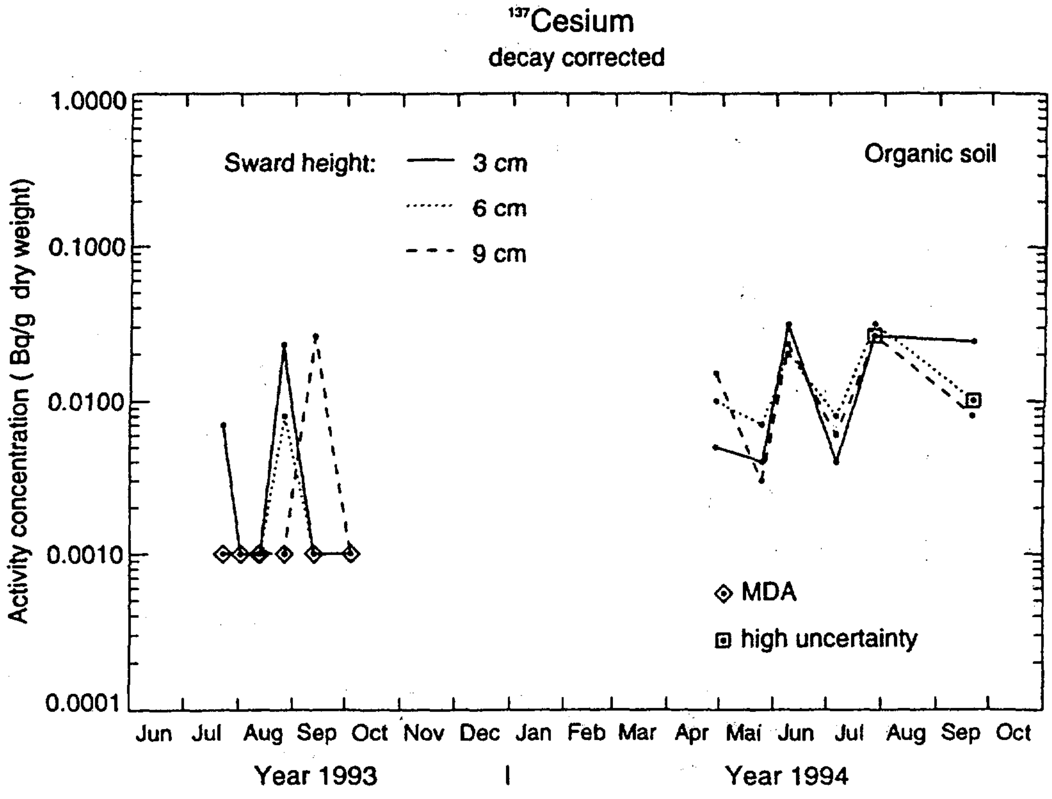
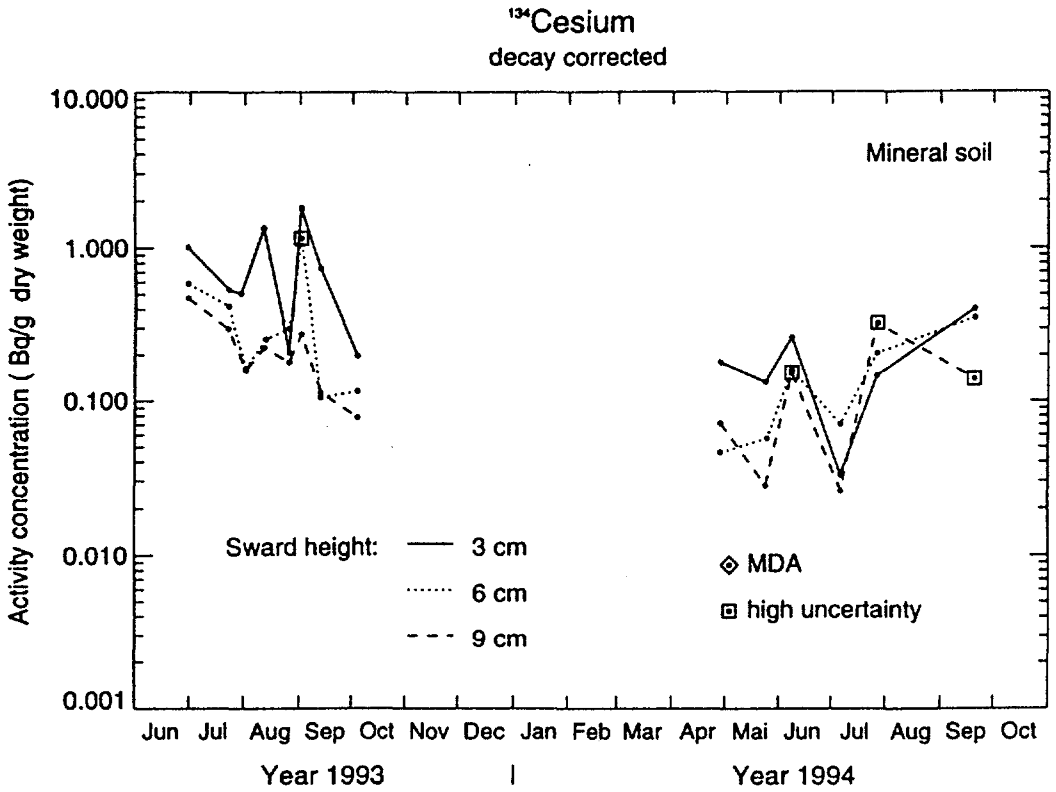
