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Distribution of Radiocesium in Grape Vine Plants after Foliar Contamination: Effect of Potassium Supply on the Release from the Roots

Verteilung von Radiocäsium in Reben nach Blattkontamination: Einfluß der Kaliumversorgung auf die Abgabe durch die Wurzeln

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Summary

The foliar uptake of radioactive cesium (^{134}Cs) by selected leaves of grape vine plants and the subsequent redistribution within the plants was examined under controlled conditions in a greenhouse. The radionuclide was applied as chloride. The plants were grown in glass containers with nutrient solution. Samples of plants and nutrient media were analyzed throughout the growing season. Radiocesium was easily taken up through the leaf surface, transported to other plant parts and to some extent released from the roots. In the present study, the release of cesium into a nutrient solution was investigated in more detail. Whereas cesium reaching the soil may be bound to clay particles causing clearly reduced availability for plants, radiocesium released from the plants into a nutrient solution may be taken up again by the roots and transported within the plants. An increased supply of potassium caused a higher release of radiocesium into the nutrient solution. From these results it becomes evident that a considerable percentage of radiocesium applied on the leaf surface may be released into the rooting medium and that this may depend on the potassium availability. Well supplied grape vine plants released more radiocesium than poorly supplied plants. However the radiocesium activity of grape vine plants grown in a nutrient solution with a high potassium content compared with that of plants grown in soil or in nutrient solution with a lower potassium content was at the end of the vegetation period not considerably lower.

Zusammenfassung

Die Aufnahme von radioaktivem Cäsium (^{134}Cs) durch bestimmte Rebenblätter und die anschliessende Verteilung dieses Nuklids in der Pflanze wurde unter kontrollierten Bedingungen in einem Gewächshaus untersucht. Radiocäsium wurde als Chlorid auf die Blätter aufgetragen. Die Pflanzen wurden in Hydrokultur gezogen. Proben von Pflanzen und Wachstumsmedien wurden während der ganzen Wachstumsperiode analysiert. Radiocäsium gelangt sehr leicht durch die Blattoberfläche, wird von dort in andere Pflanzenteile transportiert und zu einem gewissen Grad durch die Wurzeln wieder ausgeschieden. In der vorliegenden Arbeit wurde die Ausscheidung von Radiocäsium durch die Wurzeln genauer untersucht. Während im Boden ein grosser Teil des abgegeben Cäsiums an Tonpartikel gebunden wird und den Pflanzen kaum mehr zur Verfügung steht, kann Radiocäsium, das in eine Nährlösung abgegeben wurde, von den Wurzeln erneut aufgenommen und wieder in der Pflanze verteilt werden. Die Versuche zeigten, dass ein beträchtlicher Anteil des auf den Blättern deponierten Radiocäsiums von den Reben in das Wachtumsmedium ausgeschieden wurde und dass die Höhe dieser Abgabe durch die Kaliumversorgung der Pflanzen beeinflusst wurde. Mit Kalium gut versorgten Reben gaben mehr Radiocäsium ab, als knapp versorgte Pflanzen. Trotzdem war der Radiocäsiumgehalt von Reben, welche sich auf einer Nährlösung mit hohem Kaliumgehalt entwickelten, am Ende der Vegetationsperiode nicht wesentlich tiefer als in Reben, welche auf Erde oder in Nährlösung mit einem tieferen Kaliumgehalt gezogen wurden.

Introduction

Within 10 years following the Chernobyl accident in 1986 studies were carried out in an attempt to understand different mechanisms of the foliar uptake of radioactive strontium and cesium into strawberry and grape vine plants, their subsequent transport to other plant organs and finally also the release from the plants into the soil. The accumulation of radionuclides in the berries was of special interest since this represents an entry for these undesirable substances into the human food chain. Previous studies (ZEHNDER et al. 1993, 1995, 1996) showed that strontium taken up by the leaves was highly immobile in the plants whereas cesium was taken up easily and distributed in the whole plant. Grape berries proved to be a transient sink for radioactive cesium. A large percentage of radiocesium was released from the plants into the soil, where it can interact with clay minerals and is hardly available to plants. In these studies the determination of the radioactivity of the soil however was unsatisfactory because of methodical problems with the separation of the soil from the roots. The aim of the present experiments with grape vines in hydroculture was to determine the true release of radioactive cesium from the plants. In contrast to radiocesium excreted into the soil, radiocesium released from the plants into the nutrient solution may be taken up again by the plants. The potassi-

