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EFFECTS OF ARSENIC AND PHOSPHORUS ON THE GROWTH AND NUTRIENT CONCENTRATION IN RICE PLANT

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Abstract

A pot experiment was carried out with arsenic (As) *viz.* 0, 0.1, 1 and 2 mgL^{-1} as sodium arsenite and phosphorus viz, 0, 15 and 30 μgmL^{-1} as ammonium dihydrogen phosphate to evaluate their effects on dry matter yield and nutrients concentration in rice plants (*Oryza sativa* L.) in the net house. Arsenic toxicity caused more damage to root than to shoot. As reduced plant height and dry matter yields but lower level increased the same significantly. A maximum diminution of 26.70% shoot weight and 32.30% root weights were observed where 2 mgL^{-1}As and 0 μgmL^{-1} P were applied. Micronutrients were found to be more strongly antagonized by arsenic than the macronutrients. Maximum and minimum accumulation of different nutrients was found at 30 μgmL^{-1} and 0 μgmL^{-1} P applications, respectively. The lowest concentration of most of the nutrients were found at 2 mgL^{-1}As and 0 μgmL^{-1} P. Experiment revealed that the concentrations of nitrogen, potassium, sulphur, iron, copper, zinc and manganese in the root and shoot of rice plants showed an antagonistic effect with As and synergistic effect with P.

***Key words*:** Arsenic; Phytotoxicity; Nutrients; Food chain; Accumulations.

INTRODUCTION

Arsenic is a potent environmental pollutant that has caused one of the largest public health poisonings in the history of human civilization (Islam and Hossain 2019). Arsenic contamination of paddy soils irrigated with arsenic-rich groundwater in Bangladesh is well documented (Meharg and Rahman 2003, Huq and Naidu 2003) and the risk of soil contamination is higher in the areas where the groundwater has elevated arsenic (Meharg and Rahman 2003, Huq 2008, Lu *et al*. 2009). The people of Bangladesh are not only drink the arsenic contaminated groundwater but also irrigate their crops. About 33% of total arable land of the country is under irrigation facilities. Irrigation is principally performed in dry season for boro rice cultivation. In Bangladesh, a large number of shallow tube well and deep tube well have been installed to irrigate about 4.3 million hectares of crop land which contributes to the food grain production of the country significantly (Rashid *et al*. 2004). The agricultural soil of arsenic non-contaminated areas of Bangladesh contain 4 to 8 mg As kg^{-1} while that irrigated with arsenic contaminated groundwater, contain up to 83 mg As kg^{-1}. The maximum acceptable concentration of arsenic in agricultural soil is 20 mg kg^{-1}. Chowdhury *et al.* (2017) observed that the concentration of arsenic was higher in paddy soils compared to non-paddy soils, with soils irrigated with groundwater being higher in arsenic than those irrigated with surface water. At higher concentration, arsenic is toxic to most plants. It interferes with metabolic processes and inhibits plant growth and development through arsenic induced phytotoxicity. When plants are exposed to excess arsenic either in soil or in solution culture, they exhibits toxicity symptoms such as inhibition of seed germination (Abedin *et al*. 2002a), decrease in plant height (Abedin *et al.* 2002b, Jahan *et al.* 2003), depress in tillering (Rahman *et al.* 2004), reduction in root growth (Abedin *et al.* 2002a), decrease in shoot growth (Khan *et al.* 2010), lower fruit and grain yield (Abedin *et al.* 2002b; Panaullah *et al.* 2009) and sometimes, leads to death. Chowdhury *et al.* (2018) concluded that the paddy soils of different physiographic regions in Bangladesh had differences in their total, bioavailable and solid phase pool of arsenic. Recent studies have highlighted areas of Bangladesh where soil arsenic is elevated (Martin *et al.* 2014), however, these studies have not indicated the concentrations of arsenic in the soil available to plants, which is more important considering the food security and human health (Chowdhury *et al*. 2018).

The present study was carried out to evaluate the effects of As and P with 5 tonha^{-1} water hyacinth compost on the growth and macro- and micro nutrient concentrations in rice plants.