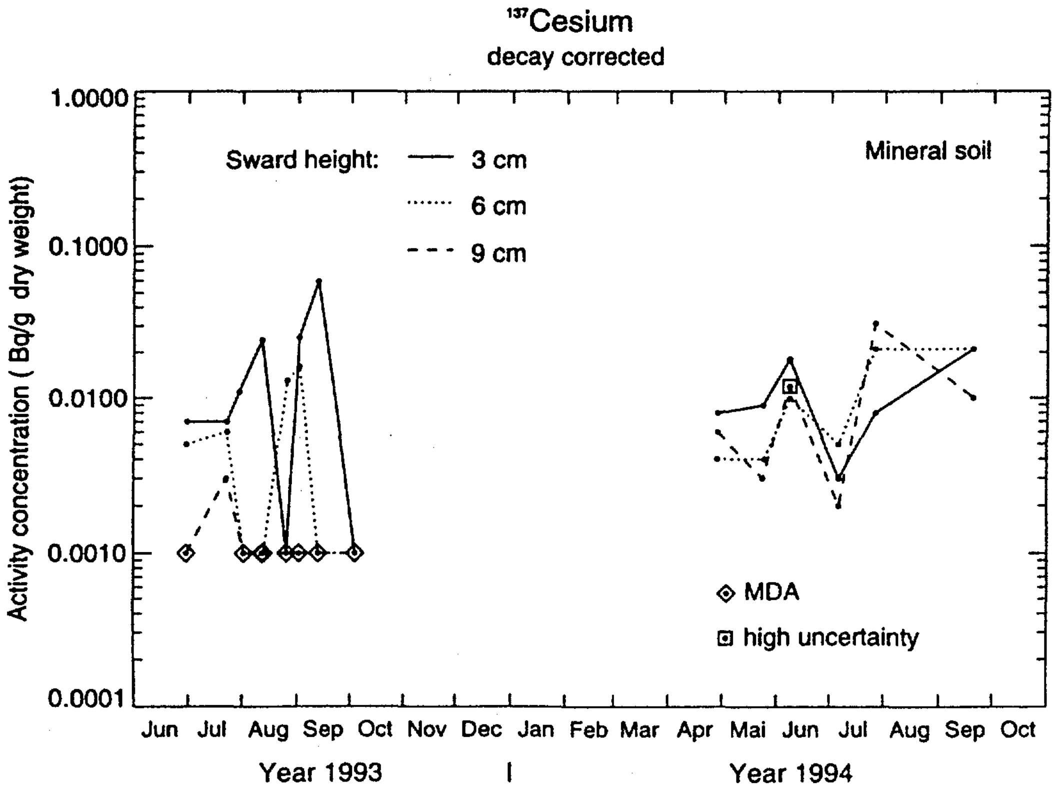
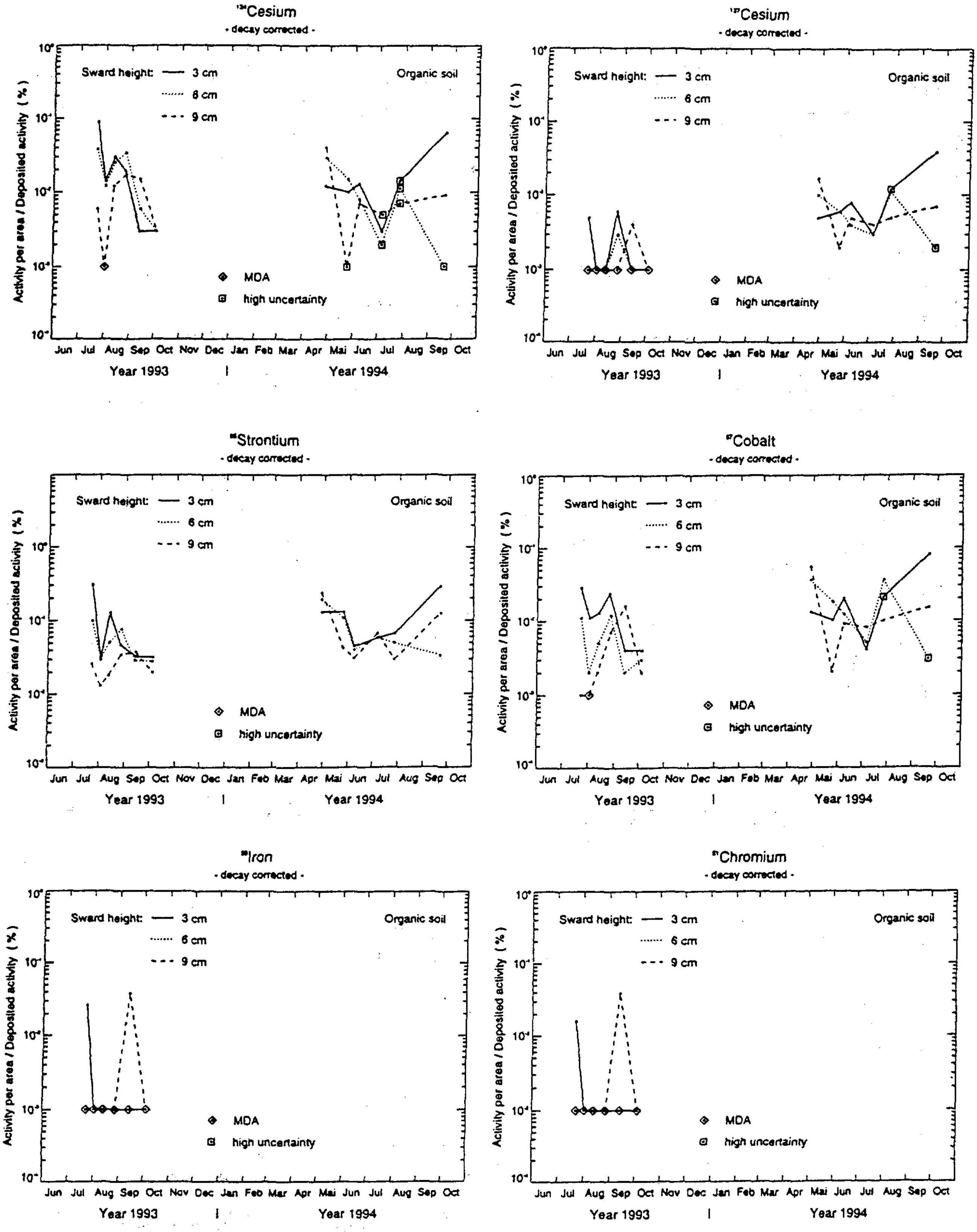