Table 1. Composition of the nutrient solutions
Zusammensetzung der Nährlösungen

Solution 1: low potassium content	
KCl	0.221 g/l
$Mg.SO_4.7H_2O$	0.074 g/l
HNO_3	0.152 g/l
$Ca(NO_3)_2.4H_2O$	0.441 g/l
KH_2PO_4	0.058 g/l
Spuren-Flory® (Hauert, Grossaffoltern, Switzerland)	0.059 g/l
Sequestren® (Novartis, Basle, Switzerland)	0.040 g/l
Softened water to make up the solution	
pH of the solution	6.5
Potassium content = 132,6mg/l = 3.5 mM	
Solution 2: high potassium content	
Above nutrient solution supplemented by 1006,7 mg KCl /l	
Potassium content = 661mg/l = 17 mM	

um supply of the plants was considered as important factor influencing the release of radiocesium into the nutrient solution. Potassium might contribute to lower the concentation of cesium-134 and cesium-137 in contaminated grape vine plants.

Materials and methods

Plants and cultivation: 2-3 years old grape vine plants of the variety 'Müller-Thurgau', obtained from a commercial nursery, were planted in cylindrical glass containers with a diameter of 14 cm and a height of 29 cm. The containers with 4 litres of nutrient solution (Tab. 1) were continuously aerated by cleaned compressed air. To prevent contamination of the nutrient solution with radiocesium from the plant parts above solution level, the top surfaces of the containers were covered with aluminium foil with only a small hole for both the stem and the aeration tube. To hold the plants in a vertical position, they were attached to strings fixed to the greenhouse construction. In spring the plants were pruned on two canes with five buds each. At a later date all emerged shoots of each cane were removed except for one. On each of the remaining two shoots the first fully developed leaf reaching a size of 50 to 80 cm² was contaminated with $^{134}CsCl$ (see below). All leaves inserted below those to be contaminated were previously removed. During the experiment no further shoots and leaves were taken away. Pesticides were used when appropriate. In some cases Sequestren® (0.5% in water) was sprayed directly onto the leaves to prevent chlorosis. During all treatments, contaminated leaves were covered by a glass shielding. The experiments were carried out in the greenhouse previously described by ZEHNDER et al. (1993, 1995).

Nutrient solutions

The composition is shown in table 1. The nutrient solutions were exchanged in 4 week-intervals by freshly prepared solutions. Water losses were replaced twice weekly. Every week the pH of the solutions in the containers was controlled and corrected with 0.1 N citric acid to a pH between 5 and 6.

Application of the radionuclides

As described previously (ZEHNDER et al. 1993, 1995), the short-life isotope cesium-134 (half-life 2 years) was used instead of the long-life isotope Cs-137 (half-life 30 years) for safety reasons. Carrier-free aqueous solutions of $^{134}CsCl$ (Amersham, UK) was used to contaminate the plants. The selected leaves were contaminated on the upper surface with 100 μl of the $^{134}CsCl$-solution. It was applied with a micropipette as 20–25 small droplets which dried within 2–3 hours in the atmosphere. Based on the measured activities in the different plant organs in previous experiments the activities applied could be reduced from 91'550 Bq per plant in 1993 to 71'200 Bq in 1994 and to 49'103 Bq in 1996.

Experimental groups

In 1993 the first experiment was carried out with 6 grape vine plants. All plants were grown in nutrient solution 1 (Tab. 1). This preliminary experiment was designed to establish hydroculture of grape vines. As a consequence in the experiments 1994 and 1996 Fe-EDDHA (Sequestren) was added to the nutrient solutions to prevent chlorosis. For the main experiment in 1994 and 1996 two groups of 6 plants were used. One group was cultured on nutrient solution 1, the other on nutrient solution 2 (Tab 1).

