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Research article

Arsenic load in rice ecosystem and its mitigation through deficit irrigation

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ABSTRACT

Rice the staple food is a notable intake source of arsenic to the rural population of eastern India through food-chain. A field survey was carried out to study the variation of arsenic load in different parts of rice genotype Shatabdi (most popular genotype of the region) exposed to varying level of arsenic present in the irrigation water and soil. As irrigation is the primary source of arsenic contamination, a study was conducted to assess arsenic load in rice ecosystem under deficit irrigation practices like intermittent ponding (IP), saturation (SAT) and aerobic (AER) imposed during stress allowable stage (16–40 days after transplanting) of the crop (genotype Shatabdi). Present survey showed that arsenic content in water and soil influenced the arsenic load of rice grain. Variation in arsenic among different water and soil samples influenced grain arsenic load to the maximum extent followed by straw. Deviation in root arsenic load due to variation in water and soil arsenic content was lowest. Arsenic concentration of grain is strongly related to the arsenic content of both irrigation water and soil. However, water has 10% higher impact on grain arsenic load over soil. Translocation of arsenic from root to shoot decreased with the increase in arsenic content of water. Imposition of saturated and aerobic environment reduced both yield and grain arsenic load. In contrast under IP a marked decrease in grain arsenic content recorded with insignificant reduction in yield. Deficit irrigation resulted in significant reduction (17.6–25%) in arsenic content of polished rice and the values were lower than that of the toxic level (<0.2 mg kg^{-1}). In contrast the decrease in yield was to the tune of 0.9% under IP regime over CP.

1. Introduction

Arsenic is a ubiquitous element in nature having class I carcinogenic effect on human (Smith et al., 2002). Till the end of the last century researchers had the idea that arsenic enters into human body through drinking water. However, in the beginning of this century various research groups (Meharg and Rahman, 2003; Williams et al., 2005; Kile et al., 2007; Meharg et al., 2009; Mondal et al., 2010) reported that food is also a vital source for arsenic intake. Even, in some cases it has been found that food plays the dominant role over drinking water towards intake of arsenic into human body (Signes et al., 2008; Liu et al., 2010; Li et al., 2011). Therefore quantity of arsenic contaminated food taken/day/kg of body weight of an adult is to be more responsible for enhancing arsenic entry in human system (Guha Mazumder et al., 2012). The permissible limit of arsenic entry to human body is 2 μg/kg body weight/day. In Western countries diets are highly varied and rice is not a dominant component in it. In contrast, rice (*Oryza sativa*) is a staple food in Eastern India and Bangladesh (Fageria, 2007). On average each adult of the region consumed 400 gm rice per day (Carbonell-Barrachina et al., 2009). Thus producing rice in arsenic contaminated soil or irrigation water caused a threat of arsenic-related health hazards (Guha Mazumder, 2008; Norton et al., 2012). Besides, rice grain and straw are dominated by arsenite (As- III) and arsenate (As- V), which are more toxic in nature (Juskelis et al., 2013; Sinha and Bhattacharya, 2015). In rural India as rice shares the major part of the diet, it is the key source of arsenic intake even to the population not exposed to high concentrations of arsenic through drinking water (Kile et al., 2007; Meharg et al., 2009; Halder et al., 2012).

The anaerobic root zone made rice responsible for 10 times more arsenic uptake over the arable crops (Williams et al., 2007). Besides, in arsenic contaminated areas of Indo Gangetic plains farmers apply 1200–1400 mm arsenic contaminated ground water

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to dry season rice. Addition of huge amount of arsenic through irrigation water (Duxbury and Panaullah, 2007; Fendorf et al., 2010) leading to increased concentrations of arsenic of rice soils (Saha and Ali, 2007; Duxbury and Panaullah, 2007; Fendorf et al., 2010; Sarkar et al., 2012), and consequently elevated concentrations of arsenic within the edible parts of crops (Williams et al., 2006; Duxbury and Panaullah, 2007; Basu et al., 2015). In contrast, Lu et al. (2009) reported that in some areas of Bengal delta due to geogenic reason the soil arsenic content is quite high and leads toward higher grain arsenic load of rice. Polizzotto et al. (2013) observed that, increase in depth of water in rice field at the end of an irrigation event, caused an increase in soil arsenic content at inlet point and the same decreased with an increase in distance across the field, but under subsequent static conditions, concentrations dropped and less variable. Inorganic arsenic levels in rice grain are problematic even where soil arsenic is at background levels, derived from geogenic sources (Lu et al., 2009; Meharg et al., 2009). However, widespread pollution of paddy soils with arsenic carried through ground water resource leads toward further escalation of arsenic load in straw and grain of rice (Carry et al., 2010; Sarkar et al., 2012).

