doi: 10.17221/363/2015-PSE

Impact of irrigation and organic matter amendments on arsenic accumulation in selected vegetables

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ABSTRACT

The present study was set up to investigate the effect of irrigation with naturally arsenic (As)-contaminated water and addition of organic amendments on the As accumulation in frequently consumed vegetables in India (pumpkin, radish and cabbage). An arsenic-stricken village (Ghentugachi, Chakdah Block, Nadia, West Bengal, India; 23°02'N, 88°34'E, 9.75 m a.s.l.) was selected. Pot studies were conducted with the selected vegetables in contaminated soils collected from the selected village. Arsenic-contaminated water (spiked with varying concentrations of As^{III} and As^{V}) was used to irrigate the pots. Use of irrigation water contaminated with arsenic (both As^{III} and As^{V}) reduced the germination and inhibited photosynthetic pigmentation. As^{III} contamination remained more harmful. The worst situation was encountered with As^{III} contamination at 0.5 mg/L of irrigation water while As^{V} contamination below 0.2 mg/L of irrigation water remained safe. Field experiments with the selected vegetables were undertaken in the arsenic-stricken village where irrigation water (0.32 ± 0.12 mg/L) and soil (total As 18.15 ± 2.12 mg/kg) were contaminated with arsenic, to characterize the arsenic contamination of the vegetables, to assess the risk of dietary exposure and to study the effect of organic amendments on such contaminations. Vegetable roots accumulated more As than other parts and the accumulation increased with age. Pond (surface) water emerged as safer source for irrigation than shallow tube well water. Organic amendments reduced arsenic contamination significantly and vermicompost was the most efficient in this regard. All the vegetables showed risk (> 100% provisional tolerable weekly intake) of dietary exposure to arsenic.

Keywords: toxicity; farmyard manure; *Cucurbita pepo*; *Raphanus sativus*; *Brassica oleracea*; groundwater

In West Bengal (India), 75 blocks in 9 districts across 38 865 km^2 are reported to be severely affected by groundwater arsenic (As) contamination (Chowdhury et al. 2000), of which 17 administrative blocks of the Nadia district are contaminated (http://www.soesju.org/arsenic/wb.htm). Nadia is very promising in vegetable production and declared as Agri Export Zone (AEZ) for vegetables (http://agriexchange.apeda.gov.in/). Arsenic contamination in groundwater in the lower Gangetic plain emerged through weathering of As-rich base-metal sulphide and subsequent supply of As-rich iron hydroxide to downstream Ganges sediments (Bhattacharya et al. 1997, Nickson et al. 2000). Arsenic uptake by crop plants grown in soil contaminated with high concentration of arsenic and irrigated with arsenic-contaminated ground water has been reported (Abedin et al. 2002, Sahoo and Mukherjee 2014, Bastías and Beldarrain 2016). Accumulation of arsenic in vegetables, however, may impact (i) the physiological and biochemical processes of vegetables and in turn the quality of the product (Zhang et al. 2005); (ii) entry of carcinogen in human through food chain (Balakhir

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and Ashraf 2016) or (iii) the quality control norms for exporting vegetables (Chang et al. 2014). Arsenic contamination in drinking water and major cereals (rice) has been adequately addressed in the last decade. Information relating to As contamination in vegetables in the experimental area are scarce, and so is the mitigation strategies like organic amendment or use of less contaminated surface water. In view of the information above, the present study was planned (i) to account for the arsenic accumulation in vegetables and its effect on quality traits (through experiments under controlled condition); (ii) to explore for possible mitigation options through field experiments and (iii) to take account of the risk of dietary exposure to arsenic through vegetables.