MATERIAL AND METHODS

Soil

Surface sample (0 to 15 cm depth) was collected from Koroia union, Kochua upazila, under Chandpur district. Samples were air- dried, ground, sieved (<3 mm sieve) and kept in polyethylene bags. Water hyacinth was collected from the same location, cut into pieces, added few grammes of soil, saturated with water and kept in gunny bags under shaded condition. After, six weeks compost was ready. Some physicochemical properties of the soil were determined following standard methods. Soil had a pH (1:2.5 w/v H_2O) of 6.28, organic carbon 2.05%, organic matter 3.53%, available N, P , K and S were 299, 34, 26, and 92 mgkg^{-1}, respectively., total N, P, K and S were 0.19, 0.13, 0.25 and 0.14% respectively., total As, Fe, Zn, Cu and Mn were 3.0, 347, 25, 179 and 67 mgkg^{-1}, respectively., moisture content 20.7, sand 1.75, silt 62.50 and clay 35.75% respectively and silty clay loam in texture. The concentration of some nutrients in water hyacinth compost was total N 0.75%, total S 0.23%, and total As, Fe, Zn, Cu and Mn were 0.51, 330, 188, 31.3 and 68 mgkg^{-1}, respectively.

Pot experiment

Four kilogram of soil was used per plastic pot (height 22 cm and diameter 27 cm). The pots were arranged in a completely randomized design (CRD).Four levels of arsenic (As) as sodium arsenite *viz*. 0, 0.1, 1 and 2 mg L^{-1} and three doses of phosphorus *viz*. 0, 15 and 30 mgkg^{-1} as ammonium dihydrogen phosphate were added. A basal dressing of N at the rate of 40 kg ha^{-1} as urea, K at the rate of 20 kgha^{-1} as muriate of potash and S at the rate of 5 kgha^{-1} as gypsum and 5 tonha^{-1} water hyacinth compost were added. Treatments were replicated three times. Arsenic was applied with irrigation water in the form of solution every alternate day. Three rice seedlings (BRRI- 48) of three weeks old were transplanted per pot. The height of the individual plant was measured from the soil level to the tip of the leaflet at 15-day intervals and only the values of 75, 90 and 105 days are presented in Table 1.

Harvesting and analysis

Fifteen weeks old plants were harvested as root, shoot and grain. Roots were washed with tape water and finally with distilled water. Samples were oven-dried at 65°C in an oven for 72 hours. Dry weight of the samples were recorded, ground with a mechanical grinder and stored in air- tight polyethylene bags for chemical analysis. The concentration of nitrogen in shoot and root was determined by using micro Kjeldahl distillation method (Cresser and Parson 1979), phosphorus was determined following vanadomolybdophosphoric yellow colour method (Jackson 1965) at a wave length 430 nm using spectrophotometer model DR 5000, potassium was determined using Jenway flame photometer model PFP 7 and sulphur was determined by spectrophotometer (Klute 1986). The concentration of iron, copper, zinc and manganese were determined in the atomic absorption spectrometer (AAS) model Varian AA 240. Results were statistically analyzed using Microsoft Excel and Software Minitab 18.

RESULTS AND DISCUSSION

Height and dry matter yield

The average heights of rice plants were recorded at 75, 90 and 105 days after transplanting (Table 1). Results varied significantly ($p< 0.05$). At 75, 90 and 105 days after transplantation, 1 and 2 mgkg^{-1} As treatments caused a significant reduction in plant height. The highest height of rice plant (85 cm) was recorded in 0.1 $mgkg^{-1}$As treatment where 30 $mgkg^{-1}$ phosphorus was applied at 105 days after transplantation. The lowest height (58 cm) was observed in 2 $mgkg^{-1}$As where 0 $mgkg^{-1}$ P was applied.

Table 1. Height of rice plants grown at different levels of As and P.

As levels ($mgkg^{-1}$)	P levels ($mgkg^{-1}$)	Plant height (cm)		
		75d	90d	105d
0 (Control)	0	61^{b}	78^{b}	81^{ab}
	15	61^{b}	78^{c}	81^{b}
	30	61^{bc}	78^{b}	81^{bc}
0.1	0	63^{a}	80^{a}	82^{a}
	15	65^{a}	82^{a}	84^{a}
	30	66^{a}	83^{a}	85^{a}
1	0	60^{b}	77^{b}	80^{b}
	15	62^{b}	80^{b}	82^{b}
	30	63^{b}	82^{a}	83^{ab}
2	0	58^{c}	74^{c}	78^{c}
	15	60^{b}	77^{c}	79^{c}
	30	60^{c}	78^{b}	80^{c}

$^{a\,b\,c}$ data bearing different superscripts within the same column differ significantly at 5% level.

