Chemically induced phytoextraction of caesium -137

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Abstract
Radiocaesium (^{137}Cs) is one of the important radionuclides from the point of environmental contamination. Phytoextraction, a green technology to remediate the contaminated soils uses plants to accumulate contaminants in the above ground tissue. Monovalent cations such as potassium (K^+) or ammonium (NH_4^+) may enhance the phytoextraction of ^{137}Cs. Potential for chemically induced phytoextraction of a Typic Haplustalf contaminated with radiocaesium was investigated in a pot culture experiment. Bioaccumulation of ^{137}Cs was studied in shoots of four plants viz., amaranthus (*Amaranthus viridis* L.), maize (*Zea mays* L.), cowpea (*Phaseolus vulgaris* L.) and sunflower (*Helianthus annuus* L.) using ammonium chloride as a chemical extractant. The ability for ^{137}Cs extraction from a *Typic Haplustalf* contaminated with ^{137}Cs at 20 Bq/g was in the order of *A. viridis* L. > *Z. mays* L. > P.*vulgaris* L. >*H. annuus* L. Bioaccumulation ratio (BAR) of more than one was recorded for *A. viridis* L. at flowering stage. BAR was increased statistically by the addition of ammonium chloride in all crops. A.*viridis* with ammonium chloride as a chemical extractant could be a viable phytoextractant for a ^{137} Cs contaminated soil.

Key Words
Caesium-137, phytoextraction, bioaccumulation ratio, *Amaranthus viridis*.

Introduction
Contamination of soil with radionuclides is a worldwide problem and of the various radionuclide contaminations, contamination of soil with ^{137}Cs deserves special attention because of its high fission yields, long half-life ($t_{1/2}$ = 30.2 years) and influence on human health (Dushenkov 2003). Current remediation practices are costly and include excavation, shipping and burial of contaminated soil at licensed radioactive waste disposal facilities. These often have adverse effect on biological activity, soil structure and fertility and disturb the ecosystem (Negri and Hibchman 2000). One possible low cost and environment friendly technique is phytoextraction, a process that uses plants to accumulate contaminants in the aboveground tissue. The efficiency of phytoextraction of ^{137}Cs is ultimately a product of simple equation – biomass x element concentration in biomass. Therefore, the important aspect to consider is the choice of plants, which on one hand should not be susceptible to the contaminant but on the other hand should extract the contaminant from the soil to the highest possible extent. BAR of more than one were reported in shoots of grasses (Smolders and Shaw 1995; Lasat *et al.* 1997) grown in hydroponics culture. However, accumulation of caesium from soil into shoots is usually limited and frequently BAR of less than one has been reported for plants grown in radiocaesium contaminated soil (Nisbet and Shaw 1994). A major factor limiting radiocaesium uptake in to roots is its strong retention in clay particles (Cremers *et al.* 1988). Although earlier reports suggest that fixed radiocaesium can be desorbed to some extent by monovalent cations NH_4^+ and to a lesser extent by K^+ (Field *et al.* 1993), the extent of this release was shown to be highly dependent on soil properties (Kirk and Staunton 1989). With this background, the investigation was carried out to study the i) bioaccumulation of ^{137} Cs by selected plant species during different physiological stages and ii) the effect of ammonium chloride application on ^{137} Cs extraction from soil in to shoots. The resulting information will contribute to the selection of suitable plant species and the effect of chemical extractants on phytoextraction of ^{137} Cs in a Typic Haplustalf.

Materials and methods
The soil selected for the study was classified as a Typic Haplustalf with sandy loam texture. The soil has 0.53 % organic carbon, pH (1:2.5 soil: water extract) of 8.45 and an electrical conductivity of 0.26 dS/m.The ammonium acetate extractable potassium content was 1139 kg/ha (Table 1). The experimental soil was filled in ceramic pots which consists of 10 kg of soil and was contaminated with ^{137}Cs @ 20 Bq/ g soil [Caesium - 137 was obtained as carrier free caesium nitrate in dilute nitric acid medium from the Board of Radiation and Isotope Technology (BRIT), Mumbai]. Following ^{137}Cs application, seeds of the test plants, maize (*Zea mays* L.),

sunflower (*Helianthus annuus* L.), cowpea (*Phaseolus vulgaris* L.) and amaranthus (*Amaranthus viridis* L.) were sown. Common cultural practices were followed in raising the crop. To induce chemical extraction, ammonium chloride, identified as the best extractant in the laboratory experiment, was applied at 0.5 M (0.262 g in 10 mL) one week prior to harvest. One more set of pots were maintained without ammonium chloride application. The design of the pot experiment was a two-factorial replicated in three completely randomized blocks.