MATERIAL AND METHODS

A controlled (pot) study with pumpkin (cv. Bongaon Kali), radish (cv. Bengal Pink) and cabbage (cv. Golden Acre) was conducted in completely randomized design with three replications. The pot was filled with 5 kg of contaminated soil (total As 18.15 ± 2.12 mg/kg) collected from arsenic-stricken village (Ghentugachi, Chakdah Block, Nadia, West Bengal, India; 23°02'N, 88°34'E, 9.75 m a.s.l.). Arsenic-contaminated water (0 As; 0.2 mg As^{III}/L; 0.3 mg As^{III}/L; 0.5 mg As^{III}/L; 0.2 mg As^{V}/L; 0.3 mg As^{V}/L; 0.5 mg As^{V}/L) was used to irrigate the pots. Sodium arsenate and sodium arsenite (Merck, Darmstadt, Germany) were used to prepare graded doses of As^{V} and As^{III} – spiked water. For cabbage and pumpkin, about 7 L of water was applied per pot (5 kg of soil). However, radish was irrigated with 3 L of water per pot. For estimating germination index, seeds of the vegetable crops were incubated at 4°C for a few days and then surface-sterilized with 5% sodium hypochlorite. Estimations were done at 70% relative humidity at 25°C with a 12 h photoperiod following ISTA (2008). Chlorophylls and carotenoids were extracted by percolation method (Hiscox and Israelstam 1978). Total protein was estimated following the method of Lowry et al. (1951). An index of depression (ID) (Miteva 2002) of plant growth was calculated as follows:

$$ID = \frac{1}{3} \times \left[\left(\frac{GI - GI_1}{GI} \right) \times 100 + \frac{(TC - TC_1)}{TC} \times 100 + + \frac{(CA - CA_1)}{CA} \times 100 + \frac{(P - P_1)}{P} \times 100 \right]$$

Where: GI_1 – germination index at As-spiked treatment and at control treatment – GI; total chlorophyll at As-spiked treatment – TC_1 and at control treatment — TC; carotenoid content at As-spiked treatment – CA_1 and at control treatment – CA; protein content at As-spiked treatment – P_1 and at control treatment – P.

The germination index (GI) of the seeds was calculated as described in the Association of Official Seed Analysis (AOSA 1983) by the following formula:

$$GI = \Sigma (G_t/T_t)$$

Where: G – no. of germinated seeds from the first count to t^{th} count; T – days of the first count to t^{th} count. Seedlings of about five weeks old were taken to observe arsenic accumulation in leaves only. Leaf samples of the plants were collected at the time of peak vegetative stage.

The field experiments with the selected vegetables were undertaken in the same location of the contaminated village for two consecutive winters of 2010–2011 and 2011–2012. The experiments were laid out in thrice replicated factorial randomized block designs, where the source of water was one factor (two levels; W_1 – pond water; W_2 – shallow tube well water) and organic amendment was the other one (five levels; T_0 – control; T_1 – farm yard manure or FYM @ 15 t/ha; T_2 – vermicompost @ 5 t/ha; T_3 – sludge @ 5 t/ha). The initial soil status and As content in water sources were listed in Table 1. The plant samples were taken from the experimental sites at different stages [pumpkin: 65 DAS (days after sowing) (flowering stage) and 130 DAS (at harvest); radish: 15 (vegetative stage), 30 (root initiation stage) and 60 DAS (at harvest); cabbage: 30 (peak vegetative stage), 60 (heading stage) and 75 DAT (at harvest)]. The plant samples both from pot and field experiment were washed with pure water to remove soil debris attached to the plant body and then with ultra-pure deionized water.

Soil samples were extracted with 0.5 mol/L $NaHCO_3$ (soil:extractant: 1:10 w/v) (Johnston and Barnard 1979) to determine the available As. Plant samples were dried, ground and kept in a sample container. The samples were digested by a mixture of concentrated acids, e.g., HNO_3, $HClO_4$ and H_2SO_4 in a proportion of 10:4:1 (v/v) as described by Jackson (1973). The plant digest/soil extract was diluted to 50 mL. Then 10 mL of the aliquot was taken in 50 mL volumetric flask; 5 mL of concentrated HCl and 1 mL of mixed reagent

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Table 1. Initial status of soil and water used in pot and field experiment

