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Transfer factors of radionuclides ^{137}Cs and ^{65}Zn from soil to pearlmillet and sorghum

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The soil to plant transfer factors (TF) of ^{137}Cs and ^{65}Zn were determined for two crops, sorghum and pearlmillet, under irrigated conditions in greenhouse and under rainfed conditions in field. In the greenhouse experiment, the accumulation of ^{137}Cs was almost doubled when the soil contamination level was doubled. Under field conditions, ^{137}Cs concentration in both pearlmillet and sorghum grains as well as straw was nearly four times more at 148 kBq kg^{-1} level of soil contamination as compared to lower level of 74 kBq kg^{-1} soil. The TF values for ^{65}Zn determined under greenhouse conditions for both the crops were nearly a hundred-fold higher as compared to ^{137}Cs.

AFTER the Chernobyl nuclear station accident in 1986, worldwide concern has grown to evaluate the dose of radiation which may affect man. The *Handbook of Parameter Values* for prediction of radionuclide transfer in the ecosystems published by the International Atomic Energy Agency[1] is based on data entirely for crops, animals and conditions found in temperate climate zones. Very few data are available for radionuclide transfer and uptake in tropical and subtropical ecosystems. In the published literature, data for the uptake of radionuclides from soil for tropical cereals, fruits, herbs, tea and root crops are few in numbers and primarily limited to Cs. Although more data are available for rice, due to the complicated nature of production and the number of varieties, the data are not consistent. Currently it is assumed that transfers to animal and man are similar to those in temperate environments. Whilst this assumption is probably not unreasonable, it has never been validated.

Keeping these points in view, a study has been initiated to assess the transfer of ^{137}Cs and ^{65}Zn from soil artificially contaminated with these radionuclides to pearlmillet and sorghum under rainfed conditions in field and under irrigated conditions in pot culture.

The field experiment was conducted in the Gamma Garden of the Indian Agricultural Research Institute research farm in 1994 kharif season. In field experiments in the main yield plots of 9 m^2 (3 m × 3 m), microplots of 1 m^2 (1 m × 1 m) were made and contaminated with 74 kBq kg^{-1} soil (2 μCi kg^{-1} soil) and 148 kBq kg^{-1} soil (4 μCi kg^{-1} soil) with ^{137}Cs. The entire upper 5 cm soil of the microplots (75–80 kg) was dug out and sprayed with the 500 ml solution of radionuclide containing the required amount of activity. The radionuclides were mixed thoroughly with the entire soil and the soil was then transferred back to the microplots and brought to 50% water saturation level to a depth of 20 cm. Radionuclides were allowed to equilibrate in soil for eight weeks and during this period the soil was kept between 35 and 50 per cent moisture saturation.

After equilibration period, pearlmillet variety M-179 and sorghum variety PC-121 were grown with a row-to-row spacing of 40 cm and plant-to-plant spacing of 20 cm. The crops were fertilized with 80 kg N ha^{-1} through urea applied in two splits, 40 kg P_2O_5 ha^{-1} through single superphosphate and 40 kg K_2O ha^{-1} through muriate of potash applied as basal.

As maturity, the plants were harvested and separated into grain and straw. In grain and straw samples from microplots, ^{137}Cs activity was measured using a 3″ × 3″ NaI (Tl) flat type detector for ^{137}Cs, 0.661 MeV peak as per the procedures given in the IAEA Technical Report[2]. The soil samples were also drawn from microplots to a depth of 20 cm. Though the upper 5 cm soil was contaminated with radionuclide, the soil samples were collected to a depth of 20 cm from six locations in each microplots with a Viehmeyer tube and pooled to a composite sample as per the procedure described in IAEA Technical Report[2]. The soil samples were air dried, ground in a wooden pestle mortar and counted in a well type NaI (Tl) detector (2.5″ × 2.5″). The counting efficiency for ^{137}Cs was 0.881% for flat type detector and 11.82% for the well type detector.

A similar experiment was conducted under pot culture conditions in the same soil. Eight kg soil was taken in ceramic pots and contaminated with ^{137}Cs and ^{65}Zn at the rate of 148 kBq kg^{-1} soil and 296 kBq kg^{-1} soil, respectively. In equilibrated soils, four seeds of pearlmillet or sorghum were sown and on germination the plants were thinned to two in each pot. Here the results on transfer factors of ^{137}Cs under both field and pot culture conditions and of ^{65}Zn in pot culture condition are presented. The data on soil to plant transfer factors of the radionuclides were computed as ratios of (Bq kg^{-1} dry-matter or grain)/(Bq kg^{-1} dry soil).