Fig. 13 Comparison of ^{134}Cs and ^{137}Cs for different sward heights on mineral soil





Figs. 14-16 Relation of the total clipped vegetation activity to the deposited activity on organic soil



^{134}Cesium - decay corrected -

^{137}Cesium - decay corrected -

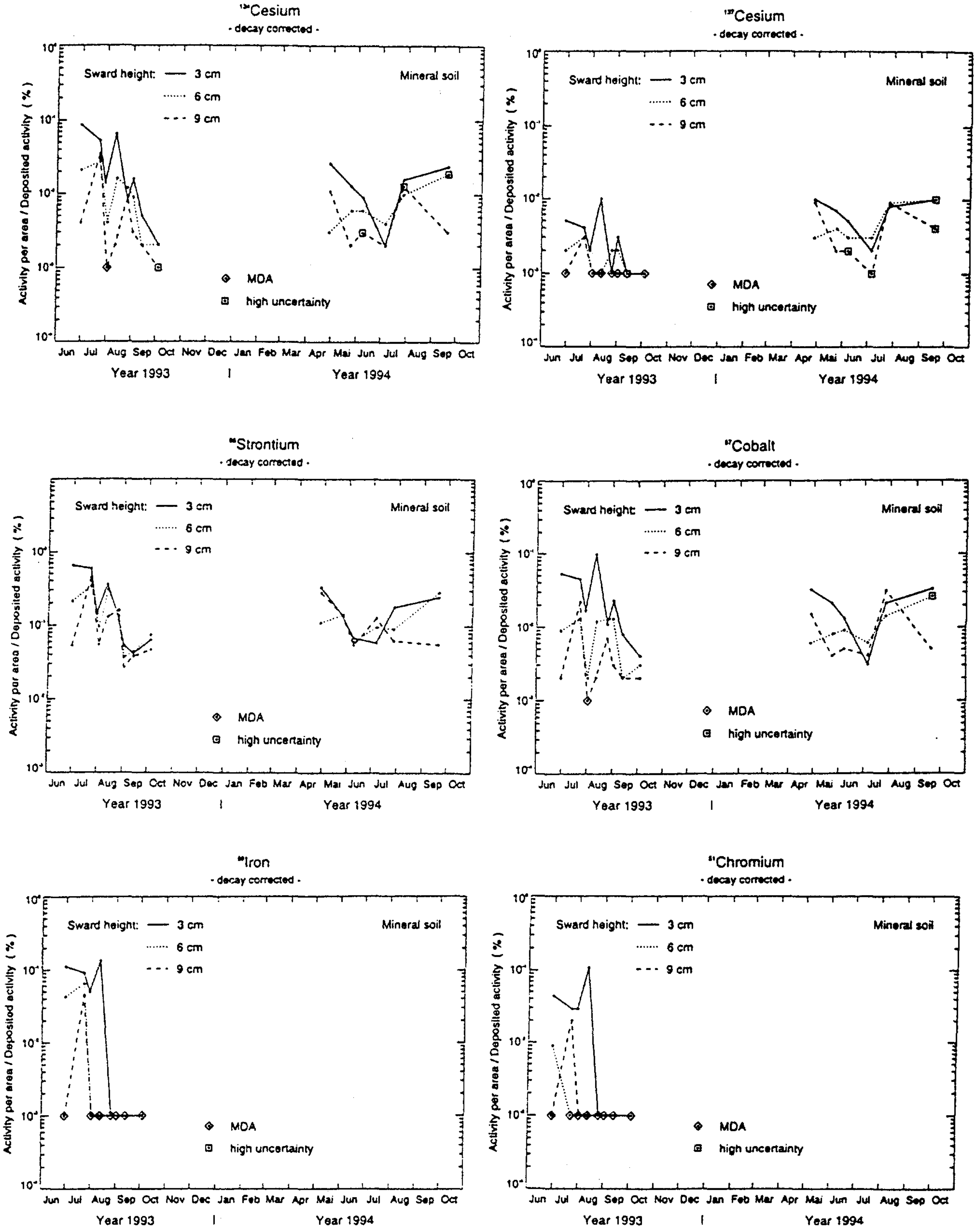
^{90}Strontium - decay corrected -

^{60}Cobalt - decay corrected -

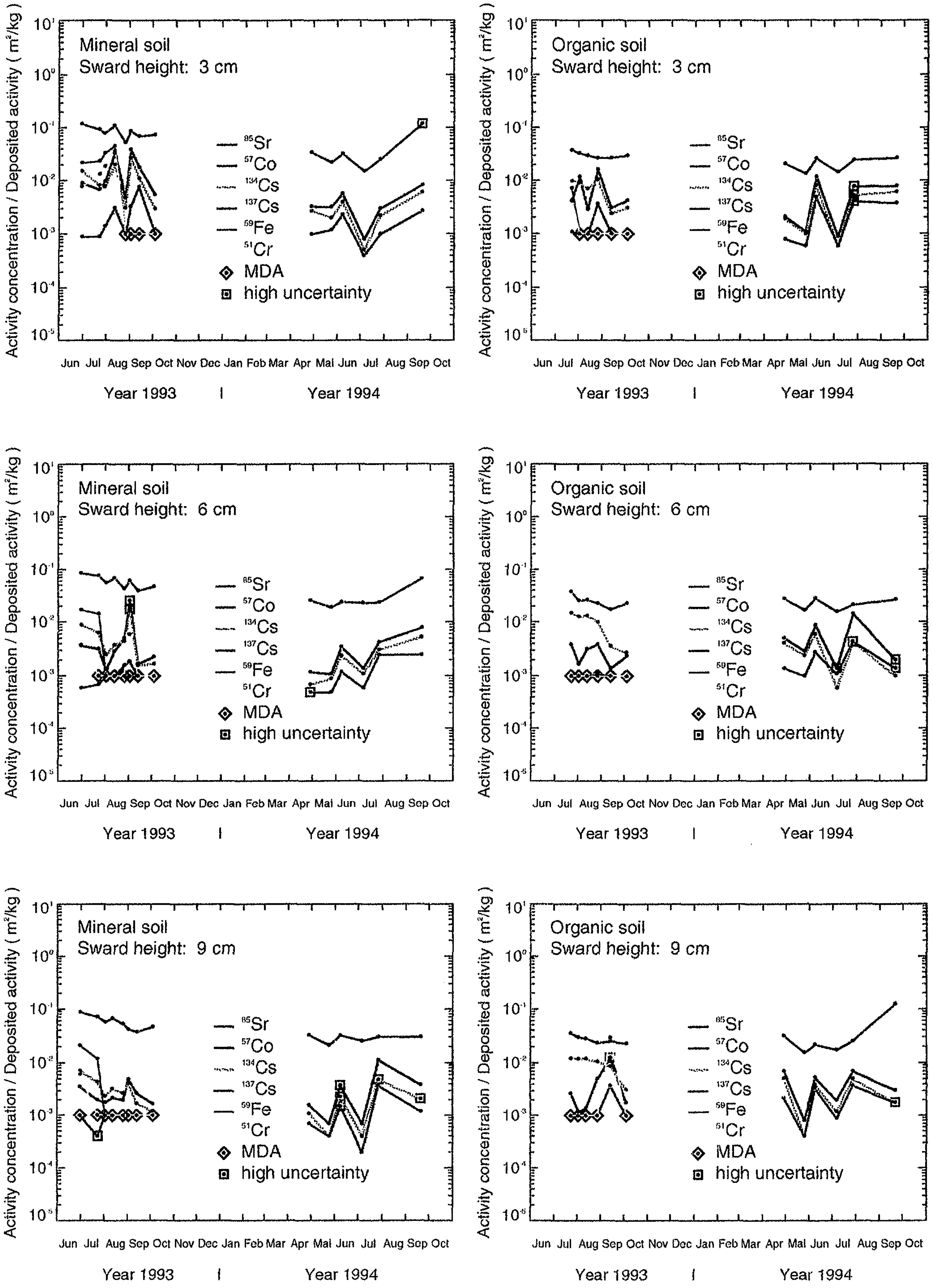
^{59}Iron - decay corrected -

^{51}Chromium - decay corrected -

Figs. 17-19 Relation of the total clipped vegetation activity to the deposited activity on mineral soil



Figs. 20-22 Relation of the activity concentration (dry weight) to the deposited activity for sward heights of 3cm, 6cm and 9cm on mineral and organic soil



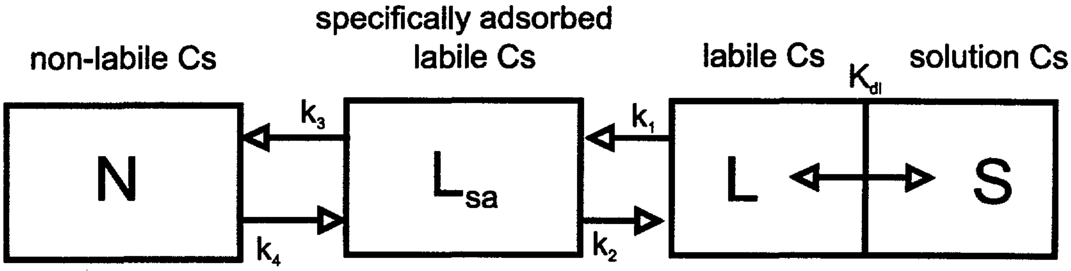
3.3. MODELLING STUDIES