Soil	Properties	Mean value	Methodology	Reference
Initial soil status				
1	pH	7.51 ± 0.21	soil:water:1.2.5	Jackson (1967)
	sand	20.66 ± 2.23		
2	silt	47.20 ± 5.65	Bouyoucos hydrometer	Dewis and Freitas (1984)
	clay	32.14 ± 4.32		
3	organic carbon (%)	0.563 ± 0.08	wet digestion	Walkley and Black (1934)
4	available N (kg/ha)	220.0 ± 11.02	hot alkaline $KMnO_4$ method	Subbiah and Asija (1956)
5	available P (kg/ha)	57.0 ± 6.63	0.5 mol/L $NaHCO_3$	Olsen et al. (1954)
6	available K (kg/ha)	190.0 ± 9.30	neutral N NH_4OAc	Brown and Warncke (1988)
7	total arsenic (mg/kg)*	18.15 ± 2.12	tri-acid digest	Sparks et al. (2006)
8	available arsenic (mg/kg)	4.70 ± 0.56	0.5 mol/L $NaHCO_3$	Johnston and Barnard (1979)
As content in source of water				
9	as in pond water (mg/L)	0.03 ± 0.002	HCl + KI + ascorbic acid	Sparks et al. (2006)
10	as in shallow water (mg/L)	0.32 ± 0.12		

Values ± are standard error of the mean (number of observations = 12); *Permissible limit for arsenic in agricultural soils @

[5% KI (w/v) + 5% ascorbic acid (w/v)] were added to it, kept for 45 min to ensure complete reaction and the volume was made up to 50 mL. The resulting solution was analysed in a PerkinElmer atomic absorption spectrophotometer with flow injection analysis system (FIAS 400, Waltham, USA) where the carrier solution was 10% *v/v* HCl, the reducing agent (to ensure all As species be reduced to AsH_3 and to be measured against a calibration with standard As^{III} solution) was 0.2% $NaBH_4$ in 0.05% NaOH at the $\lambda_{max} \approx 193.7$ nm.

Dietary exposure to (or intake of) food chemicals was estimated by combining food consumption data with food chemical concentration data e.g. Dietary exposure = food chemical concentration × food consumption. The dietary intake and the risks associated with the arsenic contamination of food materials were assessed in per cent of provisional tolerable weekly intake (PTWI) of the contaminant (WHO 2000).

PTWI of arsenic – 15 µg/body weight (≈ 900 µg for an adult of 60 kg body weight). Statistical conclusions relating to the quality attributes and arsenic accumulations in selected vegetables were drawn through analysis of variance (ANOVA). Significance ($P < 0.05$) was tested using the Windows-based SPSS software (ver 21.0, SPSS Inc 1996).

RESULTS AND DISCUSSION

The germination index, chlorophylls, carotenoid and protein content of all the vegetables under pot study were observed to reduce progressively with increasing arsenic in irrigation water and the impact of arsenite (As^{III}) was more severe than that of arsenate (As^{V}) (Table 2). An attempt was made to summarize the changes in quality traits in the form of index of depression (Table 2), which clearly reveals that the impact of As^{III} in irrigation water remained more severe to arrive at highest depression index (at 0.5 mg As^{III}/L) for all the vegetables studied, as compared to As^{V} where the contamination up to 0.2 mg As^{V}/L remained safe. The worst situation was encountered when pots were irrigated with 0.5 mg/L As^{III} spiked water. However, vegetable seed germination (GI) was not that much affected up to irrigation with 0.2 mg/L As^{III} and As^{V} contaminated water. More As reduced GI may be due to the lack of defense mechanism of vegetable seeds that made them vulnerable to metal pollution (Mahdieh et al. 2013). Arsenic addition significantly reduced Mg concentration, an important component of chlorophyll (Liu et al. 2008). Such decrease in chlorophyll content, triggered by As accumula-

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Table 2. Effect of arsenate and arsenite on qualitative traits of vegetables (pooled data of two years)