Plant growth was also influenced by phosphorus and it reached maximum level when 30 $mgkg^{-1}$P was applied. The progressive accumulation of arsenic (As) in plants with the time of exposure to As treatments caused the reduction of plant height (Barrachina *et al.* 1994). A reduction in plant height with increasing arsenic concentration was reported by Yamare (1989) in rice plants. Dry weights of shoot and root of rice plants are presented in Table 2. The results varied significantly at 5% level.

Table 2. Dry matter production (g/pot) of rice plants at different levels of As and P.

As level ($mgkg^{-1}$)	Phosphorus (0 $mgkg^{-1}$)		Phosphorus (15 $mgkg^{-1}$)		Phosphorus (30 $mgkg^{-1}$)	
	Shoot	Root	Shoot	Root	Shoot	Root
0 (Control)	2.12^{b}	0.62^{b}	2.12^{d}	0.62^{b}	2.12^{b}	0.62^{d}
0.1	2.25^{a}	0.66^{a}	2.47^{a}	0.71^{a}	2.90^{a}	0.77^{a}
1	2.21^{a}	0.64^{ab}	2.37^{b}	0.69^{a}	2.41^{b}	0.70^{b}
2	2.07^{b}	0.53^{c}	2.28^{c}	0.68^{a}	2.35^{b}	0.67^{c}

$^{a\,b\,c\,d}$ data bearing different superscripts within the same column differ significantly at 5% level.

The highest dry matter yields of shoot (2.90 g) and root (0.77 g) were obtained at 0.1 $mgkg^{-1}$As treatment where 30 $mgkg^{-1}$phosphorus was used (Table 2). The lowest values for shoots (2.07 g) and roots were (0.53 g) obtained at 2 $mgkg^{-1}$As where 0 $mgkg^{-1}$ phosphorus was applied (Table 2). Dry matter production varied significantly ($p<0.05$) in all As treatments. It was evident from the results that 1 $mgkg^{-1}$As level was the threshold value to reduce the dry matter yields in rice plants. There was a further decrement in dry matter yield from 1 to 2 $mgkg^{-1}$As level. The results of the present investigation are in agreement with the findings of Paivoke (1983) in garden pea and Marin *et al.* (1992) in rice.

Macronutrients (N P K S)

The concentration of nitrogen in shoot and root of rice plants was affected by different levels of arsenic (Table 3). Data showed that nitrogen concentration in rice shoot and root at different arsenic treatments varied significantly ($p<0.05$). The nitrogen concentration ranged from 0.576 to 0.662% in shoot and 0.965 to 1.184% in root (Table 3). The maximum concentration in both root (1.184%) and shoot (0.662%) were obtained at the 0 $mgkg^{-1}$ treatment of arsenic with different doses of phosphorous application. The minimum value was obtained at 2 $mgkg^{-1}$ treatment (0.965% in root and 0.576% in shoot) of arsenic when 0 $mgkg^{-1}$ phosphorous was used. The decrease in nitrogen content with increasing arsenic treatment was found in many plant parts in rice (Yamare 1989) and in garden pea (Paivoke 1983). Merry *et al.*(1986) observed antagonistic effects between arsenic and nitrogen in silver beet.

The concentration of P in rice plants was affected by different levels of arsenic and varied significantly ($p<0.05$). In both shoot and root, the absorption of phosphorus was influenced by As. Arsenic interferes the activity of phosphorus in plants. Maximum phosphorus concentration (0.172%) in root was obtained at 0.1 $mgkg^{-1}$As where 30 $mgkg^{-1}$ dose of P was applied (Table 3).The lowest value was recorded at 2 $mgkg^{-1}$As level which was 0.134% where 0 $mgkg^{-1}$ P was applied (Table 3). In shoot, the maximum P concentration was obtained (0.253%) at 0.1 $mgkg^{-1}$ As level where 30 $mgkg^{-1}$ P was applied (Table 3) and the lowest value (0.193%) was observed at 2 $mgkg^{-1}$ As treatment where 0 $mgkg^{-1}$ P was applied (Table 3). A strong antagonistic effect of As on P uptake in plants might be due to the act that arsenic behaves in soil-water system very much similar to that of phosphorus and was taken up by roots by the same mechanism as phosphorus (Wauchope 1983, Meharg and Maenair 1990). Phosphorus concentration was also reduced with increasing arsenic concentration in rice (Onken *et al.* 1995), in alfalfa (Khattak *et al.*1991), in bush bean (Wallace 1980) and in the leaf of cauliflower (Blatt 1990).

