FLUORIDE ACCUMULATION IN PADDY (*ORYZA SATIVA*) IRRIGATED WITH FLUORIDE-CONTAMINATED GROUNDWATER IN AN ENDEMIC AREA OF THE BIRBHUM DISTRICT, WEST BENGAL

Srimanta Gupta,[a] Sudipta Banerjee[a]

Burdwan, India

SUMMARY: Substantial accumulation of fluoride (F) was observed in different parts of paddy (rice, O*ryza sativa*) irrigated with F-contaminated groundwater (0.62–4.06 mg/L) grown in soil containing 1.45–3.80 mg water-extractable (F_{H_2O}) and 140–144 mg total (F_{TOTAL}) F/kg dry wt. Statistically significant correlations ($p<0.05$ and 0.01) were found in the irrigation water between F, TH, Mg^{2+}, and Na^{+}. The mean F_{H_2O} and F_{TOTAL} accumulation (mg/kg dry wt) in paddy decreased in the order: root (F_{H_2O} 6.28, F_{TOTAL} 80.83) > leaf (F_{H_2O} 5.88, F_{TOTAL} 50.30) > stem (F_{H_2O} 3.26, F_{TOTAL} 19.57) > seeds (F_{H_2O} 2.88, F_{TOTAL} 12.31). The transfer factor (TF) with respect to water-extractable soil F and in different parts of paddy also showed a high translocation pattern similar to the accumulation pattern.

Keywords: Birbhum District, West Bengal; F-contaminated irrigation water; Fluoride accumulation in paddy; Rice (*Oryza sativa*); Soil fluoride; Transfer factor.

INTRODUCTION

Elevated concentrations of fluoride (F) in groundwater are responsible for serious health problem in various parts of the world.[1-4] Several states in India have alarming levels of F in many of their groundwaters.[5-8] Although most F accumulation in the human body occurs through F-contaminated drinking water, substantial amounts of F can also be ingested through crops and vegetables[9] cultivated with F-contaminated irrigation water.[10] In West Bengal, one of the most affected areas is the Birbhum District,[6] where F-contaminated groundwater is used as the major source of irrigation water for cultivation of paddy (rice, *Oryza sativa*).[10]

Recently, we reported laboratory studies on F accumulation in paddy,[10] but field-based accumulation has not been reported from the Birbhum study area. The objective of the present research was the assessment of such accumulation in paddy in a field irrigated with F-contaminated water.

MATERIALS AND METHODS

Study area location: The study area lies between 24º 06' 07.5"(N) latitude and 87º 46' 54.7"(E) longitude in the Rampurhat block of the Birbhum district, West Bengal. In this area paddy seedlings were planted in the last week of February and the first week of March 2009, and the crop was harvested during the third week of May 2009. A paddy field of 1200 m^2 was selected for the present research work. Irrigation water samples were collected for analysis after the seedlings were planted. Representative soil and mature paddy samples were collected at harvest time and analyzed during the first week of June 2009.

[a]For correspondence: Dr S Gupta, Lecturer, Department of Environmental Science, Baldwin University, Burdwan, West Bengal, India. E-Mail:srimantagupta@yahoo.co.in

Methodology: For the irrigation water geochemistry, most of the parameters, viz., pH, EC, TDS, TH (total hardness), TA (total alkalinity), Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}, Cl^{-}, and SiO_2 were analyzed by standard methods.[11] The water-extractable F (F_{H_2O}) in soil was determined by water-extractable (1:1) method[12] and by calcium chloride extractable (F_{CaCl_2}) (16 g soil: 50 mL of 0.01 M $CaCl_2$ solution) method.[13] Whereas F_{H_2O} for the plant samples was estimated by calcium sulphate extraction method (10 g air-dried plant sample added to 0.1 g $CaSO_4$ in 200 mL of deionized water). These extractions were followed by analyses with an ion-selective electrode (Orion), which was also used for F analysis of the irrigation water. The total F (F_{TOTAL}) in soil and plant samples was determined by using alkali fusion-Ion selective technique.[15] The soil and paddy samples were dried, blended separately, and analyzed as explained above.