Sampling

Every week 60 ml of the nutrient solution of each plant were removed for analysis. 50 ml were put into standardised 50 ml polyethylene bottles for activity measurements, 10 ml were used for potassium determination.

Four months after contamination (beginning of leaf drop) two plants of each group were harvested and analysed, while the other plants were used for further studies. The two contaminated leaves of each of the harvested plants were removed first and washed with 50 ml of 0.1 N HCl for five minutes with shaking. Then the plants were cut into small pieces. The plant material was air-dried under ventilation at 80°C to constant weight. The dry material was put into the above described polyethylene bottles for radioactivity measurements.

Radiocesium measurement

The concentrations of ^{134}Cs in all samples were determined by means of γ-spectrometric methods as described by ZEHNDER et al. 1995. For the measurements a P-type coaxial solid state intrinsic germanium detector linked to an automatically operating sample changer with a capability to analyse 10 samples consecutively was used (Princeton Gamma-Tech (PGT), type IGC 30). The activities of the samples were calculated using the software package "inter-gamma" developed by Intertechnique SA. Because of the time lag between radiocesium application and analysis all measured activities were calculated back to the application date to provide a valid basis for a direct comparison of the measured activities at different times.

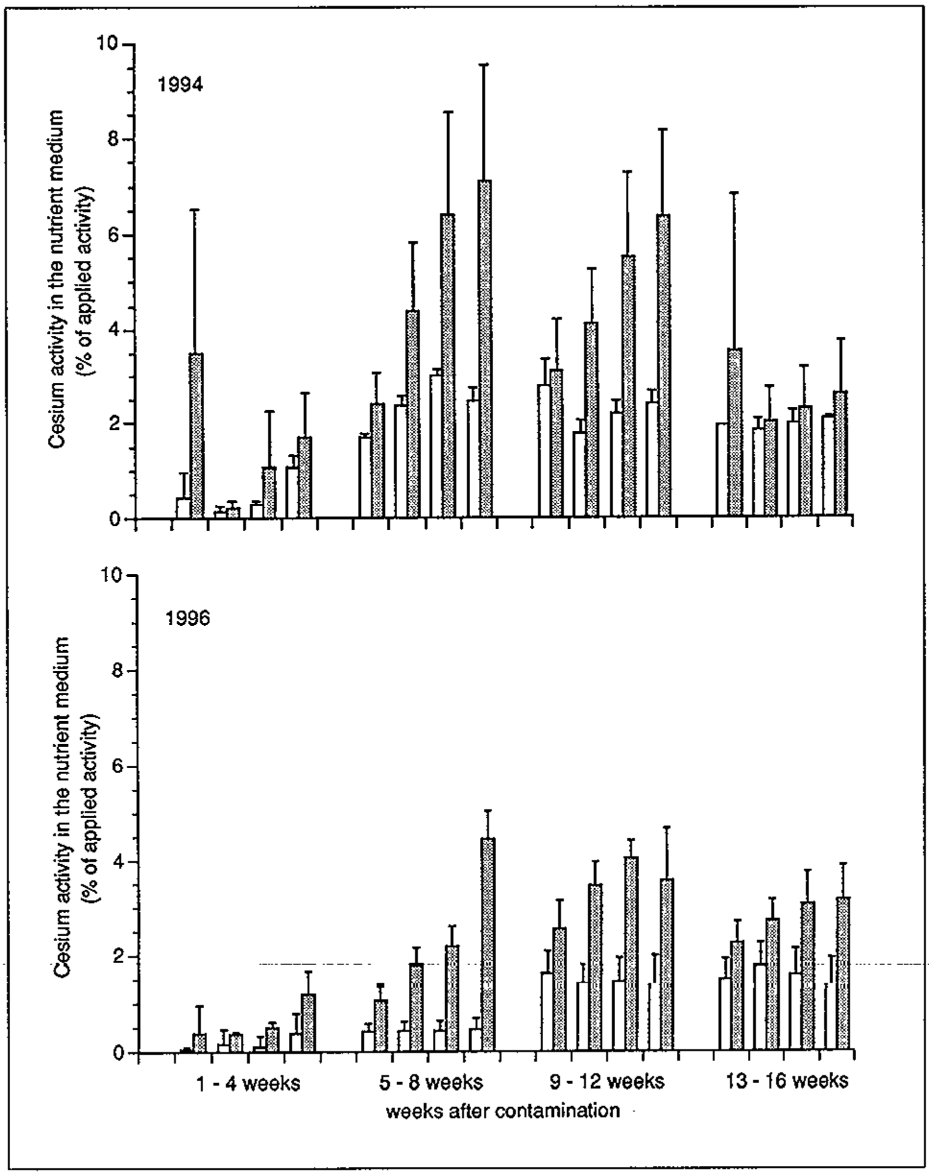

Fig. 1. Radiocesium content in the nutrient solution of leaf-contaminated grape vine plants in hydroculture (experiments 1994 and 1996). Means ± sd of 6 replicates are shown. Nutrient solution was exchanged at 4 week-intervals.
☐ low potassium supply (3.4 mM)
▩ high potassium supply (17 mM)

Gehalt an Radiocäsium in der Nährlösung von blattkontaminierten Reben in Hydrokultur (Experimente 1994 und 1996). Mittelwerte und Standardabweichungen von 6 Wiederholungen sind dargestellt. Die Nährlösung wurde in Intervallen von 4 Wochen ausgetauscht.
☐ *knappe Kaliumversorgung (3.4 mM)*