In the greenhouse experiment, the pearlmillet and sorghum plants were harvested at maturity and separated into grain and straw. The grain and straw yields of pearlmillet were 9.34 ± 1.75 and 22.46 ± 2.33 g/pot, respectively. The similar figures for sorghum were 11.27 ± 1.38 and 27.62 ± 3.45 g/pot, respectively. The data for ^{135}Cs transfer factors presented in Table 1, revealed that under greenhouse conditions at lower level of soil contamination with ^{137}Cs (148 kBq kg^{-1} soil) it was 6.01×10^{-3} and 11.80×10^{-3} in pearlmillet grain and straw respectively. At higher level of soil contamination (296 kBq kg^{-1} soil), the transfer factors were much less both in grain and straw, the values being 4.49×10^{-3} and 6.38×10^{-3}, respectively. The transfer factor values for sorghum grain were 4.52×10^{-3} and 5.80×10^{-3} respectively, and for sorghum straw, 12.52×10^{-3} and 8.98×10^{-3} respectively at single or double levels of soil contamination with ^{137}Cs. Gerzabek *et al.*[3] have reported from two field studies at two sites contaminated by Chernobyl fallout, the transfer factor values for potato tuber of 1.7×10^{-3} and for wheat straw 0.7×10^{-2}. McCee *et al.*[4] calculated the plant soil concentration ratio, transfer factor and plant–plant ratios from fallout ^{137}Cs data of soil and plants and found that the greatest spread was associated with plant soil transfer factors. In absolute terms, however, the accumulation of ^{137}Cs in pearlmillet and sorghum grains (Bq kg^{-1} grain) almost doubled when the soil contamination level was doubled.

Table 1. Transfer factor of ^{137}Cs in pearlmillet and sorghum grain and straw under pot and field conditions

Soil contamination level (kBq kg^{-1})		Plant contamination (Bq kg^{-1})	Transfer factor (×10^3)
	Pearlmillet (Pot experiment)		
145.8 ± 1.43	Grain	877 ± 188	6.01 ± 1.24
	Straw	1723 ± 331	11.80 ± 2.17
293.6 ± 1.20	Grain	1318 ± 133	4.49 ± 0.47
	Straw	1874 ± 60	6.38 ± 0.22
	Sorghum (Pot experiment)		
146.3 ± 0.33	Grain	662 ± 23	4.52 ± 0.15
	Straw	1832 ± 56	12.52 ± 0.40
295.3 ± 0.43	Grain	1714 ± 580	5.80 ± 1.96
	Straw	2651 ± 659	8.98 ± 2.22
	Pearlmillet (Field experiment)		
18.48 ± 0.09	Grain	39.7 ± 8.7	2.15 ± 0.48
	Straw	61.0 ± 9.6	3.31 ± 0.49
36.74 ± 0.10	Grain	163.3 ± 5.1	4.45 ± 0.13
	Straw	312.3 ± 33.3	8.49 ± 0.90
	Sorghum (Field experiment)		
18.31 ± 0.07	Grain	36.7 ± 14.7	2.01 ± 0.81
	Straw	74.7 ± 12.1	4.09 ± 0.67
36.84 ± 0.22	Grain	226.3 ± 11.4	6.13 ± 0.28
	Straw	255.0 ± 11.1	6.91 ± 0.27

Table 2. Transfer factor of ^{65}Zn in pearlmillet and sorghum grain and straw under pot culture conditions

Soil contamination level (kBq kg^{-1})		Plant contamination (kBq kg^{-1})	Transfer factor (×10^1)
	Pearlmillet		
145.5 ± 2.98	Grain	101.0 ± 22.3	6.96 ± 1.63
	Straw	56.8 ± 8.5	3.91 ± 0.61
293.6 ± 1.21	Grain	95.2 ± 15.3	3.24 ± 0.52
	Straw	87.3 ± 9.0	2.97 ± 0.30
	Sorghum		
146.3 ± 0.33	Grain	63.5 ± 0.7	4.34 ± 0.05
	Straw	82.8 ± 2.2	5.66 ± 0.16
295.3 ± 0.44	Grain	117.7 ± 1.3	3.98 ± 0.03
	Straw	150.5 ± 10.3	5.10 ± 0.35

In the field experiment, the grain yields of pearlmillet and sorghum were 24.14 ± 0.99, and 22.44 ± 1.08 and straw yields were 73.67 ± 3.37 and 89.42 ± 4.24 q/ha, respectively. Under field conditions the transfer of ^{137}Cs from soil to pearlmillet grain was 2.15×10^{-3} and 4.45×10^{-3} at lower level (74 kBq kg^{-1} soil) and higher level (148 kBq kg^{-1} soil) of ^{137}Cs contamination of soil, respectively. In sorghum grain the transfer factor of ^{137}Cs was 2.01×10^{-3} and 6.13×10^{-3} at lower and higher levels of soil contamination. Similar trend was observed in both pearlmillet and sorghum straw. However in absolute figures (Bq kg^{-1} dry matter), the ^{137}Cs concentration in both pearlmillet and sorghum grain as well as straw was nearly four to six times more at higher level of soil contamination (148 kBq kg^{-1} soil) compared to that at lower level of 74 kBq kg^{-1} soil.