The experimental data was used to further develop and test soil-vegetation models developed at Nottingham University (NU) (Absalom et al 1996, Crout et al, 1991). There were two aspects to this study.

- Soil samples were supplied by GSF to NU and these were used to measure the radiocaesium kinetics of the soils.
- The resulting soil kinetic parameters of the soils were used within a model of radiocaesium fixation in soils and transfer to vegetation.

3.3.1. SOIL FIXATION MODELLING

It has been demonstrated that the time-dependent fixation of radiocaesium in soils can be described by a simple first order kinetic model describing transfers between solution, non-specific labile, specific labile and fixed compartments (Absalom et al 1996) as shown schematically below.



The equations of this model are:

$$\frac{dL}{dt} = -k_1 L + k_2 L_{sa}$$

$$\frac{dL_{sa}}{dt} = -k_3 L_{sa} - k_2 L_{sa} + k_1 L + k_4 N$$

$$\frac{dN}{dt} = -k_2 N + k_3 L_{sa}$$

$$S = \frac{L}{K_{dl}}$$

where S= solution ^{137}Cs (Bq kg^{-1})
L =adsorbed labile ^{137}Cs (Bq kg^{-1})
N = non-labile (fixed) ^{137}Cs (Bq kg^{-1})
K_{dl}=labile ^{137}Cs distribution coefficient (l kg^{-1}).

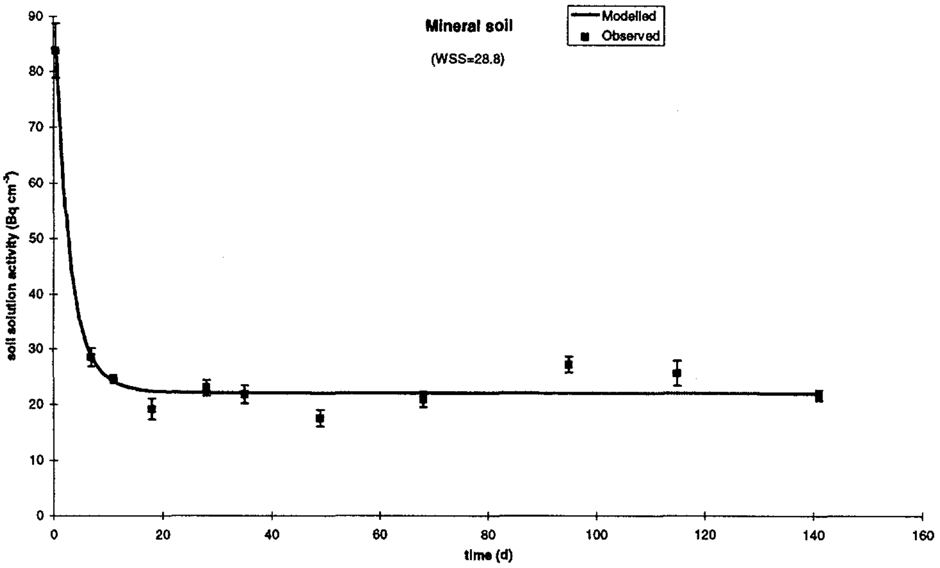
For a given soil parameters for this type of model can be empirically derived from experimental data on the solution activity of radiocaesium vs time since contamination (for details see Absalom et al, 1996). For this study the two soil types were artificially contaminated by radiocaesium and the subsequent solution activity concentration measured over a three month period. Full details of the experimental methods used are given by Absalom et al (1995). The derived model parameters are given in table 11.

