AN EXPERIMENTAL STUDY ON MASS LOADING OF SOIL PARTICLES ON PLANT SURFACES

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Summary

Radionuclide contaminated soil adhered to plant surfaces can contribute to human ingestion dose. To determine this contribution, a method of ^{46}Sc neutron activation analysis was established and tested, by which a detection limit of 0.05 mg soil per g dry plant biomass can be obtained. In the field and greenhouse experiment the mass loading of soil on ryegrass (Lolium perenne L.) and broad-bean (Vicia faba L.) was investigated and the contribution from rainsplash and wind erosion were evaluated seperately. Soil retained on plant surfaces in field conditions in Seibersdorf/Austria was 5.77±1.44 mg soil per g dry plant for ryegrass and 9.51±0.73 mg soil per g dry plant for broadbean. Estimates of contribution from rainsplash and wind erosion to soil contamination of plants during the experimental period are 68% and 32% for broadbean, 47% and 53% for ryegrass respectively.

Mass loading results from field studies indicate that soil adhesion on plant surfaces can contribute up to 23% of plant ^{137}Cs contamination, the transfer factors modified by mass loading decline differently, depending on ^{137}Cs concentration of the soil and the soil mass adhered to plant surfaces.

1. Introduction

Few data are available on mass loading for various types of vegetation (Pinder III and McLeod 1989). Most of the mass loading studies were conducted in arid or semi-arid regions. The values of soil mass loading ranged from 1.1 (cabbage) to 260 (lettuce) mg soil per g dry plant biomass.

There are different methods to estimate the mass of soil present on plant surfaces. Arthur and Alldredge (1982) used ultrasonic washing to treat vegetation. Soil attached to plant surfaces was estimated by plutonium content. Green and Dodd (1988) used the titanium method which was established by Kiriyama and Kuroda (1982) to estimate the soil adhering to herbage. A detection limit of about $2.0 \cdot 10^{-3}$ mg soil/g dry plant can be obtained. Pinder III and McLeod (1989) used ^{238}Pu as a monitor of soil transport to plants and obtained a detection limit of approximately 0.5 mg/g dry plant biomass. Although ^{238}Pu may be measured at very low detection limits (~ 1 mBq per sample by alpha-spectroscopy), it was discarded as useful method in this experiment for two reasons. Firstly, the ^{238}Pu content of Austrian soils is only about 0.2 mBq/g which yields insufficiently low detection limits for mass loading of soil on plants. Secondly, the determination of ^{238}Pu by alpha-spectroscopy involves a chemical separation of the Pu which may not be 100% with the minute amounts of soil on the plant. The chemical efficiency is not known and not correctly determinable by spiking.

Scandium is geologically ubiquitous in soils but poorly absorbed by plant roots and not biologically mobile in vegetation (O'Toole et al. 1981). Therefore scandium is a perfect element for mass loading studies.

2. Materials and methods

2.1. The method for determining mass loading

With Sc, the isotope ^{46}Sc with a half life of 83.85 days is deployed. The long half life allows a rather lengthy decay permitting a decay of the large majority of radionuclides (^{24}Na, ^{28}Al, ^{38}Cl, ^{56}Mn, etc), which results in a low Compton background. This and the high activation cross section of ^{45}Sc results in a detection limit of 0.05 mg soil on plant if a decay time of longer than 10 days between irradiation and measurement is adopted.

The plant samples were dried at 100°C for 48 hours, and ground by a laboratory mill. An equivalent of approximately 1.5 g of the plant was weighed into polyethylene capsules (5 ml volume) for neutron activation. Soil samples were air-dried for 7 days, sieved through a 2 mm steel screen, an equivalent of 0.1 g was weighed and put into the capsules for neutron activation. The plant and corresponding soil samples were irradiated at close distances for 6 minutes ensuring an equal neutron flux of $8.0 \cdot 10^{13}$ neutrons cm^{-2} s^{-1}. After a storage time of two weeks, to allow the decay of the short lived activation products, samples were measured by gamma spectrometry with Ge(Li)-detector of 20% relative efficiency. A long measurement time of 50,000 seconds for the plant and comparatively short time of 2,000 seconds for soil samples was applied resulting in the detection limit of 0.05 mg soil per g plant biomass.

2.2. Mass loading experiment

The soil used in the experiment was a Calcic Chernozem, the characteristics of which are listed in table 1.

Table 1: The characteristics of the soil used in the mass loading experiment in Seibersdorf/Austria

% sand	% silt	% clay	pH $CaCl_2$	pH H_2O	% humus	% $CaCO_3$	mg K_2O/100 g
60.9	24.4	14.7	7.5	8.2	1.9	28.0	31.2

Two plants, ryegrass (Lolium perenne L.) and broadbean (Vicia faba L.) were grown under three conditions:

i) BG, RG: Plants were grown in pots (5 kg of soil) and in a closed cabinet located in the greenhouse.

ii) BP, RP: Plants were grown in the field on small plots (2 x 8 m) with polyethylene film protection of the soil surface.

iii) BF, RF: Plants were grown on small plots (2x8 m) without any protection, with a tube irrigation system. The performence of the experiment is shown in table 2.