The transfer factor values of ^{65}Zn determined under greenhouse conditions and presented in Table 2, were found nearly a hundred fold higher than compared to ^{137}Cs for both pearlmillet and sorghum. As an example, at lower level of soil contamination with ^{65}Zn (148 kBq kg^{-1} soil or 4 μCi kg^{-1} soil), it was 6.96×10^{-1} for pearlmillet grain and 4.34×10^{-1} for sorghum grain respectively. The probable reason for higher transfer factor for ^{65}Zn observed is that, zinc being an essential plant nutrient is absorbed by plant roots in large amount and translocated to above ground portions, while ^{137}Cs enters the plant system along with potassium. A similar trend is also reported earlier for rice crop by D'Souza and Mistry[5]. However, the transfer factors for ^{137}Cs and ^{65}Zn reported here are lower than for rice crop under field capacity moisture regime, probably due to the differences in soil properties of tropical laterite, black and alluvial soils. Further, in absolute amounts, the ^{65}Zn concentration was higher in pearlmillet grain than in straw portion, whereas in sorghum it was otherwise, more in straw than in grain. It has been reported by Tulin *et al.*[6] from a study in soils contaminated due to Chernobyl accident that the increasing levels of potassium fertilization reduce the absorption of ^{137}Cs from soil by oats. Similar observations were reported by Orlovius and Sattler[7]. Although in the present investigation the crop was fertilized with 40 kg K_2O ha^{-1} and has illite as the dominating clay mineral, the contamination level did not show a decline in soil to plant transfer of ^{137}Cs in both pearlmillet and sorghum.

The results reported here indicate that release of considerable amounts of radionuclides from nuclear facilities resulting in contamination of soils, may find their way into crops in the tropical regions and eventually into the food chain of man.

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Stylar length variation in *Caesalpinia pulcherrima* (Caesalpiniaceae) – Basic patterns

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Caesalpinia pulcherrima **(Caesalpiniaceae) produces four categories of morphologically distinguishable flowers within the same inflorescence, viz. flowers with long, medium, short and rudimentary styles. The stylar length variation within an inflorescence was found to be discontinuous. The long-styled flowers were functionally hermaphroditic and are produced towards the basal region of inflorescences whereas medium, short and rudimentary styled flowers were essentially males and are produced towards top region. The adaptive significance of this variation has been discussed in the light of stochastic events of resource availability and plant–pollinator interaction.**

STYLE lengths of flowers borne on different individuals vary notably among species exhibiting di and tri-stylous condition[1,2]. Among andromonoecious species, male plants bear flowers with rudimentary styles while flowers of hermaphrodite plants possess normal styles[3–5]. However, among angiosperms, perfect flowers borne on a plant or even within an inflorescence also exhibit subtle differences in floral morphology and/or function. For instance, flowers of *Callonia grandiflora* (Polemoniaceae) exhibit intra-individual differences with respect to style length, pollen tube growth rate and morphology of stigmatic papillae[6]. Cruden and Hermann-Parker[7] have shown that *Caesalpinia pulcherrima* produces two types of flowers within an inflorescence: hermaphroditic flowers with abundant nectar and normal style; male flowers with rudimentary style and poor nectar.

Of late, floral variations within an inflorescence have been viewed as a result of dynamic interaction among plants and their pollinators. In a recent study Ganeshaiah *et al.*[8] have shown that figs guard their flowers against depredation from agonid wasps by varying the stylar length among flowers within a synconium. Stochastic events of fruit set and availability of resources to developing young buds within an inflorescence may also determine the extent of variation in floral features. Hence intra-inflorescence variation in floral features may be more common in flowering plants and might also represent an important mechanism to increase pollination efficiency. However, studies documenting such variations are scanty.

We have attempted to assess variation in stylar length within inflorescences in *Caesalpinia pulcherrima* (Cesalpiniaceae), its association with floral functioning and also the possible adaptive significance of such variations.

The experiment was undertaken at College of Agriculture, Raichur (16°15'N, 77°20'E; 389 m above MSL), Karnataka, India.

Caesalpinia pulcherrima (Caesalpiniaceae) is a perennial woody shrub of Indo-Malayan origin[9]. Plants bear either bright red or yellow flowers throughout the year. The flowers exhibit psychophilic syndrome and hence are pollinated by butterflies and moths[7]. In *Caesalpinia*, the inflorescence is a compound raceme with primary, secondary, tertiary and quaternary inflorescences emerging from a common axis and blooming occurs in