During flowering stage plant samples were harvested. Fresh weight of shoots was recorded and expressed in g/pot. The weighed samples were dried in an oven at 70° C to a constant weight. From the dry weight recorded the total dry matter yield (g/ pot) was calculated. After processing, the radioactivity of the samples was determined in a Gamma Ray Spectrometer (Type GRS 101P of PLA) by differential counting by keeping the single channel analyzer at optimal settings. Using the radioassay data obtained, the content of ^{137}Cs radionuclide in the plant (Bq/ g), uptake of radionuclide by the plant (Bq/ pot) and Bioaccumulation ratio of ^{137}Cs were worked out.

Results

Biomass production

Caesium -137 phytoextracted from the soil also depends on the shoot biomass. The crops studied registered considerable difference in the biomass yield at flowering stage (Table 1). The greatest amount of biomass was produced by Z.*mays* followed by A.*viridis*. Irrespective of the crops, ammonium chloride addition has a significant positive effect on shoot biomass production.

Caesium -137 content and uptake

Regardless of ammonium chloride application, shoot ^{137}Cs content was highest in A.*viridis* and was significantly superior to other crops (Table 1). Addition of ammonium chloride significantly increased the ^{137} Cs content in shoots of all the plants studied. In A.*viridis* ammonium chloride application increased the ^{137}Cs accumulation in shoots by 16%. *Amaranthus viridis* L. recorded invariably higher ^{137}Cs uptake because of high ^{137}Cs activity even though biomass production was less than maize. The ^{137}Cs uptake values recorded in *A.viridis L* was 983.33 Bq/ pot with addition of ammonium chloride and 570.85 Bq /pot without ammonium chloride addition (Table 1).

Table 1. Shoot biomass yield, ^{137} Cs content, ^{137} Cs uptake and bioaccumulation ratio in crops as influenced by ammonium chloride addition

Parameters	Extractant	Crop			
		Maize	Sunflower	Cowpea	Amaranthus
Biomass yield (g/pot)	+ ammonium chloride	111.82	32.50	24.30	40.35
	- ammonium chloride	106.10	30.70	22.76	35.88
		SEd		CD	
	Crop (c)	2.30		4.60	
	Extractant (e)	1.63		3.25	
	c x e	2.30		4.60	
Cs-137 content (Bq/g)	+ ammonium chloride	1.94	1.69	1.69	24.37
	- ammonium chloride	1.63	1.48	1.64	20.46
		SEd		CD	
	Crop (c)	0.81		1.62	
	Extractant (e)	0.58		1.15	
	c x e	0.36		0.71	
Cs-137 uptake (Bq/pot)	+ ammonium chloride	217.49	54.86	41.07	983.33
	- ammonium chloride	173.37	45.56	37.21	570.85
		SEd		CD	
	Crop (c)	34.11		58.15	
	Extractant (e)	24.12		48.19	
	c x e	48.25		96.38	
BAR	+ ammonium chloride	0.10	0.08	0.09	1.42
	- ammonium chloride	0.08	0.07	0.08	0.80
		SEd		CD	
	Crop (c)	0.010		0.020	
	Extractant (e)	0.007		0.014	
	c x e	0.015		0.030	

Bioaccumulation Ratio (BAR) of Caesium -137

The ^{137}Cs BAR was significantly higher for A. *viridis* L. (1.42) than for *Z. mays* L. (0.10), *P. vulgaris* L. (0.09) and *H.annuus* L. (0.09) (Table 1). Though ammonium chloride application increased BAR in all the crops in *A.viridis* it was highly significant with an increase of 77.5 % over control (no ammonium chloride).