Potassium concentration in rice plants was affected by different levels of As and P (Tables 3). Results of shoot and root differed significantly ($p<0.05$). The range for K content of rice plants was found to be a from 0.1287 to 0.3634% in roots. The ranges for potassium content in shoot were 1.8598 to 2.5604%. Arsenic was found to reduce potassium content significantly in rice plants at different levels of As in shoot. Maximum potassium concentration in root was obtained at 0 $mgkg^{-1}$As in the nutrient solution where 0, 15 and 30 $mgkg^{-1}$ doses of P was applied separately and the highest concentration of potassium was 0.3634%. The lowest value was measured at 2 $mgkg^{-1}$As level which was 0.1287% where 15 $mgkg^{-1}$P was applied (Table 3). In shoot, the maximum potassium concentration was obtained (2.5604%) at 0 $mgkg^{-1}$As level where 0, 15 and 30 $mgkg^{-1}$ P was applied separately and the lowest value (1.8598%) was observed at 2 $mgkg^{-1}$As treatment where 15 $mgkg^{-1}$ P was applied. Arsenic-potassium antagonistic interaction was found in capsicum (Karimian *et al*. 1983), in rice (Yamare1989) and in the root of bush bean (Wallace *et al.*1980).

The highest and lowest concentrations of sulphur in rice roots were observed at 0.1 $mgkg^{-1}$ and 2 $mgkg^{-1}$ As treatment where 0 $mgkg^{-1}$ and 15 $mgkg^{-1}$ P was applied, respectively and the highest value was 0.6025% and the lowest value was 0.2878% (Tables 3). Results varied significantly ($p<0.05$) in root and shoot. The ranges of sulphur content in root and shoot were 0.2878 to 0.6025% and 0.2510 to 0.2969% respectively. In rice root and shoot As levels caused significant decrease in sulfur concentration. In shoots, the maximum sulphur concentration was obtained (0.2969%) at 0.1 $mgkg^{-1}$ As level where 15 $mgkg^{-1}$ P was applied and the lowest value (0.2510%) was observed at 1 $mgkg^{-1}$ As treatment where 0 $mgkg^{-1}$ P was applied. Merry *et al.* (1986), Kitagishi and Yamare (1981) reported that there is an interaction between S and As. Arsenic blocks the sites of sulfur in thio-enzymes. Jahan *et al.* (2003) performed a pot experiment on the accumulation of arsenic in rice plants and its effects on nutrient uptake viz. N, P, K, Ca, Fe and Zn using 7 levels of arsenic namely 0, 10, 20, 30, 40, 50 and 60 $mgkg^{-1}$ soil and found that arsenic resulted in decreasing the uptake of most of the above plant nutrients. They also recorded the content of arsenic was higher in rice root than that of shoots.

Micronutrients (Fe Cu Zn Mn)

The concentration of micronutrients *viz*. iron, copper, zinc and manganese are presented in Table 4. Iron is the only element observed which was synergized by arsenic. Iron concentrations in root were in the range of 12918 to 31245 $mgkg^{-1}$ and in shoot from 614 to 1047 $mgkg^{-1}$. Results varied significantly ($p<0.05$). The highest and lowest concentrations of iron in rice roots were recorded at 0.1 $mgkg^{-1}$As where 30 $mgkg^{-1}$ and 15 $mgkg^{-1}$ P was applied respectively, the highest value was 31245 $mgkg^{-1}$ and the lowest value was 12918 $mgkg^{-1}$. Root accumulated more Fe than shoot. Its concentrations in root was about two times than that of shoot. In shoot, the lowest value of iron was 614 $mgkg^{-1}$ at 1 $mgkg^{-1}$As level where 0 $mgkg^{-1}$ P was applied and the highest value of iron was 1047 $mgkg^{-1}$ at 2 $mgkg^{-1}$As level where 30 $mgkg^{-1}$ P was applied. Arsenic-iron synergisms were reported previously in rice plants (Yamare1989) and in tomato plants (Barrachina *et al.* 1994). Yamare (1989) also found an increase in Fe concentration in rice with the increase of arsenic concentrations.