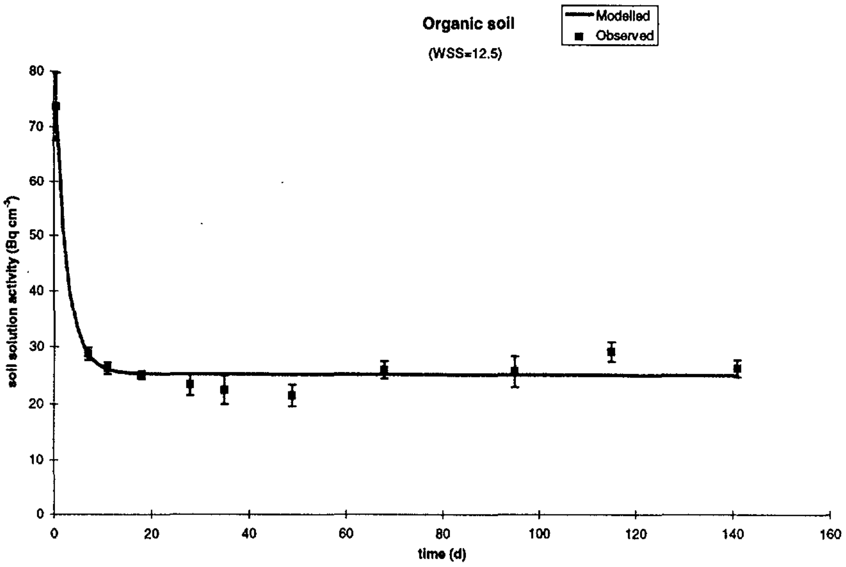
Table 11 Radiocaesium fixation model parameters derived for the two soil types

	Parameter				
Soil	K_{dl} (l kg^{-1})	K_1 (d^{-1})	K_2 (d^{-1})	K_3 (d^{-1})	K_4 (d^{-1})
organic	779.77 ± 64.76	0.42 ± 5.30	0.35 ± 7.45	0.13 ± 2.7	0.218 ± 0.45
mineral	526.03 ± 0.032	0.24 ±0.025	0.087 ± 0.012	1.65E-18 ± 6.54E-4	3.96E-11 ± 0.0

The resulting comparison between modelled and observed solution radiocaesium for both soil types is shown in fig. 23. Both soils show a similar pattern of behaviour, rapid fixation over a period of <20 days, followed by an apparent equilibrium. The experimental period was not long enough to determine whether there is a further longer term decline in solution activity.

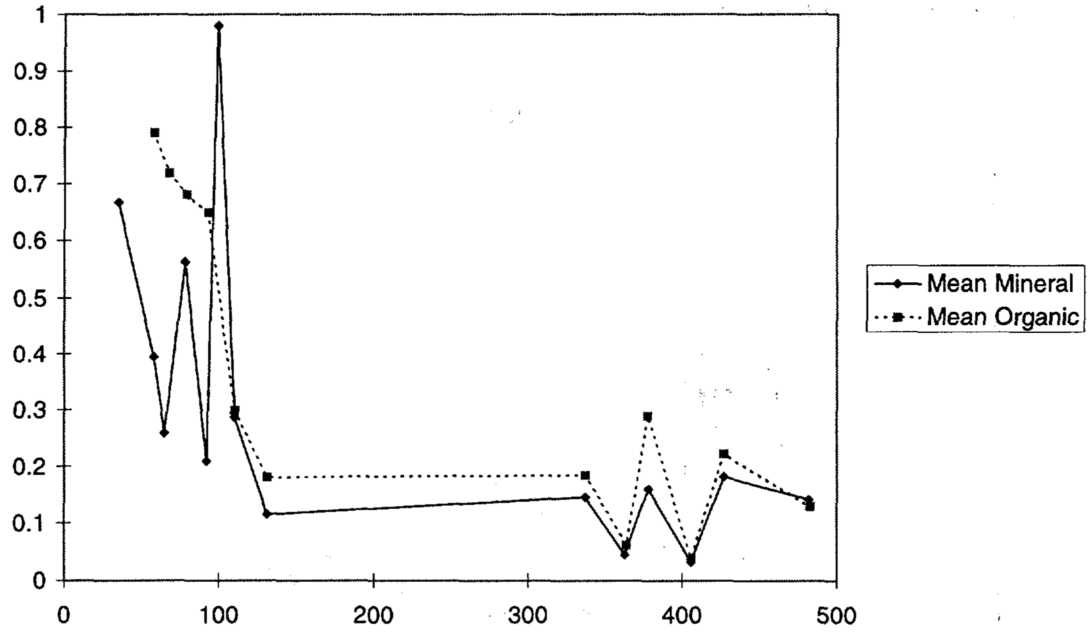
Fig. 23 Modelled and observed time-dependent soil solution activity concentration of radiocaesium for the two soil types used in the lysimeter studies





