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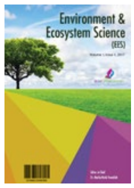

Accumulation and Tolerance of Radiocesium in Plants and its Impact on the Environment

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ABSTRACT

Cesium 133Cs natural concentration is low and not toxic. It acts as short term pollutant in air but in soil it has long persistence. Plant uptake being the pathway of entrance of Cesium in biosphere. Two major radioisotopes of Cesium that proved to be pollutants are Cs 137 & Cs 134 they emit β and γ radiation. Those radiation enters terrestrial environment through nuclear testing and accidental or legalized discharge of nuclear waste from nuclear reactors. However it has been evaluated that concentration of uptake determines its hazard potential to plants. Details are presented in present chapter about its percolation, factors effecting its uptake and impacts on the plants. Radiocesium has a long term radiological impact on the environment as this radionuclide is readily transferred to human through food chain. Plant uptake is the major contributor in this shift. In the current chapter factors involve in translocation of radiocesium in environment has been reviewed. Plants significant in phyto remediation of radiocesium from environment has been assessed. Radiocesium phytoremediation was found too slow in restoration activity. In accidental situation fast growing Cs accumulating plants are required whereas at small or domestic scale traditional counter measures like crop varieties that do not uptake Cs should be used to block or restrict entry into food chain. however the limitation found in this is the slow uptake and accumulation of radioactive biomass at the end.

1. INTRODUCTION

Cesium (Cs) is one of the most hazardous contaminant on earth (Mosquera et al., 2006). Natural concentration of cesium 133Cs in soil is low and nontoxic to plants. Cesium isotope exist in nature as aluminosilicate minerals pollucite where its concentration reaches to 25µg/gm, it has high solubility in water. Two of the radioisotopes of cesium (Cs 137 & Cs 134) are of environmental concerns they emit β and γ radiation. Major route of radiocesium circulation in terrestrial environment has been through nuclear testing and accidental or legalized discharge from nuclear reactors (Middleton et al., 1960). Nuclear fission and major incident of these nuclide release has been Chernobyl accident in April 1986 (Bystrzejewska-Piotrowska and Urban, 2004). This critical nuclide impacts the long time health, social, psychological and economic factors (Berreck and Haselwandter, 2001).

Cs137 has long physical half life its sink in environment is of 30.17 years (Bystrzejewska-Piotrowska and Urban, 2004). In air it is categorize as short term air pollutant but in soil it persist for long time. Plant uptakes from biotic and non biotic environment serve as major pathway for entrance of Radiocesium in biosphere. (Zhu and Smolders, 2000). However there extent of contamination to food chains is dependent on its uptake and concentration in plants (Broadley and Willey, 1997). Research on cesium dates back to 4th decade of 19th century (Collander, 1941). Initially studies were focused on differences among plants in nutrient uptake for eg. K+. Radiocesium deposition during nuclear weapon testing in 5th and 6th decades excel research focus on mechanism of radiocesium transfer to plants through soil or air. Such researches further attracted attention after Chernobyl Nuclear incident (1986). Radiocesium percolation in food chains and transfer factors has been investigated by various scientists. They address this issue at different angles at different times (Berreck and Haselwandter, 2001, Broadley and Willey, 1997, Bystrzejewska-Piotrowska and Urban, 2004, Chakraborty et al., 2007, Entry et al., 1993, Fuhrmann et al., 2002, Mascanzoni, 1990, Mosquera et al., 2006, Paasikallio et al., 1994, Van Bergeijk et al., 1992, Zhu and Smolders, 2000, Lasat et al., 1998, Livens et al., 1991, Massas et al., 2002).
Soil pollution with Radiocesium has been still an unsolved issue in world, Knowledge on mechanism of uptake, accumulation will be important for devising strategies to reduce its exposure to environment and propose restoration measures. Present manuscript is focused on:

- Accumulation and Tolerance of Radiocesium in plants
- Impact of Radiocesium on the Environment
- Bioremediation of Radiocesium

Interaction between plants and radiocesium is crucial because when cesium is absorbed by roots and taken up by the shoots, it enters into food chain via herbivores thus enhancing the dose radiation. Furthermore, roots growing in nuclear waste disposed site may invade in the radioactive contents of those radioactive materials and move up them to soil surface in transpiration stream. (Sanford et al., 1998). This ability of taking up is also termed as transpiration factor expressed as:

