Effect of Water Management and Phosphorus rates on the Growth of Rice in a High-Arsenic Soil-Water System

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Introduction

Water and phosphorus management of soil can potentially be used to mitigate arsenic phytoxicity and uptake of arsenic in rice. Under high soil arsenic conditions, addition of phosphate to aerobic soils may displace arsenate from the soil adsorption sites and enhance downward movement of arsenic, leading to increased leaching from the topsoil (Davenport *et al., 1991* and Peryea *et al., 1997*). On the other hand, arsenic may also compete with phosphate for uptake by plants, increasing the availability of arsenic in the soil solution resulting in higher uptake of As by the plants (Creger *et al., 1994)*. Under anaerobic soil conditions, phosphate addition will more likely displace arsenite from adsorption sites making it more readily available for plant uptake since it is not competitive with phosphate. Rice is the staple food for the population, and rice straw (leaves and stalk) is used as cattle feed. Therefore, it is necessary to evaluate the impact of using irrigation water contaminated with arsenic with the application of phosphorus on the arsenic uptake and accumulation in rice grain and straw. So, this study has been undertaken to evaluate (i) the impact on crop productivity (yield) and (ii) impact on crop quality.

Material and Methods

Aman and boro rice were grown in pots at the Wheat Research Centre, Nashipur, Dinajpur, Bangladesh, during 2003-04 season. Soil used in the pots was extracted from a typical field in Dinajpur and had very low amount of organic matter (0.23%), phosphorus (7.31 µ of P g $soil^{-1}$), iron (23.24 µ of P g $soil^{-1}$) and arsenic (1 mg of As kg $soil^{-1}$).

Two 30-45 day old seedlings per pot were transplanted into plastic pots and grown to maturity in a polyethylene tent house. Treatments consisted of three levels, each of arsenic (0, 20 and 40 mg of As kg $soil^{-1}$) and phosphorus (0, 12.5 and 25 mg of P kg $soil^{-1}$) and two water management (flooded and saturated conditions) regimes. The design was completely randomized and each treatment was replicated three times. Yield and yield component data were collected at plant maturity and rice plant parts (grain, straw and roots) were sampled for determination of arsenic content. Data were subjected to analysis of variance MSTAT-C. Treatment means were compared using Duncan's Multiple Range Test (DMRT) at $p = 0.05$.

Results and Discussion

Main effects of As, P and water management on yield and rice plant parts

The concentration of arsenic in soil has a marked effect on plant growth and yield (Figures 1 & 2). With increasing of arsenic doses grain yield significantly decreased from 30 to 20 g/pot in t-aman and from 49 to 25 g/pot in boro rice. Phosphorus rate and water management also had significant effects on grain yield. The treatment without arsenic yielded the most straw (32 g/pot in t-aman and 106 g pot^{-1} in boro rice) while the lowest straw production (22 and 69 g pot^{-1} in t-aman and boro rice, respectively) was found in the highest arsenic treatment (40 mg of As kg soil^{-1}). The lowest root bio-mass (10 g in t-aman and 31 g pot^{-1} in boro) were obtained in the highest arsenic treatment (40 mg of As kg soil^{-1}) followed by the use of medium dose of arsenic (20 mg of As kg soil^{-1}). The highest root biomass (16 and 49 g pot^{-1} in t-aman and boro rice, respectively) was recorded from zero arsenic. No significant differences ($p>0.05$) were observed in root biomass production from the use of P, but there were significant effects of saturated water management on straw and root biomass. These results are also consistent with the findings of Abedin *et al* (2002). They reported that increasing the concentration of arsenic in irrigation water significantly decreased plant height, grain yield, the number of filled grains, grain weight, and root biomass.

Interaction effects of As, P and water management on yield and rice plant parts

The interaction effects of arsenic, phosphorus and water management had a significant role on straw and root biomass production (Table 1). The highest grain yield (35 and 63 g in t-aman and boro rice, respectively) was obtained in plants grown without arsenic and with a moderate dose of phosphorus (12.5 mg of P kg soil^{-1}) under saturated conditions (Table 1). A similar trend was also observed with rice straw and root biomass. Rice straw and root biomass varied significantly with arsenic concentration. The highest straw yields (36.10 and 120.5 g pot^{-1} in t-aman and boro rice, respectively) and root biomass (16.20 in t-aman and 57.0 g pot^{-1} in boro rice) were recorded in plants grown without arsenic, with a medium rate of phosphorus (12.5 mg P kg soil^{-1}) under saturated conditions. Plants grown under saturated conditions treated with arsenic and phosphorus (except T_{13} and T_{16}) produced superior plant height, number of tillers, filled grain, grain and straw yield and root biomass compared to plants grown under flooded condition. Under saturated conditions, P is less available in the soil solution and may be in a from (As V) assimilated competively with phosphate which ultimately reduces the phytotoxicity of arsenic.

In conclusion, arsenic depressed rice yields, indicating phytotoxicity. Adding phosphorus to the soil reduced arsenic toxicity. Saturated soil conditions reduced arsenic toxicity compared to flooded soil conditions for all phosphorus levels. Both water and phosphorus management are thus tools to manage potential arsenic toxicity in rice.