As spiking	Germination index			Chlorophyll *a* (mg/g)			Chlorophyll *b* (mg/g)			Total chlorophyll (mg/g)		
	radish	pumpkin	cabbage	radish	pumpkin	cabbage	radish	pumpkin	cabbage	radish	pumpkin	cabbage
No spike	2.79^{a}	2.83^{a}	2.80^{a}	1.02^{a}	0.90^{a}	0.80^{a}	0.33^{a}	0.28^{a}	0.33^{a}	1.34^{a}	1.18^{a}	1.13^{a}
$As^{III}_{0.2}$	2.81^{a}	2.68^{a}	2.82^{a}	0.82^{b}	0.77^{ab}	0.75^{a}	0.27^{a-c}	0.25^{ab}	0.28^{ab}	1.09^{b}	1.01^{ab}	1.03^{ab}
$As^{III}_{0.3}$	2.27^{bc}	2.32^{b}	2.38^{b}	0.64^{c}	0.57^{bc}	0.56^{bc}	0.21^{cd}	0.18^{bc}	0.20^{cd}	0.85^{cd}	0.74^{d}	0.77^{cd}
$As^{III}_{0.5}$	1.50^{d}	1.63^{d}	1.55^{d}	0.58^{c}	0.53^{c}	0.48^{c}	0.17^{d}	0.15^{c}	0.18^{d}	0.75^{d}	0.69^{d}	0.66^{d}
$As^{V}_{0.2}$	2.77^{ab}	2.79^{a}	2.76^{a}	0.74^{bc}	0.89^{a}	0.80^{a}	0.24^{b-d}	0.28^{a}	0.33^{a}	0.98^{bc}	1.17^{a}	1.13^{a}
$As^{V}_{0.3}$	2.43^{a-c}	2.22^{bc}	2.08^{bc}	1.00^{a}	0.59^{bc}	0.77^{a}	0.32^{ab}	0.20^{a-c}	0.30^{ab}	1.33^{a}	0.79^{cd}	1.07^{ab}
$As^{V}_{0.5}$	2.25^{c}	2.00^{c}	1.81^{cd}	0.85^{ab}	0.72^{a-c}	0.62^{b}	0.29^{a-c}	0.23^{a-c}	0.26^{bc}	1.13^{b}	0.95^{bc}	0.88^{bc}
	leaf As (mg/kg)			carotenoid (µg/g)			protein (mg/g)			index of depression		
	radish	pumpkin	cabbage	radish	pumpkin	cabbage	radish	pumpkin	cabbage	radish	pumpkin	cabbage
No spike	1.62^{d}	2.30^{e}	1.20^{d}	3.88^{a}	5.34^{a}	4.68^{a}	43.23^{a}	53.94^{a}	54.00^{a}	–	–	–
$As^{III}_{0.2}$	1.71^{cd}	2.39^{de}	1.31^{c}	3.58^{ab}	4.34^{b}	4.14^{bc}	38.10^{a-c}	47.02^{c}	43.87^{cd}	12.55^{d}	16.91^{e}	12.94^{c}
$As^{III}_{0.3}$	1.74^{b-d}	2.44^{de}	1.40^{c}	3.34^{bc}	3.90^{bc}	3.81^{cd}	35.47^{b-d}	44.06^{cd}	43.37^{cd}	29.12^{b}	33.39^{b}	28.52^{b}
$As^{III}_{0.5}$	1.79^{bc}	2.51^{cd}	1.53^{b}	3.13^{c}	3.52^{c}	3.52^{d}	29.67^{d}	40.19^{d}	40.17^{d}	46.98^{a}	47.84^{a}	45.72^{a}
$As^{V}_{0.2}$	1.80^{bc}	2.61^{bc}	1.52^{b}	3.72^{a}	5.29^{a}	4.61^{a}	41.23^{ab}	51.75^{ab}	52.28^{ab}	12.25^{d}	2.30^{f}	2.17^{d}
$As^{V}_{0.3}$	1.89^{ab}	2.73^{ab}	1.60^{b}	3.66^{ab}	4.84^{a}	4.40^{ab}	39.79^{a-c}	48.11^{bc}	49.23^{ab}	9.31^{e}	24.88^{d}	15.19^{c}
$As^{V}_{0.5}$	2.00^{a}	2.81^{a}	1.88^{a}	3.60^{ab}	4.11^{b}	4.19^{bc}	34.85^{cd}	44.43^{cd}	48.00^{bc}	20.54^{c}	29.75^{c}	26.30^{b}