Table 2: Reference data for the mass loading experiment (greenhouse and field)

Plant	Time of planting	time of sampling	Period (days)
BG	24.05.1993	29.06.1993	36
RG	24.05.1993	29.06.1993	36
BP	19.05.1993	01.07.1993	43
RP	19.05.1993	01.07.1993	43
BF	19.05.1993	01.07.1993	43
RF	19.05.1993	01.07.1993	43

B: broadbean P: protected field
R: ryegrass F: field
G: greenhouse

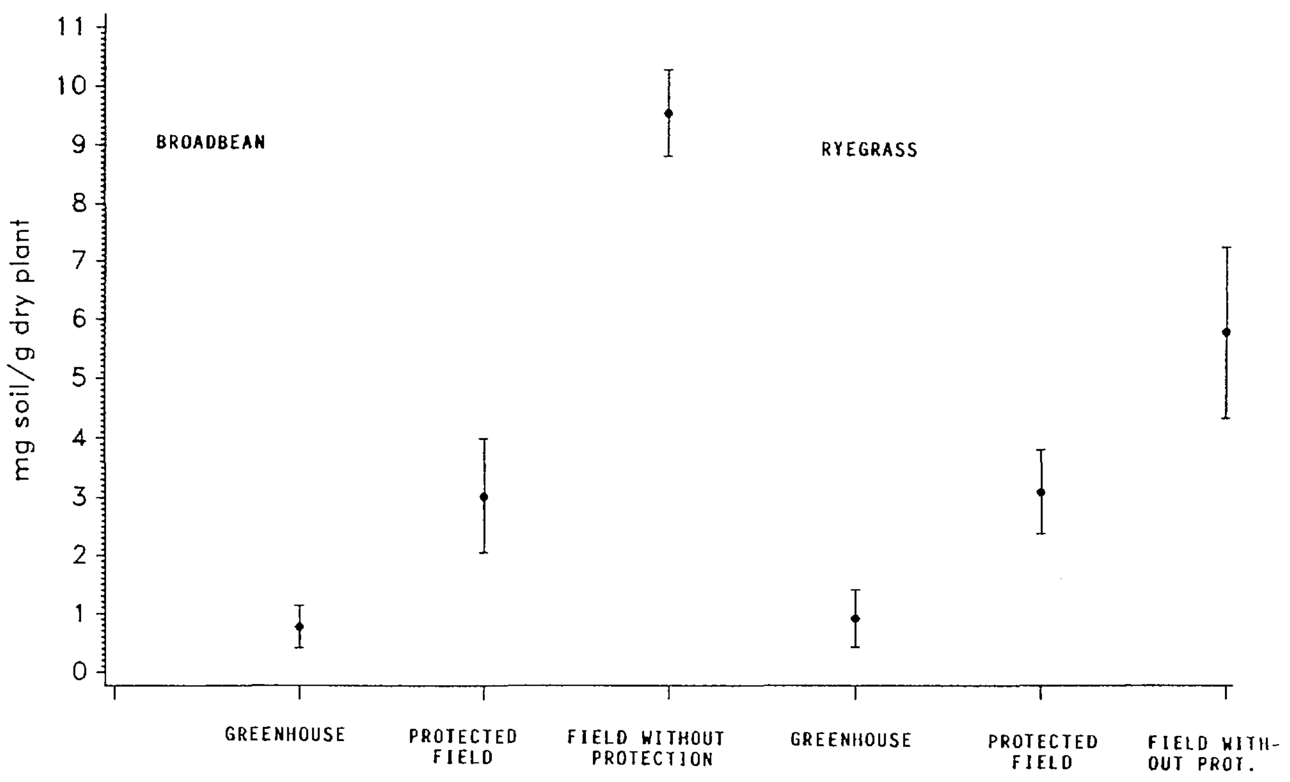
2.3. Measurements of the samples from field studies

Samples from the field studies on soil-to-plant transfer of the Austrian Research Centre Seibersdorf (Horak et al. 1989) were investigated. Plant and soil samples were taken from different regions of Austria contaminated by the Chernobyl accident derived ^{137}Cs. By determining the mass loading on plant samples by ^{46}Sc neutron activation analysis (2.1) the contribution of outer contamination to the soil-to-plant transfer factors was estimated.

3. Results and discussion

The mass loading values of soil particles on plants and their variance obtained from the experiment are shown in figure 1. Obviously, the concentration of soil on plants increases from protected plants in the greenhouse (BG, RG) to the plants in the field, but protected against rainsplash (BP, RP), and finally to the unprotected plants in the field (BF,RF).