▩ *gute Kaliumversorgung (17 mM)*

Determination of potassium

The potassium concentration in the nutrient solution samples was determined with a Unicam 939 atomic adsorption spectrometer (Unicam, Cambridge, UK) linked to an automatically operating sample changer with a capability to analyse 48 samples consecutively. Prior to the measurement the samples were, according to the expected potassium content, diluted 50–800 times and mixed with 5 ml of cesium chloride-lanthanum chloride buffer solution (Schinkel solution, Merck, Darmstadt, Germany) per 100 ml as a modifier (Method according the instrument handbook, modified to wine analysis, OETTLI 1997).

Results and discussion

Since it was not possible to separate all root parts from the soil, in our earlier experiments it remained open to what extent the ^{134}Cs-activity found in the soil was released from living roots or by parts of roots torn off (ZEHNDER et al. 1995). In the present study, where the leaf contaminated grape vines were cultivated in hydroculture, it became evident, that the cesium activity measured in the nutrient solution was secreted by the living roots (Fig. 1). Minor amounts of activity might originate from rotten root parts. Although the relative cesium release in 1994 was clearly higher than in 1996, the overall time courses and the effects of the potassium levels were very similar.

It is well known that radiocesium is adsorbed to clay particles in the soil and only a minor fraction of it is available for plant uptake (ANDERSEN 1967, ROCA et al. 1989, SCHALLER et. al 1990, ANTONOPOULOS-DOMIS et al. 1991, WAGNER und DIEHL 1991, BECKMANN and FAAS 1992, ZEHNDER et al. 1995). In the nutrient solution however, the released cesium enters a cycle: it will stay in solution, can be taken up by the grape vine roots, is transported to the shoots via the xylem and redistributed in the plant via the phloem. The transfer of cesium from the xylem to the phloem was demonstrated in potato plants by EGLI (1996) by the split-root method. Fig. 2 shows the weekly release of radioactive cesium in the nutrient solution by the grape