Statistical analysis: The Pearson correlation among F and other ions in irrigation water was calculated by using the following formula:

$$r = \frac{\sum_{i-1}^{x} (X_i - \overline{X})(Y_i - \overline{Y})}{(n-1)S_x S_y}$$

Where X and Y are two variables, with means $\overline{X}$ and $\overline{Y}$, respectively, with standard deviations S_X and S_Y. The significance of the observed correlation co-efficient (r) was tested by using student t-test. The SE of r was computed as:

$$S\rho = \sqrt{\frac{(1-r^2)}{(n-2)}}$$

where (n-2) represents the degree of freedom (two-tailed)

Transfer Factor (TF): Like heavy metal translocation from soil to plant parts, the translocation of F was also calculated to determine the relative uptake of F_{H2O} by the plants with respect to soil:[16]

$$TF = \frac{\text{Concentration of } H_2O\text{-extractable F in plant body at contaminated site}}{\text{Concentration of } H_2O\text{-extractable F in soil at that site}}$$

RESULTS AND DISCUSSION

F content in irrigation water: F concentrations in the irrigated water varied from 0.6 to 4.06 mg/L (Table1). F has a significant ($p<.05$ and $p<.01$) negative correlation with Mg^{2+} and TH, respectively, whereas a significant ($p<.01$) positive correlation is found with Na^{+} (Table 2). This observation is very similar to our earlier observations.[6]

Table 1. Irrigation water geochemistry (values are expressed in mg/L except pH and EC

Sl No.	pH	EC	TDS	TH	TA	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cl^{-}	SiO_4^{2-}	F^{-}
1	9.1	610	397	32.00	48.00	24.00	1.95	46.40	1.10	129.96	14.45	0.73
2	9	330	215	27.20	24.00	9.60	4.29	27.60	1.30	49.98	19.43	0.62
3	9.1	480	312	16.00	40.00	9.60	1.56	68.90	1.20	69.98	14.74	4.06

Table 2. Correlation coefficients along with t-test

Correlation between	r	SE of r	Calculated t	Table t .05/.01	Level of significance
F & pH	0.53	0.28	1.88	2.262/3.250	not significant
F & EC	0.07	0.33	0.21	2.262/3.251	not significant
F & TDS	0.07	0.33	0.21	2.262/3.252	not significant
F & TH	–0.95	0.10	–9.13	2.262/3.253	significant p<.01
F & Ca^{2+}	–0.47	0.29	–1.60	2.262/3.254	not significant
F & Mg^{2+}	–0.63	0.26	–2.43	2.262/3.255	significant p<.05
F & TA	0.22	0.33	0.68	2.262/3.256	not significant
F & Cl^-	–0.25	0.32	–0.77	2.262/3.257	not significant
F & SiO_4^{2-}	–0.48	0.29	–1.64	2.262/3.258	not significant
F & Na^+	0.90	0.15	6.19	2.262/3.259	significant p<.01
F & K^+	–0.03	0.33	-0.09	2.262/3.260	not significant

F content in irrigated soil: As seen in Table 3, F_{H_2O} and F_{CaCl_2}varied between 1.45 and 3.80 mg/kg (mean 2.63) and between 0.85 and 6.75 mg/kg (mean 3.8), respectively. In this study F_{CaCl_2} is higher than the (1:1) F_{H_2O}, in agreement with earlier research showing that a solution of $CaCl_2$ is generally more efficient than water in extracting fluoride from soil.[17] On the other hand, F_{TOTAL} varied between 140 and 144 mg/kg (mean 142), suggesting a significant contribution towards its accumulation in paddy from all these sources.

F level in paddy: A substantial accumulation of both F_{H_2O} and F_{TOTAL} were found throughout the plant body, viz., root, stem, leaf, and seeds (Table 3). Maximum accumulation of F (mg/kg dry wt.) occurred in the root (mean F_{H_2O} 6.28 and mean F_{TOTAL} 80.83), followed by the leaf (5.88 and 50.30), stem (3.26 and 19.57) and seeds (2.88 and 12.31). The translocation of F ion from soil to plant parts (transfer factor, TF) was calculated to determine the relative uptake of F_{H_2O} ion by the plants with respect to presence of F in soil solution. The ratio of F concentration between soil and plant parts (TF) is an important criterion for the contamination assessment of soils with a high level of ionic F. The ratio ">1" means hyper accumulation of F in plant parts than soil. In the study area, with respect to F_{H_2O} in soil and all the paddy parts (i.e. root, stem, leaf, and seeds) the ratio was >1, suggesting hyper accumulation of F in the sequence: TF_{ROOT} (2.38) >TF_{LEAF} (2.35) >TF_{STEM} (1.23) >TF_{SEEDS} (1.10). A similar trend was also seen in the F_{CaCl2} in the sequence: TF_{ROOT} (1.65) >TF_{LEAF} (1.55) >TF_{STEM} (0.86) >TF_{SEEDS} (0.76).