Acknowledgement

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References

Abedin, M.J.,M.S. Cresser, A.A. Meharg, J. Feldmann and J.Cotter-Howells. 2002. *Environ. Sci. Technol*. 36:962-968.

Creger, T.L. and F.J. Peryea.1994. Hortic. Sci. 29:88-92.

Davenport, J.R. and F.J. Peryea. 1991. Water Air Soil Pollut. 57-58, 101-110.

Peryea, F.J. and R. Kammereck. 1997. Water Air Soil Pollut. 93:243-254.

Fig 1: Effects of Phosporus, Arsenic and Water Management on transplanted aman rice in a pot culture

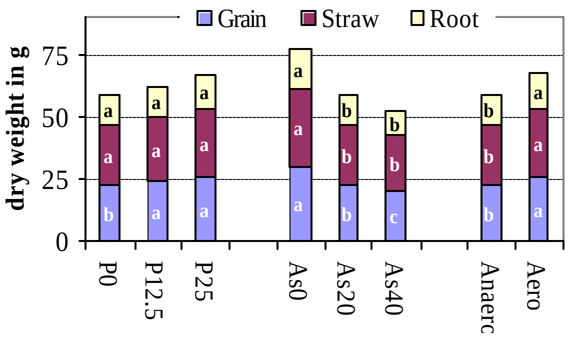
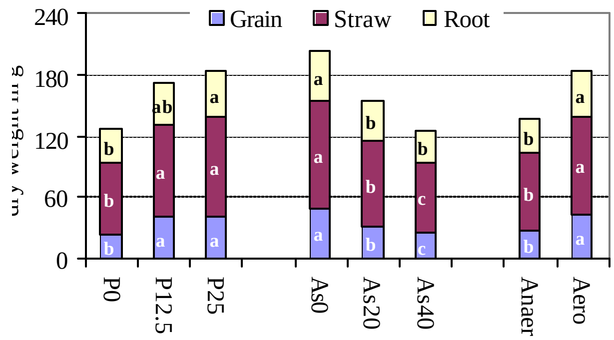


Fig 2: Effects of Phosphorus, Arsenic and Water Management on transplanted boro rice in a pot culture



Notes: P, phosphorus (mg of P kg soil^{-1}); As, arsenic (mg of P kg soil^{-1}); water management (saturated and flooded) within the bar graph figures having the same letters are not significantly difference at 5% level by DMRT

Table 1: Interactions effects of Phosphorus, arsenic and Water management on plant growth, yields and plant parts in transplanted aman and boro rice in a pot culture

Treat ment code	Treatment combination			Grain yield (g pot^{-1})		Straw yield (g pot^{-1})		Root biomass (g)	
	P (mg/kg soil)	As (mg/ kg soil)	W M	t-aman	boro	t-aman	Boro	t-aman	boro
T_1	0	0	An	27.8 bc	30.1 d	28.4 cd	88.1 fg	13.1 c-f	43.1 bc
T_2	0	20	An	18.2 ij	17.2 g	19.5 g	58.1 j	9.2 ghi	29.1 de
T_3	0	40	An	16.5 j	7.7 h	20.8 fg	35.8 k	7.1 i	19.9 f
T_4	12.5	0	An	30.1 b	50.4 b	33.2 ab	115.8 ab	17.1 a	40.3 bc
T_5	12.5	20	An	18.5 hij	24.2 ef	21.0 fg	78.3 gh	10.5 fg	34.7 cd
T_6	12.5	40	An	17.7 j	16.2 g	18.2 g	58.0 j	8.0 hi	27.1 def
T_7	25	0	An	28.7 bc	46.4 bc	27.3 cd	101.9 cd	15.5 abc	47.4 b
T_8	25	20	An	25.6 cde	29.5 de	25.0 def	85.0 fgh	13.1 c-f	34.4 cd
T_9	25	40	An	21.0 fi	20.6 fg	24.1 def	66.2 ij	11.5 fg	35.6 cd
T_{10}	0	0	A	29.7 b	43.1 c	28.4 cd	90.5 ef	17.2 a	48.1 b
T_{11}	0	20	A	23.5 def	27.9 de	25.7 cde	76.2 hi	14.2 b-e	35.2 cd
T_{12}	0	40	A	21.5 fgh	20.5 fg	21.1 fg	63.7 j	11.6 efg	25.0 ef
T_{13}	12.5	0	A	35.0 a	63.0 a	36.1 a	120.5 a	16.2 ab	57.0 a
T_{14}	12.5	20	A	22.6 efg	44.1 c	24.6 def	98.8 de	11.7 efg	45.0 b
T_{15}	12.5	40	A	19.5 gj	41.1 c	22.1 efg	80.0 fgh	9.9 gh	35.1 cd
T_{16}	25	0	A	18.1 bc	58.7 a	33.7 a	117.0 ab	15.2 abc	60.0 a
T_{17}	25	20	A	26.1 cd	45.8 bc	29.6 bc	110.0 abc	14.3 bcd	48.2 b
T_{18}	25	40	A	23.5 def	43.2 c	27.1 cd	108.3 bcd	12.6 def	42.0 bc
CV (%)				4.20	5.38	5.11	4.06	6.33	6.82

An, anaerobic water management; A, aerobic water management

±Within the treatment interactions the figures having the same letters are not significantly difference at 5% level by DMRT