Subscript digit signifies a dose of respective nutrient in mg/L; means followed by a different letter are significantly different (otherwise statistically at par) at $P < 0.05$ by Duncan's multiple range test

Table 3. Effect of organic intervention on arsenic accumulation (mg/kg dry matter) in cabbage (pooled data of two years)

	Days after transplanting (DAT)								
	30			60			75		
	root	stem	leaf	root	stem	head	root	stem	head
Source of irrigation									
W_1	3.36^{b}	1.04^{b}	1.24^{b}	3.58^{b}	1.25^{b}	1.47^{b}	3.93^{b}	1.19^{b}	1.32^{b}
W_2	3.66^{a}	1.27^{a}	1.45^{a}	3.85^{a}	1.49^{a}	1.66^{a}	4.25^{a}	1.37^{a}	1.58^{a}
Organic intervention									
T_0	3.71^{a}	1.36^{a}	1.55^{a}	3.90^{a}	1.52^{a}	1.80^{a}	4.29^{a}	1.43^{a}	1.71^{a}
T_1	3.49^{bc}	1.16^{bc}	1.35^{c}	3.68^{bc}	1.39^{bc}	1.56^{b}	4.07^{bc}	1.30^{bc}	1.42^{bc}
T_2	3.42^{c}	1.07^{c}	1.25^{d}	3.64^{c}	1.31^{c}	1.48^{b}	4.00^{c}	1.21^{c}	1.34^{c}
T_3	3.58^{b}	1.21^{b}	1.45^{b}	3.77^{b}	1.44^{ab}	1.61^{ab}	4.16^{ab}	1.33^{ab}	1.50^{b}
Interaction									
W_1T_0	3.55^{bc}	1.20^{b-d}	1.42^{c}	3.77^{bc}	1.35^{d}	1.63^{b}	4.10^{c-e}	1.28^{b-d}	1.53^{bc}
W_1T_1	3.34^{de}	1.05^{de}	1.25^{de}	3.54^{de}	1.28^{de}	1.46^{b}	3.91^{ef}	1.20^{d}	1.31^{de}
W_1T_2	3.26^{e}	0.96^{e}	1.14^{e}	3.49^{e}	1.20^{e}	1.41^{b}	3.84^{f}	1.16^{d}	1.20^{e}
W_1T_3	3.45^{cd}	1.10^{c-e}	1.35^{cd}	3.66^{cd}	1.30^{de}	1.50^{b}	4.00^{d-f}	1.22^{d}	1.40^{cd}
W_2T_0	3.86^{a}	1.51^{a}	1.68^{a}	4.03^{a}	1.68^{a}	1.97^{a}	4.47^{a}	1.57^{a}	1.88^{a}
W_2T_1	3.64^{b}	1.27^{bc}	1.44^{bc}	3.81^{bc}	1.50^{bc}	1.65^{ab}	4.23^{bc}	1.39^{bc}	1.52^{bc}
W_2T_2	3.57^{bc}	1.17^{b-d}	1.32^{cd}	3.79^{bc}	1.41^{cd}	1.55^{b}	4.15^{b-d}	1.25^{cd}	1.48^{b-d}
W_2T_3	3.70^{ab}	1.32^{b}	1.55^{b}	3.88^{ab}	1.57^{ab}	1.72^{ab}	4.32^{ab}	1.43^{ab}	1.60^{b}

W_1 – irrigation through pond water; W_2 – irrigation through shallow tube well water; T_0 – no organic matter; T_1 – FYM (farmyard manure) @ 15 t/ha; T_2 – vermicompost @ 5 t/ha; T_3 – sludge @ 5 t/ha. Means followed by a different letter are significantly different (otherwise statistically at par) at $P < 0.05$ by Duncan's multiple range test