Figure 1 Average soil mass loading values on broadbean and ryegrass in different experimental treatments with 95 % confidence intervals



The soil concentrations on broadbean and ryegrass in the field without protection are both higher than those in the field with plastic film protection. The precipitation in Seibersdorf during the experimental period was 62.6 mm. Because the plants grown in the protected field were well protected from rainsplash, rough estimates of the contribution from rainsplash and wind erosion to plant contamination can be calculated (table 3), assuming that ^{46}Sc-contents in plants from the greenhouse are due to small soil contaminations instead of root uptake of ^{46}Sc. For broadbean 68% of soil contamination are from rainsplash, only 32% from wind erosion. For ryegrass 47% soil adhesion appears to be from rainsplash and 53% from wind erosion. These results might be due to the differences in plant anatomy and leave structure.

Table 3: Contribution of pathways to soil contamination on plant surfaces obtained from the massloading experiment

Plant	Soil concentration on plant surfaces (mg soil/g dry plant)		Total
	Wind erosion	Rainsplash	
Broadbean	3.01 (32%)	6.50 (68%)	9.51
Ryegrass	3.08 (53%)	2.69 (47%)	5.77

Data in brackets are the percentage of soil concentration compared to the total concentration.

The second part of the paper deals with the practical use of mass loading values in soil-to-plant transfer studies (2.3). The transfer factors do not discriminate the contribution of soil particles on plant surfaces between the radionuclide contamination of crops from that of root uptake. The transfer factors due to pure root uptake may be estimated by substracting the mass loading contribution according to the formula:

$$Ar = At - As \cdot Ms / 1{,}000$$

Ar: Activity concentration of plant due to root uptake (Bq/kg);

At: Activity concentration in plant determined by transfer measurements (Bq/kg);

As: Activity in soil (Bq/kg);

Ms: Mass loading value (mg soil/g plant)

The corrected ^{137}Cs transfer factors from field experiments (Horak et al. 1989) are given in table 4 in comparison to the orginal transfer factors.

Table 4: Soil adhesion on plant shoots from field studies after the Chernobyl fallout in Austria obtained by ^{46}Sc neutron activation method and its impact on soil-to-plant transfer factors

Sample *	Concentration mg soil /g dry plant	D.L.a)	n.	Bq ^{137}Csb) /kg dry plant (% of total)	TF1c)	TF2d)
P1	6.01	0.050	6	0.141 (18.34)	0.029	0.023
P2	1.33	0.045	3	0.063 (5.53)	0.027	0.025
P3	2.31	0.048	2	0.087 (3.41)	0.059	0.057
P4	4.23	0.076	1	1.328 (23.18)	0.016	0.012
P5	1.16	0.028	1	0.023 (2.61)	0.039	0.038
P6	1.53	0.029	3	0.223 (14.48)	0.009	0.008

* P1-P4: barley straw P5-P6: wheat straw
a) Detection limit (mg soil/g dry plant);
b) Radioactivity derived from soil adhesion;
c) Transfer factor (Bq/kg fresh plant) / (Bq/kg dry soil);
d) Transfer factor modified by the contribution of soil adhesion.

Table 4 also shows the relative importance of soil adhesion to the plant surface ^{137}Cs contamination. Based on the soil concentrations of the plants from this experiment, the soil fraction on plant surfaces (without considering the distribution differences of ^{137}Cs in soil particles, Gerzabek et al. 1992) would contribute up to 23.2% to ^{137}Cs contamination in plant samples. For sample P4 (barley straw), the transfer factor (TF) with soil massloading correction is 0.012, thus decreasing by 23%, compared to the orginal TF (0.016). This change is due to the high ^{137}Cs concentration of the soil (314 Bq/kg soil) and the high soil mass loading value (4.23 mg soil/g dry plant). For sample P1, despite the fact that the soil mass loading was highest among the measurements (6.01 mg soil/g dry plant), as a result of the low ^{137}Cs soil concentration, the transfer value with soil correction decreased only by a rate of 18%.

Because of the fact that radionuclide concentration in resuspendable soil particles (<125 µm in diameter, Dreicer et al. 1984) is higher than that of the entire soil (Livens and Baxter 1988, Pinder III and McLeod 1989), it is possible that the the radionuclide contamination of plants from soil adhesion may be underestimated in table 4. For example, the ^{137}Cs concentrations in soil particles smaller than 2 µm can be 2.7 times higher than that in the entire soil (Gerzabek et al. 1992).

The importance of soil in contributing ^{137}Cs contamination (or other pollutants) to plant surfaces depend upon the type of plants, the concentration of ^{137}Cs in the soil, and the resuspension and retention characteristics of the particles. Other factors such as weather conditions (wind speed, precipitation, humiditity), agricultural activities (plowing, irrigation, mechanical harvest) etc., may be as well important to the soil adhesion (Arthur and Alldredge 1982, Dreicer et al. 1984, Nicholson 1988, Pinder III and McLeod 1988).

A limitation of the proposed method arises from the fact that it is not possible to obtain information on radionuclide uptake from contaminated particles on the plant surface into plant tissue and the subsequent translocation. That means there may be a further contribution of soil adhesion to plant contamination by radionuclide plant uptake into shoots during the vegetation period through contaminated particles, which may not be present at harvest due to weather effects.

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