Table 3. F content (ranges and means ±SD) in irrigated soil and paddy plant samples (mg/kg dry wt)

Irrigated soil	Plant materials	F_{H_2O}	F_{TOTAL}
F_{H_2O}: 1.45–3.80 (2.63±1.66)	Paddy root	6.27–6.29 (6.28±0.01)	79.00–82.66 (80.83±2.6)
F_{CaCl_2}: 0.85–6.75 (3.8±4.17)	Paddy leaf	5.80–5.90 (5.88±0.04)	52.00–48.60 (50.30±2.40)
F_{TOTAL}: 140–144 (142±2.82)	Paddy stem	3.24–3.27 (3.26±0.01)	18.75–20.39 (19.57±1.15)
	Paddy seeds	2.80 –2.92 (2.88±0.04)	11.86–12.76 (12.31±0.64)

ACKNOWLEDGEMENTS

The advice and support of Prof JK Datta and Dr AR Ghosh, Department of Environmental Science, The University of Burdwan, regarding preparation of the manuscript is greatly appreciated. The project was funded by the Department of Science and Technology, Government of India.

REFERENCES

1 Apambire WB, Boyle DR, Michel FA. Geochemistry, genesis, and health implications of fluoriferous groundwaters in the upper regions of Ghana. Environ Geol 1997;33(1):13-24.
2 Dissanayake CB, Chandrajith R. Medical geology in tropical countries with special reference to Sri Lanka. Environ Geochem Health 2007;29:155-62.
3 Bassin EB, Wypij D, Davis RB, Mittleman AM. Age-specific fluoride exposure in drinking water and osteosarcoma (United States). Cancer Causes and Control 2006;17:421-8.
4 Shitumbanuma V, Tembo F, Tembo JM, Chilala S, Van Ranst E. Dental fluorosis associated with drinking water from hot springs in Choma district in southern province, Zambia. Environ Geochem Health 2007; 29:51-8.
5 Jain P, Sharma JD, Sohu D, Sharma P. Chemical analysis of drinking water of villages of Sanganer Tehsil, Jaipur District. Int J Environ Sci Tech 2006; 2(4):373-9.
6 Gupta S, Banerjee S, Saha S, Datta JK, Mondal N. Fluoride geochemistry of groundwater in Nalhati-1 block of the Birbhum district, West Bengal, India. Fluoride 2006;39(4):318-20.
7 Chaudhary V, Sharma M, Yadav BS. Elevated fluoride in canal catchment soils of Northwest Rajasthan, India. Fluoride 2009;42(1):46-9.
8 Salve PR, Maurya A, Kumbhare PS, Ramteke DS, Wate SR. Assessment of groundwater quality with respect to fluoride. Bull Environ Contam Toxicol 2008; 81:289-93.
9 Poureslami HR, Khazaeli P, Nooric GR. Fluoride in food and water consumed in Koohbanan (Kuh-e Banan), Iran. Fluoride 2008;41(3):216-9.
10 Gupta S, Banerjee S, Mondal S. Phytotoxicity of fluoride in the germination of paddy (*oryza sativa*) and its effect on the physiology and biochemistry of germinated seedlings. Fluoride 2009;42(2):142-6.
11 Lenore S, Arnold E, Andrew D, editors. Standard methods for the examination of water and wastewater. 20th ed. Washington: American Public Health Association;1998.
12 Jha SK, Nayak AK, Sharma YK, Mishra VK, Sharma DK. Fluoride accumulation in soil and vegetation in the vicinity of brick fields. Bull Environ Contam Toxicol 2008;80:369-73.
13 Larsen S, Widdowson AE. Soil fluorine. J Soil Sci 1971;22:210-21.
14 Madziar MJ, Pńskwar P. Fluoride in common reeds (*Phragmites Australis) s*ampled from the old Warta reservoirs near Luboń and Radzewice, Poland*.* Fluoride 2003;36(1):21-4.
15 McQuaker NR, Gurney M. Determination of total fluoride in soil and vegetation using an alkali fusion selective ion electrode technique. Anal Chem 1977; 49:53–6
16 Barman SC, Sahu RK, Bhargava SK, Chatterjee C. Distribution of heavy metals in wheat, mustard and weed grown in fields irrigated with industrial effluents. Bull Environ Contam Toxicol 2000;64:489-96.
17 Supharungsun S, Wainwright M Determination, distribution and adsorption of fluoride in an atmospheric polluted soils. Bull Environ Contam Toxicol 1982;28:632-6.