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tion is a bio-indicator of oxidative stress caused by this metalloid (MacFarlane and Burchet 2001). Increasing As^{V} in irrigation water was observed to increase radish chlorophyll, although it reduced cabbage and pumpkin chlorophylls. Arsenic toxicity often limits photosynthesis through reduced pigmentation like carotenoid (Farnese et al. 2014). Reduced proteins in vegetables observed in the present study were more conspicuous with increasing As^{III} levels rather than with As^{V} due to more aggressive reactivity of As^{III} with sulfhydryl groups in enzymes (Tripathi et al. 2007). However, the effect of arsenic on photosynthetic pigments may be inhibitory as well as stimulatory, depending upon the plant species (Perales-Vela et al. 2007). Leaf arsenic accumulation of cabbage, pumpkin and radish were increased with increasing arsenic in irrigation water and were maximum where As^{V} concentration were 0.5 mg/L regardless of the vegetables grown. Tlustoš et al. (2002) also observed that total arsenic concentrations in both leaves and roots of radish increased significantly in treated soils irrespective of the arsenic compound added.

Field studies showed that arsenic accumulation in all plant parts increased with the age of the selected vegetables (Tables 3–5). Bhumbla and Keefer (1994) observed that plants accumulate higher amounts of arsenic as they age, more precisely at harvest as compared to earlier growth stages (Sultana et al. 2015). The arsenic accumulations are usually very high in roots followed by head > stem (in cabbage), root > leaf > fruit > stem > rind (in pumpkin) and root > leaf (in radish). The highest accumulations were observed in radish root (4.10–4.54 mg/L), followed by cabbage head (1.20–1.88 mg/L) and pumpkin fruit (0.96–1.41 mg/L). Signes-Pastor et al. (2008) analysed several vegetables grown in As contaminated sites of the district 24 Parganas (North) and found mean As level of 0.75 mg/kg, with radish having the highest As concentration, 1.67 mg As/kg. Ren et al. (2010) reported higher accumulation of As in the edible portions of leafy or root crops than the storage organs or fruits.

Use of surface (pond) water for irrigation significantly reduced arsenic accumulation in all plant parts of the vegetables significantly from

Table 4. Effect of organic intervention on arsenic accumulation (mg/kg dry matter) in pumpkin (pooled data of two years)

	Days after sowing (DAS)									
	65					after harvesting (130)				
	root	stem	leaf	fruit	rind	root	stem	leaf	fruit	rind
Sources of irrigation										
W_1	3.37^{b}	0.96^{b}	2.12^{b}	1.14^{b}	0.74^{b}	3.76^{b}	1.20^{b}	2.37^{b}	1.38^{b}	1.01^{b}
W_2	3.65^{a}	1.25^{a}	2.45^{a}	1.33^{a}	0.92^{a}	4.03^{a}	1.39^{a}	2.69^{a}	1.48^{a}	1.29^{a}
Organic intervention										
T_0	3.68^{a}	1.27^{a}	2.45^{a}	1.38^{a}	0.99^{a}	4.06^{a}	1.42^{a}	2.66^{a}	1.55^{a}	1.27^{a}
T_1	3.51^{b}	1.10^{b}	2.32^{ab}	1.23^{b}	0.82^{b}	3.89^{b}	1.30^{bc}	2.55^{a}	1.44^{ab}	1.15^{ab}
T_2	3.43^{b}	1.02^{b}	2.24^{b}	1.19^{b}	0.75^{b}	3.82^{b}	1.21^{c}	2.46^{a}	1.35^{b}	1.09^{b}
T_3	3.55^{ab}	1.20^{a}	2.36^{ab}	1.31^{ab}	0.90^{ab}	3.97^{ab}	1.37^{ab}	2.59^{a}	1.48^{ab}	1.22^{ab}
Interaction										
W_1T_0	3.52^{bc}	1.15^{c}	2.30^{c-e}	1.27^{bc}	0.90^{a-d}	3.90^{b-d}	1.32^{bc}	2.51^{a}	1.48^{a-c}	1.12^{b-d}
W_1T_1	3.38^{cd}	0.95^{d}	2.15^{de}	1.14^{c}	0.71^{cd}	3.77^{cd}	1.20^{cd}	2.39^{a}	1.39^{bc}	1.00^{cd}
W_1T_2	3.30^{d}	0.84^{d}	2.08^{e}	1.11^{c}	0.66^{cd}	3.69^{d}	1.12^{d}	2.30^{a}	1.31^{c}	0.96^{d}
W_1T_3	3.39^{cd}	1.10^{c}	2.21^{b-e}	1.21^{bc}	0.80^{b-d}	3.84^{cd}	1.26^{b-d}	2.44^{a}	1.41^{a-c}	1.10^{b-d}
W_2T_0	3.84^{a}	1.38^{a}	2.59^{a}	1.49^{a}	1.08^{a}	4.22^{a}	1.52^{a}	2.81^{a}	1.61^{a}	1.41^{a}
W_2T_1	3.64^{ab}	1.24^{a-c}	2.48^{a-c}	1.31^{a-c}	0.92^{a-c}	4.00^{a-c}	1.39^{ab}	2.70^{a}	1.49^{a-c}	1.30^{ab}
W_2T_2	3.55^{bc}	1.19^{bc}	2.39^{a-d}	1.26^{bc}	0.84^{a-d}	3.95^{bc}	1.30^{bc}	2.61^{a}	1.39^{bc}	1.22^{a-c}
W_2T_3	3.70^{ab}	1.30^{ab}	2.51^{ab}	1.40^{ab}	1.00^{ab}	4.10^{ab}	1.47^{a}	2.73^{a}	1.54^{ab}	1.33^{ab}