Transpiration factor =

Cesium uptake by plants has been the point of interest since 1940s (Collander, 1941). It was until 1960 no further research was done on mechanism and factor effecting cesium uptake was studied (Middleton, 1960). Caesium (Cs) being weak hydrate alkali metal, it exist as free hydrated cation (Cs+) in solution and show tendency to form complexes, translocated from this solution to above ground parts of plants by roots. Role of different biotic and abiotic factors supporting cesium 137 uptake is important because the pervasive occurrence of this isotope in the biosphere effects it's continued intake by man (Scotti and Carini, 2000). Radiocesium particles can enter in plants either from soil via roots or by air through foliar deposition. Soil plays vital role in this respect. Gerzabek et al. (1998) explained the correlation of cesium uptake with the soil. Previous researches indicate the characteristics of soils like pH, soil texture like clay contents, K concentration and its status, etc. determine cesium uptake from soil to plants.
Bange and Overstreet (1960) & Epstein and Hagen (1952) believe that qualitatively cesium behaves similar to potassium in root uptake while Collander (1941) believe they show same behavior in whole plant. Till 1960's there was no experiment performed that helps in determining their simultaneous rate determination (Middleton et al., 1960). Cs+ shows chemical similarity with potassium (K) (Rich, 1968), therefore exchangeable K concentration in soil is considered to be one of the key soil parameters that control cesium availability to plant roots (Vandenhove et al., 2003, Roca and Vallejo, 1995). Because of chemical similarity with potassium, cesium availability for root uptake via soil solution is low (Kanyar et al., 1990, Kuhn et al., 1984, Haak, 1985).

Enzyme proteins that bind Cs+ in a cell are those with the specific affinity for K+ (Dragović et al., 2004). (Myttenaere et al. (1993)) also predicted the relation of K and radiocesium in the forest ecosystem for determining Radiocesium concentrations in forests. Physiological studies on higher plants confirms that K+ and Cs+ competition for influx suggests that the influx same mechanism is operating these cations. White and Broadley (2000) for instance in Nitella flexilis uptake and accumulation of Cs137 takes place in cells capable of Cation-exchange and they use potassium channel for this purpose (Demidchik et al., 2001). Relative uptake of Potassium and Cesium by Barley excised roots and whole can be calculated by ratio proposed by Middleton et al. (1960) i.e.:

The relative uptake of K42 and Cs137 by excised roots and intact shoots were measures by formula given above. In case of roots when external concentration of potassium was kept 1.0 meq/liter, the OR was between 0.15-0.25. When concentration increased to 10 meq / liter, the OR falls to 0.4 showing lower selectivity for K+ at this level. A visible effect of K42 concentration on the ratio was noticed in the case of root- shoot transfer. When concentration of K42 was 0.1 meq/liter, it was taken up at 10 to 20 times more speed compared to cesium but when concentration increased to 10 meq / liter, K42 transfer rate doubles the rate of cesium (O.R. = 0.5). Their proportions were varied over larger ratios. When the rate of potassium uptake was low or when water movement was restricted, the O.R. in the shoots was greater than 1, showing high transfer of Cs137. In the experiments described above, except under limited circumstances, barley plants absorbed K42 to a greater extent than Cs137, relative to the external solution concentration.

Impact of Ammonium ions in Cs uptake is not significant. Shaw (1993) compared impact of Ammonium and Potassium ion on Cs uptake and found that K impose more prominent role than Ammonium. Smolders, Sweeck, Merckx, and Cremers (1997a) also did not found any correlation between transfer factors (TF) of Cs137 in spinach plants grown in K & NH4 concentrations. Only Roca et al. (1997) postulated dependence of Cesium uptake on K and NH4 absorption. Heavy metals do not show any impact on the Radionuclide's cesium uptake when applied to aubergine plants (Scotti and Carini, 2000)

Ca-Mg ratios also plays vital role in uptake of Cs from soil only for short time. An experiment performed on spinach with increased Ca-Mg solution, reduced the Cs uptake, cation exchange complex enhance the soil pH thus increasing the charge on clay minerals hence increasing Cs sorption (Wauters et al., 1994). However this loamy sand and soil does not show significant impact on grasses absorption capabilities (Campbell and Davies, 1997).