One the basis of these results we would expect similar vegetation activities to be observed for the two soils (for a given species and environment). The mean vegetation activity concentration observed in the lysimeter studies for the two soil types is shown in fig. 24. As expected from the soil solution results these are similar, although initially the organic soil shows a higher vegetation activity concentration.

Fig. 24 Vegetation activity concentration (mean across sward height treatment) for the two soil types



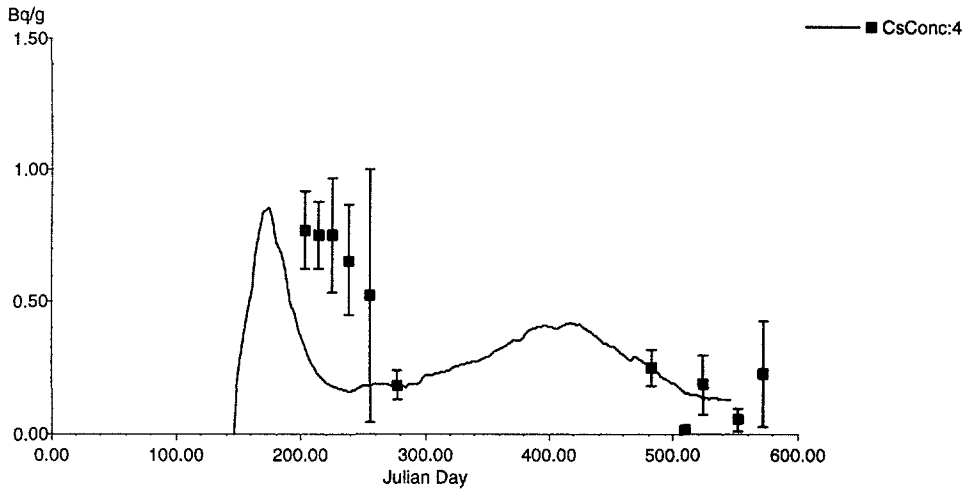
3.3.2. MODELLING VEGETATION UPTAKE

The uptake and subsequent recycling of radiocaesium by plants is modelled by assuming that, at any moment in time only radiocaesium within the soil solution is available for plant uptake. Uptake is assumed to be controlled by plant transpiration which is calculated via a grass sward growth model adapted from Johnson & Thornley (1983). This sward model also calculates grass growth and senescence in relation to climate.

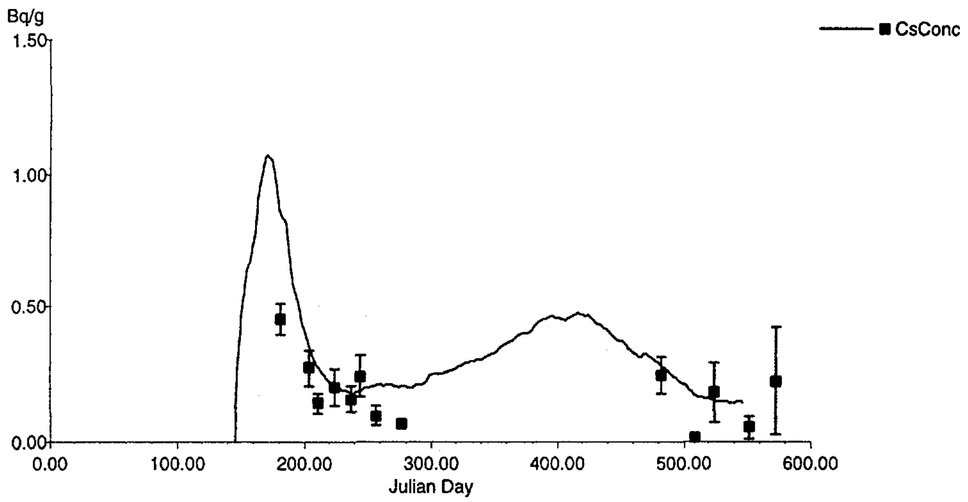
For the purposes of this limited study the model was only applied to the vegetation data from the 9cm sward because this has the least grass removal and therefore the balance of growth and senescence is more easily predicted. The resulting comparisons between model and observation are shown in fig. 25.