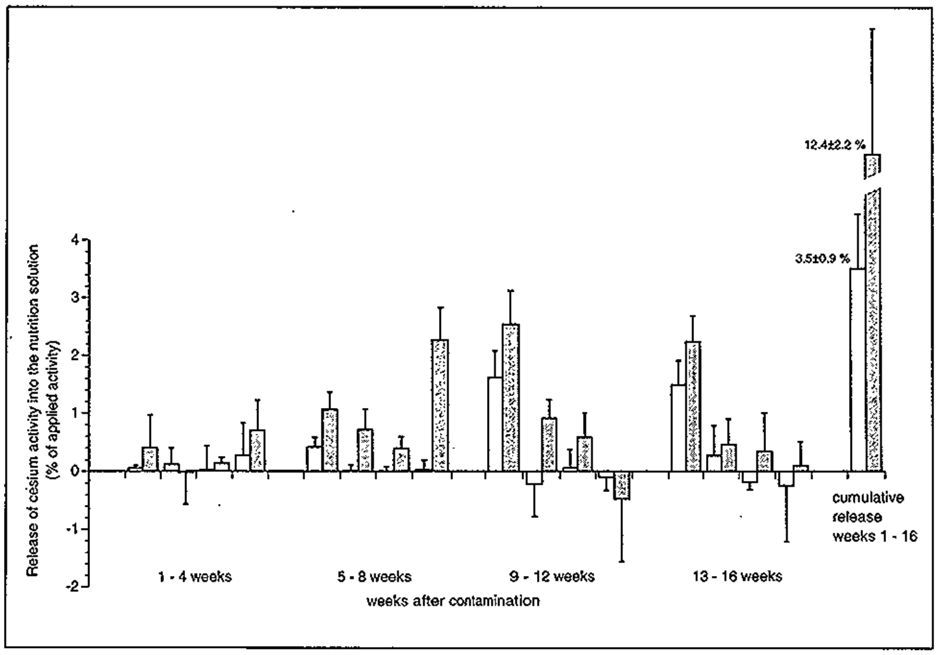

Fig. 2. Weekly release of radiocesium into the nutrient solution of leaf-contaminated grape vine plants in hydroculture (experiment 1996). Means ± sd of 6 replicates are shown. Nutrient solution was exchanged at 4 week-intervalls.
☐ low potassium supply (3.4 mM)
▩ high potassium supply (17 mM)
Wöchentliche Abgabe von Radiocäsium von blattkontaminierten Reben in Hydrokultur in die Nährlösung (Experiment 1996). Mittelwerte und Standardabweichungen von 6 Wiederholungen sind dargestellt. Die Nährlösung wurde in Intervallen von 4 Wochen ausgetauscht.
☐ *knappe Kaliumversorgung (3.4 mM)*
▩ *gute Kaliumversorgung (17 mM)*

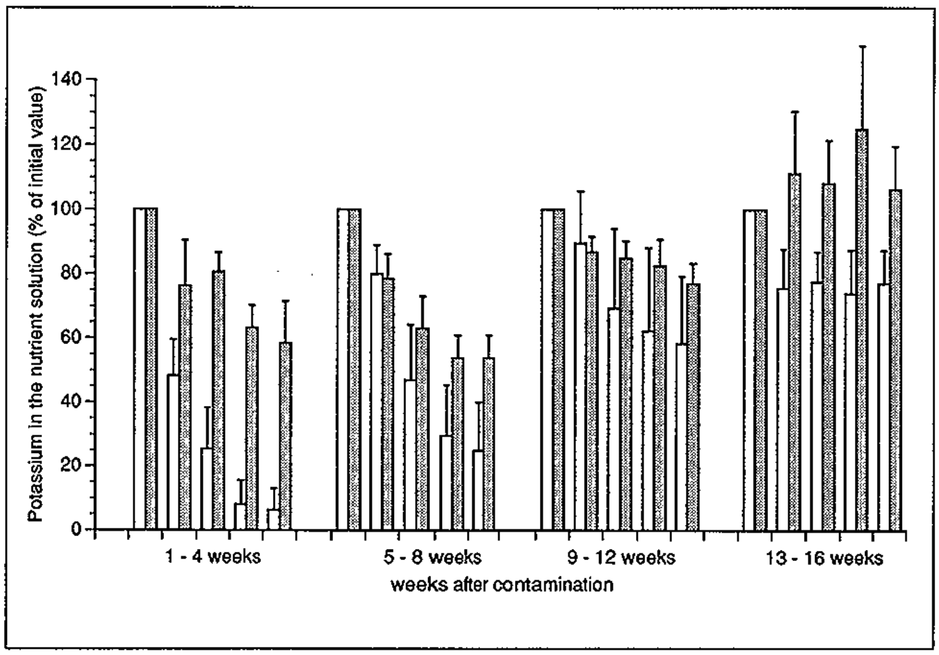

Fig. 3. Potassium content in the nutrient solution of grape vine plants in hydroculture (experiment 1996). Means ± sd of 6 replicates are shown. Nutrient solution was exchanged at 4 week-intervals.
☐ low potassium supply (3.4 mM)
▩ high potassium supply (17 mM)
Kaliumgehalt in der Nährlösung von Reben in Hydrokultur (Experiment 1996). Mittelwerte und Standardabweichungen von 6 Wiederholungen sind dargestellt. Die Nährlösung wurde in Intervallen von 4 Wochen ausgetauscht.
☐ *knappe Kaliumversorgung (3.4 mM)*
▩ *gute Kaliumversorgung (17 mM)*