W_1 – irrigation through pond water; W_2 – irrigation through shallow tube well water; T_0 – no organic matter; T_1 – FYM (farmyard manure) @ 15 t/ha; T_2 – vermicompost @ 5 t/ha; T_3 – sludge @ 5 t/ha. Means followed by a different letter are significantly different (otherwise statistically at par) at $P < 0.05$ by Duncan's multiple range test

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Table 5. Effect of organic intervention on arsenic accumulation (mg/kg dry matter) in radish (pooled data of two years)

	Days after sowing (DAS)					
	15		30		after harvesting (60)	
	root	leaf	root	leaf	root	leaf
Sources of irrigation						
W_1	1.49^{b}	1.38^{b}	3.53^{b}	1.59^{a}	4.21^{a}	1.69^{a}
W_2	1.62^{a}	1.51^{a}	3.94^{a}	1.70^{a}	4.37^{a}	1.82^{a}
Organic intervention						
T_0	1.69^{a}	1.58^{a}	3.91^{a}	1.78^{a}	4.59^{a}	1.90^{a}
T_1	1.54^{bc}	1.43^{ab}	3.72^{ab}	1.65^{a}	4.17^{b}	1.75^{a}
T_2	1.51^{c}	1.40^{b}	3.66^{b}	1.59^{a}	4.19^{b}	1.68^{a}
T_3	1.60^{ab}	1.49^{ab}	3.80^{ab}	1.67^{a}	4.41^{ab}	1.82^{a}
Interaction						
W_1T_0	3.28^{de}	1.59^{ab}	3.65^{cd}	1.70^{a}	4.48^{ab}	1.80^{a}
W_1T_1	3.20^{de}	1.48^{b}	3.54^{d}	1.59^{a}	4.20^{ab}	1.71^{a}
W_1T_2	3.16^{e}	1.47^{b}	3.46^{d}	1.54^{a}	4.10^{b}	1.62^{a}
W_1T_3	3.25^{de}	1.51^{ab}	3.61^{cd}	1.62^{a}	4.28^{ab}	1.74^{a}
W_2T_0	3.85^{a}	1.78^{a}	4.16^{a}	1.85^{a}	4.69^{a}	2.00^{a}
W_2T_1	3.54^{bc}	1.59^{ab}	3.90^{a-c}	1.71^{a}	4.14^{b}	1.79^{a}
W_2T_2	3.43^{cd}	1.54^{ab}	3.86^{bc}	1.64^{a}	4.28^{ab}	1.73^{a}
W_2T_3	3.71^{ab}	1.69^{ab}	3.99^{ab}	1.72^{a}	4.54^{ab}	1.89^{a}

W_1 – irrigation through pond water; W_2 – irrigation through shallow tube well water; T_0 – no organic matter; T_1 – FYM (farmyard manure) @ 15 t/ha; T_2 – vermicompost @ 5 t/ha; T_3 – sludge @ 5 t/ha. Means followed by a different letter are significantly different (otherwise statistically at par) at $P < 0.05$ by Duncan's multiple range test

the plants raised with underground (shallow tube well, STW) irrigation water, simply due to low As concentration in pond water than STW water in the experimental area. Use of less contaminated surface water may be considered as possible mitigation of arsenic contamination of food stuff although such propositions are not acceptable to farmers using STW drafted water due to easy availability and deficiency of water bodies in this thickly populated and intensively cultivated area (Sinha and Bhattacharyya 2014).