Several factors like Physical and chemical form of element, environmental conditions, and certain plant species also plays vital role in foliar absorption of radiocesium (Oestling et al., 1989).

2.0 ENVIRONMENTAL IMPACTS OF RADIOCESIUM

Soil contamination has been exclusive terrestrial environment contamination cases as this amplifies through food chains into human being (Table 1.1). The first reaction of plants under influence of such 137Cs + 133Cs concentrations was closing of stomata and decrease in transpiration processes, as well as decreasing hydration level in plant tissues (Bystrzejewska-Piotrowska et al., 2004, Bystrzejewska-Piotrowska and Nowacka, 2004).

1. Solution of Cesium chloride induces strong osmotic stress over the plants even millimolar (mM) concentration of Cesium decrease growth, stomatal conductance and transpiration. Longer osmotic stress decreases biomass by stressing photosynthetic carbon reduction cycle. (Urban and Bystrzejewska-Piotrowska, 2003)
2. Radionuclide of Cesium (3–4 mM conc. solutions) disturb tissue hydration by reducing water uptake (Urban and Bystrzejewska-Piotrowska, 2003).
3. Cesium concentrations of 2–4 mM causes osmotic stress in Arabidopsis (Zhu and Smolders, 2000).
4. Cesium concentrations of 4 mM disturb biomass accumulation as dry weight decreased down. (Urban and Bystrzejewska-Piotrowska, 2003)
5. Higher radiocesium concentrations (6–10 mM) did not further decrease biomass production. (Urban and Bystrzejewska-Piotrowska, 2003)
6. Cesium concentrations of 0.2–4 mM decrease dry weight in beans. (Cline and Hungate, 1960).

Table 1.1. Different concentration of CS 137 and their impact on the in plants.

Concentration of Cs137 in shoot or root	Impacts on Plants
6–10 mM	Decrease biomass production.
4 mM	Disturbed accumulation of biomass
3–4 mM	Disturb water uptake and tissue hydration
2–4 mM	Osmotic stress in *Arabidopsis*
0.3 mM	Impact growth and metabolism in plants like Zea mays, Onion, Lepidium and Barlwy and Zea mays
0.2 mM	Decrease in dry weight

1. At concentration of 0.3 mM growth and metabolism in plants like Zea mays, Onion, Lepidium and Barlwy and Zea mays. (Bystrzejewska-Piotrowska et al., 2004, Bystrzejewska-Piotrowska and Nowacka, 2004)
2. At above 200mM concentration excessive cesium could inhibit the growth of plants like bean, tomato, Arabidopsis, and rice (Cline and Hungate, 1960)
3. TAKANO et al. (2012) performed preliminary survey in zone around Fukushima Daiichi Nuclear Power Plant to check the radionucesium contamination levels in trees exposed to radiation emitted by March 2011 accident. Their rough estimation showed the internal exposure dose rate received by the cone was estimated to be 15 µGy/h, that appears sufficiently high to be within the range of the criteria dose rate of 4-40 µGy/h as proposed by ICRP4 "derived consideration reference level" for Pines. They proposed the probability for certain deleterious effects that could result in reducing reproduction, and highlights the necessity for further analysis of cytogenetic and reproductive changes in plants in the most contaminated forest area, Garnier-Laplace et al. (2011) also gave this suggestion.
4. Potassium (K) being the essential macronutrient, required at concentrations of 100-150 mM by the plant cells to stabilize protein, enzymes, and stabilize nucleotide structure (Leigh and Wyn Jones, 1984; Marschner, 1995).it inhibits the potassium channels in the cells plasma membranes ((White and Broadley, 2000). Cs+ competes with K+ for binding sites in enzymatic proteins and inhibit its activities (Avery, 1995).
5. At above 200mM concentration excessive cesium could inhibit the growth of plants like bean, tomato, Arabidopsis, and rice(Cline and Hungate, 1960)
6. Radiocesium shows the chemical similarity with calcium therefore it can easily slip in human bones and impact the tissues by irradiations and results in causing Sarcoma and leukemia (Chen, 1997).