Arsenic accumulation in rice grain depends on many abiotic and biotic factors (Zheng et al., 2011). Among the abiotic factors, concentration of arsenic in irrigation water, water-air ratio in soil pores and availability of arsenic in soil are the dominant one in rice (Arao et al., 2009; Li et al., 2009; Basu et al., 2015). Rice is a semi aquatic plant; however it has been found that, during vegetative stage it can tolerate certain extent of water stress with insignificant reduction in grain yield (Sarkar, 2001). Even it has been observed that imposition of intermittent ponding at that stage produced almost equal amount of grain yield like that of under non stressed environment. Notable reduction in grain arsenic content under alternate wetting and drying method over that of continuous flooding method (Rahaman et al., 2014; Das et al., 2016; Shah et al., 2016), implies that this technique can be devised as tool for mitigation of arsenic in the arsenic contaminated areas of dry season rice. Considering the background a baseline survey was planned to assess the arsenic uptake pattern of rice genotype Shatabdi at 22 locations differ in arsenic content of irrigation water. An attempt was also made to mitigate the arsenic uptake through appropriate water management. The water management study was carried out in a farmer field where irrigation water arsenic content was 0.167 mg L^{-1}.

2. Materials methods

2.1. Field survey

Field survey was carried out in six arsenic contaminated villages (Ghentugachchi, Goentra, Mitrapur, Jaguli, Nonaghata and Dakshin Panchpota) of Nadia district, West Bengal. As majority of the farmers of the study site grow rice genotype Shatabdi, the survey was confined with this particular genotype. In total 22 sites were finalized for collection of irrigation water, soil and plant samples. Water samples were collected in the month of March when the crop was at peak vegetative stage. At the time of harvest rice plants from 10 hills were uprooted from the central area of the farmer's field. At that time soil samples from adjoining areas of the hills were also collected. Survey was carried out during two consecutive years 2010 and 2011.

2.2. Collection of samples

Water samples were collected in prewashed polythene bottles and after collection acidify by 2 drops of concentrated HCl. Soil samples were collected in plastic bags and kept for air drying in shades. After drying soil samples were finely grounded and sieved through 2 mm sieve. Mature rice plants were uprooted from the fields and dried in plant drier at 60 °C. After drying, root and straw were chopped into smaller pieces, rice grains were grind by small grinder.

2.3. Water management study

Water management study was carried out in a farmer's field at village Gontra to assess the role of deficit irrigation to mitigate arsenic uptake by rice plant. Arsenic load in soil and various plant parts were monitored under four irrigation regimes. The regimes were: (i) continuous ponding (CP), which is practiced by the farmers of the locality and was considered as the control treatment; (ii) intermittent ponding (IP), where irrigation was given when soil matric potential (Ψ_m) at 20 cm depth reached −0.03 M Pa after disappearance of ponded water; (iii) saturation (SAT) where 0–500 mm soil profile was maintained at saturated state and (iv) aerobic (AER) where irrigation was given when Ψ_m at 500 mm depth reached −0.05 M Pa. In this treatment the soil moisture status in 0–500 mm soil layer reached field capacity ($\Psi_m = -0.03$ M Pa) level after each irrigation. Soil matric potential was measured with the help of tensiometer and calculation was made as suggested by Hillel (1998). Deficit irrigations were imposed only during stress allowable sage (Sarkar, 2001) of the crop i.e., 16–40 days after transplanting (DAT). During 0 to 15 and 41 to 80 DAT irrespective of irrigation regimes crop was exposed to CP. Amount of water irrigated under different treatments are presented in Table 1. Total arsenic content of irrigation water of the study field was 0.167 mg L^{-1}.

2.4. Total arsenic analysis

Dried soil, root, shoot, leaf and grain samples were soaked overnight by tri-acid mixture HNO_3, $HClO_4$ and H_2SO_4 in10:4:1(v/v) ratio followed by digestion with the same until a clear solution is obtained. Water samples and all digested samples were filtered through Whatman No. 42 and diluted up to 50 ml. After further necessary dilution 5 ml HCl and 1 ml of each reagent 5% KI (w/v) and 5% Ascorbic acid (w/v) was added to all samples followed by

Table 1
Total arsenic content in irrigation water, soil and different plant parts of rice.

Sl No.	Water, Arsenic content, mg L^{-1}	Soil	Root	Straw	Grain
		Arsenic content, mg kg^{-1}			
1	0.056	9.05	11.60	0.42	0.21
2	0.089	13.28	11.07	0.388	0.32
3	0.104	11.87	13.97	0.31	0.37
4	0.116	12.79	14.83	0.534	0.39
5	0.117	13.32	15.79	o.52	0.42
6	0.127	16.88	17.36	0.453	0.46
7	0.146	17.84	17.46	0.467	0.49
8	0.167	16.63	17.56	0.525	0.51
9	0.191	16.78	18.25	0.43	0.53
10	0.200	16.75	16.34	0.654	0.55
11	0.201	15.07	17.37	0.66	0.55
12	0.210	14.55	17.83	1.02	0.56
13	0.235	14.45	22.30	1.15	0.57
14	0.327	17.67	22.57	1.052	0.58
15	0.353	18.74	15.55	1.31	0.61
16	0.443	20.63	16.68	1.23	0.67
17	0.454	21.13	17.10	2.02	0.69
18	0.524	21.2	18.92	2.78	0.7
19	0.573	21.20	17.65	2.66	0.72
20	0.573	21.50	25.45	2.524	0.7
21	0.585	23.67	27.35	3.64	0.72
22	0.585	25.80	28.97	4.43	0.67