vines. The extent of the cesium release is related obviously to the potassium uptake of the grape vines from the nutrient solution. Grape vines well supplied with potassium generally release more radiocesium than do plants with a poor potassium supply. The cumulative release during the experiment (weeks 1–16) was 3.5 ± 0.9% of the originally applied activity for the low and 12.4 ± 2.2% for the high potassium supply. In general at the beginning of a supply period, when the potassium uptake rate was high, the plants released the highest cesium quantity into the nutrient solution. During the later phase of the 4 week intervals, there was even an uptake of radiocesium from the nutrient solution. An earlier uptake may be masked by a simultaneous release of cesium into the nutrient solution. This consumption was greater with plants living on a minimum potassium level. The elements cesium and potassium are closely related. Cesium may partly replace potassium in plants. As shown in Fig. 3, potassium uptake of grape vines was strongest during the first two of the total four supply periods of the experiment. During the last period the grape vines with a high potassium supply even showed a loss of potassium. However, during the whole experimental time these plants consumed much more potassium than the grape vines with a low supply (Fig. 4).

As a counteraction against the accumulation of radiocesium in plants after fallout high potassium fertilisation was considered. SHAW (1993) concluded, that "... fertiliser-based counter measures are most often

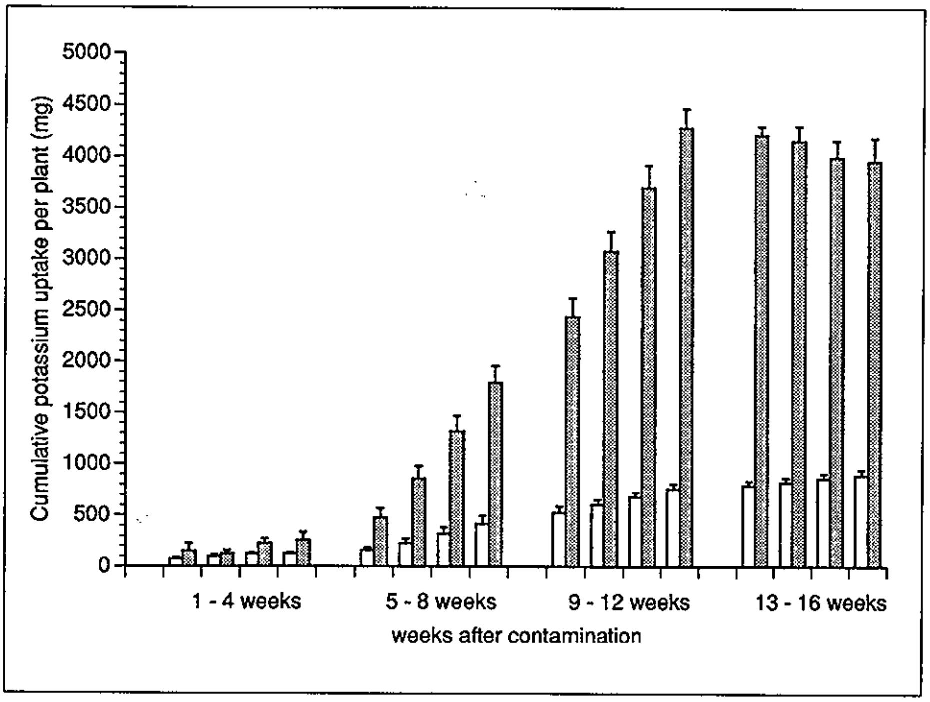

Fig. 4. Cumulative absolute potassium uptake of grape vine plants in hydroculture from the nutrient solution (experiment 1996). Means ± sd of 6 replicates are shown. Nutrient solution was exchanged at 4 week-intervals.
□ low potassium supply (3.4 mM)
▩ high potassium supply (17 mM)
Kumulierte absolute Kaliumaufnahme von Reben in Hydrokultur aus der Nährlösung (Experiment 1996). Mittelwerte und Standardabweichungen von 6 Wiederholungen sind dargestellt. Die Nährlösung wurde in Intervallen von 4 Wochen ausgetauscht.
□ *knappe Kaliumversorgung (3.4 mM)*
▩ *gute Kaliumversorgung (17 mM)*

effective in nutrient poor soils with a low degree of base saturation". This hypothesis was confirmed by the practical experiments of ROBISON and STONE (1992) with coconut palm trees on coral soils at Bikini atoll.