3.0 BIOREMEDIATION OF CS FROM SOIL

Cs 137 is absorbed by plants in enormous amount and stored in different plant parts. Various scientist identified plants responsible for accumulating cesium (Wauters et al., 1994, Waegeneers et al., 2001, Strandberg, 1994, Oestling et al., 1989, Middleton, 1960, Lasat et al., 1998, Evans and Dekker, 1968a, Dushenkov, 2003, Chakraborty et al., 2007, Campbell and Davies, 1997). Bioaccumulation of radionuclides by using biological agents has been extensively experimented, there has been growing interest and awareness on bioremediation (Watt et al., 2002). It's an alternative for restoring radiocesium contaminated sites (Dushenkov et al., 1999). After pilot projects in US and Ukraine USA (Lasat et al., 1998, Dushenkov, 2003) although no hyper accumulating species are identified yet. Several experiments were performed to search for radiocesium bio accumulating crop.

Ocimum basilicum seeds show considerable adsorption of Cs137 & Sr90. When used as biosorbants, its seeds act as exo polysaccharides to absorb the Cs137 & Sr90 and serve as natural immobilized base. Mucilaginous seeds were used in the study. Mucilagenous fibers structure was found to be responsible for uptake. Water imbibed seeds shows higher adsorption of both Cs137 and Sr90 as compared to seeds pretreated with HCl, NaOH and Na-periodate solution. The uptake was pH dependent while some divalent metal ions had no impact. Alkali metal ions Na+, Li+, and K+ decreased the uptake (Chakraborty et al., 2007).

Sunflower, cucumber, radish and soybean were studied for Cesium uptake in presence of three different rates of Ca (OH)2. At higher concentration the Cs uptake reduced to 6 folds and soybean to 1.6 fold in sunflower. Simultaneously the K concentration also reduced down. It was found out that the soil liming has significant impact on Cs uptake. As by increasing concentration of Calcium enhance immobilization of Cs hence lowering its availability for plants uptake. (Massas et al., 2010)

Onion is supposed to be a good accumulator of Radiocesium its Transfer Factor is 2.87 (KBq/Kg Dry Weight of plant)/(kBq/kg Dry Weight of soil) ((Urban and Bystrzejewska-Piotrowska, 2003) as compared with other plants that are supposed to be having less TF i.e. (Mollah et al., 1998) below 1 sometimes. Therefore onion has been proposed as good phytoremediator in case of radiocesium.Urban and Bystrzejewska-Piotrowska (2003).
Heather (only member of Ericaceae) being a important bee flora and herbivore food was investigated to check its radiocesium concentration and it was found that in acidic soil it shows absorption of radiocesium from soil (Bystrzejewska-Piotrowska And Urban, 2003, Waegeneers Et Al., 2001, Strandberg, 1994). Clint and Dighton (1992) identified Heather as a potential bioaccumulation of radiocesium because of its mycorrhizal association, he observed shoot: root ratio was higher in mycorrhizal plants as compare to non mycorrhizal flora i.e. with increase of 5 to 500 μM of radiocesium in soil, its uptake increases to 35-96 fold.

Plants from thirty different plant species and families were tested to check their efficiency for cesium uptake. Broadley and Willey (1997) observed difference of 20 folds between Koeleria and Chenopodium. Chenopodiaceae taxa shows highest cesium uptake as compared to grasses. Mushroom also shows high bioaccumulation potential (Mietelski et al., 1994, Rühm et al., 1999).

Sometimes soil condition plays vital role in determining plant efficiency for cesium uptake like there was a difference of 28 folds among 44 agricultural crops (beans, cabbage, rape, sunflower etc.) (Andersen, 1967) and 22 folds and 38 folds differences were observed among six and 35 aricultural crops include cereals, forage and vegetable crops. ((Evans and Dekker (1968b), Skarlou et al., 1996, Evans and Dekker, 1968a)

4.0 CONCLUSION

In plants minerals uptake is the mechanism for Cesium transport in biosphere. Cs 137 & Cs 134 are two main radioisotopes of cesium that that emit β and γ radiations. These radiations can enter into terrestrial environment through artificial discharges such as nuclear testing, nuclear wastes and accidental discharge. This has been proved experimentally that the concentration of uptake determines cesium hazard potential to plants. Therefore plants can play a significant role in phytoremediation of radiocesium from environment. However phytoremediation process is consider to be very slow in restoration activity. In any hazard situation hyper accumulator, rapid growing fast plants are required for radiocesium whereas crop varieties that do not uptake radiocesium should be used to block or restrict entry into food chain at small scale or domestic levels.

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