Discussion

Careful species selection that increase the bioavailability of ^{137}Cs could greatly enhance the prospects for the use of plants to remediate ^{137}Cs contaminated soil. Broadly and Willey (1997) found maximum 30 fold differences in ^{134} Cs concentration between a total of 30 plant taxa grown on one soil. In this investigation also significant variation was observed among the plant species studied. Greatest ^{137}Cs accumulation occurred in shoots of *A.viridsi* L. which recorded 14 fold increases in ^{137}Cs concentration over H.*annuus* L. and P.*vulgaris* L. Application of ammonium salts to contaminated soil might have decreased the ^{137}Cs sorption capacity of the soil and thereby increased the ^{137}Cs bioavailability, and subsequently its accumulation in plants. When ammonium salts are added to the soil, they dissociate in the soil solution to positively charged ions and negatively charged anions. The cationic components can exchange ^{137}Cs from sorption sits in soil. This is in line with the findings of Lasat *et al.* 1997 and Blaylock and Huang 2000.

Uptake of a particular radionuclide depends on plant species and physiology of the plant. In this study *A. viridis* L. is an effective accumulator of ^{137}Cs which is characterized by high degree of uptake of ^{137}Cs. Since crops differ with regard to their physiological and metabolic characteristics they vary in their ability with regard to uptake, accumulation and translocation of ^{137}Cs. Different BAR can result from differences in rooting pattern, rooting depth, absorption characteristics of the root surface, root turn over, root growth rate etc., *A. viridis* L. recorded the highest BAR of 1.42 with addition of ammonium chloride. Lasat *et al.* (1998) also recorded significantly higher BAR for *A. retroflexes* grown in a coarse loamy soil. The effect of NH_4^+ on ^{137}Cs bioaccumulation was caused by increased radiocaesium bioavailability in the soil following NH_4^+ application. Results obtained from this study suggest that phytoextraction of ^{137}Cs contaminated soil is feasible and *A.viridis* L. seems to be one of the promising crops. Selection of a chemical extractant such as ammonium chloride (0.5 M) that can increase the bioavailability of ^{137}Cs will help in efficient phytoextraction of ^{137}Cs contaminated soil.

References

Blaylock MJ, Huang, JW (2000) Phytoextraction of metals. In 'Phytoremediation of toxic metals'. (Eds J Raskin, BD Ensley) pp. 71-88 (Wiley: New York).

Broadley MR, Willey NJ (1997) Differences in root uptake of radiocaesium by 30 plant taxa. *Environmental Pollution* **97**, 11–15.

Cremers A, Elsen A, De Preter P, Maes A (1988) Quantitative analysis of radiocaesium retention in soils. *Nature* **335**, 247-249.

Dushenkov S (2003) Trends in phytoremediation of radionuclides. *Plant and Soil* **249**, 167–175.

Field JG, Belden RD, Serne RJ, Mattigod SV, Freeman HD, Scheck RW, Goller ED (1993) 100 area Hanford soil washing treatability tests. 'Meeting the Challenge' In 'Environmental Remediation Conference, October 24–28, Augusta, Georgia. 1, 377–381'. (US Dept of Energy, Office of Environmental Restoration: Washington, DC).

Kirk GJ, Staunton S (1989) On predicting the fate of radioactive caesium in soil beneath grassland. *Journal of Soil Science* **40**, 71–84.

Lasat MM, Fuhrmann ME, Kochian C (1998) Phytoremediation of a radiocaesium – contaminated soil. Evaluation of Cesium -137 bioacumulation in the shoots of three plant species. *Journal of Environmental Quality* **27**, 165-169.

Lasat MM, Norvell WA, Kochian C (1997) Potential for phytoextraction of ^{137}Cs from a contaminated soil. *Plant and Soil* **195**, 99-106.

Negri MC, Hibchman RR (2000) The use of plants for the treatment of radionuclides. In 'Phytoremediation of toxic metals'. (Eds I Raskin, BD Ensley) pp. 107-132. (Wiley: New York).

Nisbet AF, Shaw S (1994) Summary of five year lysimeter study on the time dependant transfer of ^{137}Cs, ^{90}Sr, ^{239,240} Pu and ^{241} Am to crops from three contrasting soil types. 1. Transfer to the edible portion. *Journal of Environmental Radioactivity* **23**, 1-17.

Smolders E, Shaw G (1995) Changes in radiocaesium uptake and distribution in wheat during plant development: a solution culture study. *Plant and Soil* **176**, 1-6.