However, from the cited literature it can be inferred that the major path of radiocesium uptake into crops growing on medium textured soils is via the leaves as long the fallout is deposited on the plant. Our experiments with grape vines grown in hydroculture showed that radiocesium taken up by the leaves and transported into other plant organs may be displaced by potassium. As stated before, radiocesium released from the plant into a medium textured soil is adhered to a great extend to clay particles. Since fixed radiocesium is not available for plants and therefore no longer a problem for the human food chain, potassium fertilisation may really be an interesting tool to lower the contamination in plants. In our earlier experiments with grape vines growing in pots a mixture of sandy loam soil and some peat was used (ZEHNDER et al. 1995). The majority of agricultural soils in Switzerland are sandy loam soils. These soils contain usually 120–200 mg ammonium-acetate-soluble potassium per kg dry mass (ANON 1997). In the actual experiments with grape vines growing in nutrient solution, we used 133 and 661 mg potassium per litre respectively. However, although the potassium supply of the plants in one series of these experiments was much higher than with the pot experiments, at the end of the experimental period all grape vines plants showed approximately the same cesium activity (Fig. 5). This study demonstrates that a treatment of vines with high doses of potassium is not really effective in causing a faster decontamination of the plants on the soil used.

The rather small difference in the total radiocesium content after the experiment between plants with low and high potassium supply (Fig. 5) can be explained by the fact that during the entire experiment only 3.5% (low potassium supply) and 12.4% (high potassium supply) were released into the growing medium and most of the activity was retained in the contaminated plants (Fig. 2).

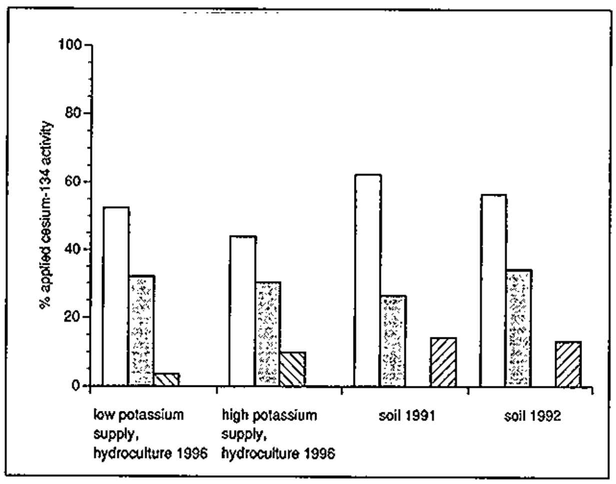

Fig. 5. Influence of potassium supply on cesium-134 activity in grapevine plants, wash solution, nutrient solution and soil 16 weeks after leaf contamination (experiments 1996 in hydroculture and 1991, 1992 in soil). Means of 2 replicates are shown.
□ wash solution ▧ nutrient solution
▩ plant ▨ soil
Einfluss der Kaliumversorgung auf die Cäsium-134-Aktivität in Reben, Waschlösung, Nährlösung und Boden 16 Wochen nach Blattkontamination (Experimente 1996 in Hydrokultur und 1991, 1992 in Boden). Mittelwerte von 2 Wiederholungen sind dargestellt.
□ *Waschlösung* ▧ *Nährlösung*
▩ *Pflanze* ▨ *Boden*

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