Fig. 25 Comparison between observed and modelled vegetation radiocaesium activity concentration for the two soil types

ORGANIC



MINERAL



At first glance the results do not look especially impressive, however it should be remembered that these predictions are based entirely on the soil kinetics and pattern of grass growth. There is no use of soil-plant transfer factors.

In both cases, but especially with the organic case the model does not accurately predict the initial spike of activity. This is a difficult aspect to predict as the rapid dynamic changes in the radiocaesium activity in soil solution occur in parallel with the initial growth of the vegetation. We would expect to see high initial concentrations because the biomass is low (a quite small uptake therefore gives a high concentration) and there is a relatively high solution activity. Certainly in the case of the organic soil the timing of these aspects doesn't seem correct. However we note that there is considerable variability in the data.

The model assumes that the grass roots access the full soil profile and that transpiration is taken equally with depth. Similarly it is assuming that the radiocaesium is distributed over the whole depth. Obviously both of these assumptions are in error although we cannot be sure how sensitive the model is to these factors. It is probable that the initially high concentrations of both roots and Cs at the surface will tend to increase the initial uptake and this may explain some of the differences. Also the early growth of the vegetation is especially difficult to predict which could have an effect on the early prediction of radiocaesium uptake.

4. CONCLUSIONS

In order to compare different grazing regimes Cs-137 activities in vegetation and milk of two farms were investigated. The movement of animals to different pastures of farm A applying a rotational grazing regime was not reflected in the milk radiocaesium activity concentration which was also rather stable except for a small increase at the end of September due to an unexplainable increase in activity concentration in pasture grass by a factor of 10. No influence of the oscillating grass activities over time in the grazed pasture mainly due to the movement to the different pastures is reflected by the milk activities. Additionally K-40 activities in milk of both farms were found to be rather stable, and independent of season and different locations.

In farm B a tenfold lower Cs-137 activity concentration was observed in milk though activity concentrations in soil and pasture grass were the same as that at farm A, indicating the same transfer rate soil-plant at both locations. Because animals are forced to graze the limited area more intensively, activity concentrations theoretically can be decreased by a factor of about 2 to 3 in the grazed plant parts according to the RUINS model by Crout. However, this could not be observed in vegetation samples measured here. Cs-137 uptake with soil by animals of farm A to result in a higher milk activity can be neglected because the absorption from soil particles through the GUT is usually much lower than that from vegetation, however, the binding of soluble (plant incorporated) Cs-137 in the rumen and consequent prevention of absorption by ingested soil particles has to be considered and might be responsible for the lower milk activities in farm B. The additional feeding with uncontaminated feed, however in unknown exact amounts (but estimated to be maximum half of the daily intake, since additional feeding of fresh grass was provided in the evening only), cannot be considered as a reason for further reduction in milk activities of farm B. Under the assumption that half of the daily intake is due to uncontaminated feed with an average activity concentration of ≤ 0.01 Bq kg^{-1} resulting in ≤ 0.33 Bq per day, this portion would account for less than 0.1 % of the total Cs-137 intake.

The mobility of Chernobyl released radiocaesium has changed over the years. Now radiocaesium is transferred into vegetation by root-uptake only and is in a more available form for uptake by animals (incorporated in vegetation) compared to plant adhered forms. The Cs-137 transfer coefficients feed-milk had, by 1992, reached values identical to the ones determined after the weapon's fallout. Grazing intensity in combination with grazing regime may influence Cs-137 milk concentrations, but not vegetation concentrations. Reasons for this finding may be uptake with more soil particles under a higher grazing pressure preventing soluble radiocaesium from uptake through the GUT and consequent milk transfer. It could be shown under normal agricultural conditions that with a higher grazing pressure lower activity concentrations in milk (in this case a factor of about 2 to 3) were obtained. Therefore changing stock density in combination with a continuous grazing regime on a given pasture after a major nuclear accident can be considered as a possible countermeasure which can be easily applied without any additional effort and costs.

The experiments performed on farms are usful for realistic predictions of radiocaesium concentrations in feed of animals under farm conditions. However due to rather high variations of activities in soils, vegetation, and the inhomogenousity in heigths of the grazed sward over a given pasture, these results are difficult to use for models such as the RUINS model. Mainly to get more homogenous growth rates and a homogenous distribution of radiocontamination, and reduce variations, plot experiments were performed to simulate the influence of grazing

Under the experimental design used here no effect of grazing intensity on the transfer of radionuclides to vegetation could be found. This is consistent with results of a similar experiment by Salt. Effects of grazing intensity as found for the farm experiment, therefore must be due to other sources than vegetation activities, and is suggested to be due to soil ingestion preventing uptake of soluble plant incorporated radiocaesium in the animal rumen.

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