Soil amendment with organic manures was observed to significantly reduce arsenic accumulation in all plant parts of the selected vegetables across growth stages over control situations. Vermicompost application made such reductions in arsenic accumulation most consistently and efficiently followed by FYM and sludge. Such reductions in edible parts of the selected vegetables, as revealed in Figure 1, showed that organic amendments reduced As accumulation in cabbage head, followed by pumpkin fruit and radish root. Organic amendments such as composts and manures that contain a high amount of humified

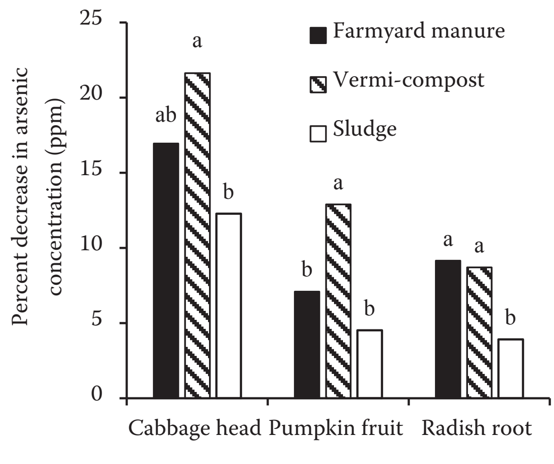

Figure 1. Percentage decrease in arsenic concentration due to the use of organic amendments. Mean values for treatments with different lowercase letters indicate significant differences (otherwise statistically at par) at $P < 0.05$ by the Duncan's multiple range test

doi: 10.17221/363/2015-PSE

Table 6. Assessment of the risk of dietary exposure to arsenic

Vegetable	Average weekly consumption (kg fresh weight)	Arsenic ingestion in a week (mg)		PTWI (%)	
		min.	max.	min.	max.
Cabbage	0.95*	0.10	0.13	10.08	13.44
Pumpkin	0.74*	0.13	0.16	10.70	13.15
Radish	0.63*	0.09	0.10	5.99	7.00

*National Nutritional Monitoring Bureau, Goverment of India: West Bengal rural survey 2004–2006 database on food consumption; PTWI – provisional tolerable weekly intake

organic matter can decrease the bioavailability of heavy metals through adsorption and by forming stable complexes with humic substances (Sinha et al. 2011). Earlier studies also indicated that in West Bengal the crops and vegetables cultivated in the arsenic-contaminated soil accumulate a significant amount of arsenic and finally enter to the human food chain (Santra et al. 2013). The risk of dietary exposure to arsenic through these vegetables was assessed and is recorded in Table 6. A risk assessment study in Denmark observed a risk of 4% PTWI of dietary exposure to arsenic-contaminated carrot (NFAD 1995/1996). Although, arsenic accumulation in edible parts of the selected vegetables was quite high, the arsenic ingestion through the selected vegetables remained far below the unsafe limit of dietary risk (5.99–13.44% of provisional tolerable weekly intake of arsenic). The low importance of vegetables in daily As intake was mainly due to the fact that vegetables have a high water content (approximately 90%). Under circumstances of food shortage, rice becomes the most important food and represents about 70% of the daily food intake, and at the same time, it becomes the largest source of As. During times when vegetables, milk, and bakery products are more abundant, the importance of rice decreases and represents about 35% of daily food intake and vegetables become more abundant source of dietary risk of exposure to arsenic (Signes-Pastor et al. 2008).

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Received on June 5, 2015
Accepted on May 13, 2016

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