Table 3. The concentration of macronutrients in shoot and root of rice plants at different levels of As and P.

As level (mg kg^{-1})	Shoot & root	Phosphorus (0 $mgkg^{-1}$)				Phosphorus (15 $mgkg^{-1}$)				Phosphorus (30 $mgkg^{-1}$)			
		N (%)	P (%)	K (%)	S (%)	N (%)	P (%)	K (%)	S (%)	N (%)	P (%)	K (%)	S (%)
0*	Shoot	0.662^{a}	0.242^{a}	2.5604^{a}	0.2750^{a}	0.662^{a}	0.242^{a}	2.5604^{a}	0.2750^{b}	0.662^{a}	0.242^{b}	2.5604^{a}	0.2750^{b}
	Root	1.184^{a}	0.161^{a}	0.3634^{a}	0.5816^{b}	1.184^{a}	0.161^{ab}	0.3634^{a}	0.5816^{a}	1.184^{a}	0.161^{ab}	0.3634^{a}	0.5816^{a}
0.1	Shoot	0.621^{b}	0.243^{a}	2.3352^{a}	0.2729^{a}	0.635^{b}	0.251^{a}	2.2601^{b}	0.2969^{a}	0.645^{a}	0.253^{a}	2.3102^{a}	0.2838^{a}
	Root	1.067^{b}	0.169^{a}	0.1558^{bc}	0.6025^{a}	1.112^{b}	0.171^{a}	0.2879^{b}	0.3405^{b}	1.134^{a}	0.172^{a}	0.2498^{b}	0.5283^{c}
1	Shoot	0.593^{bc}	0.209^{b}	2.4603^{a}	0.2510^{c}	0.605^{c}	0.212^{b}	2.0851^{bc}	0.2772^{b}	0.612^{b}	0.223^{c}	2.0349^{b}	0.2903^{a}
	Root	0.997^{c}	0.148^{b}	0.1758^{b}	0.4497^{d}	1.002^{c}	0.151^{bc}	0.1358^{c}	0.3449^{b}	1.023^{b}	0.152^{bc}	0.2278^{bc}	0.5384^{b}
2	Shoot	0.576^{c}	0.193^{c}	1.9098^{b}	0.2619^{b}	0.594^{c}	0.199^{b}	1.8598^{c}	0.2598^{c}	0.605^{b}	0.212^{d}	2.0051^{b}	0.2532^{c}
	Root	0.965^{c}	0.134^{c}	0.1453^{c}	0.5741^{c}	0.983^{c}	0.145^{c}	0.1287^{c}	0.2878^{b}	0.992^{b}	0.148^{c}	0.2178^{c}	0.4104^{d}

[a b c d] data bearing different superscripts within the same column differ significantly at 5% level; * Control

Concentration of Cu in rice root and shoot varied from 21 to 71 $mgkg^{-1}$ and 1610 to 2532 $mgkg^{-1}$, respectively. Shoot accumulated more copper than root. Maximum copper concentration in root was observed under 0.1 $mgkg^{-1}$As treatment where 0 $mgkg^{-1}$ P was applied and the highest value of copper was 71 $mgkg^{-1}$, while in shoot, maximum copper concentration (2532 $mgkg^{-1}$) was observed at 0.1 $mgkg^{-1}$ As treatment where 15 $mgkg^{-1}$ P was applied. A significant decrease in copper content in root was obtained from 2 $mgkg^{-1}$As treatment where 15 $mgkg^{-1}$ P was applied and the lowest value of copper was 21 $mgkg^{-1}$. In case of shoot, a significant decrease was found from 2 $mgkg^{-1}$As where 15 $mgkg^{-1}$ P was applied and the value was 1610 $mgkg^{-1}$. Results varied significantly ($p<0.05$) for root and shoot. It was observed that arsenic influenced the concentration of copper in rice plants. The results of the present investigation support the earlier findings of Barrachina *et al.* (1994) who observed a decrease in Cu content in tomato plants with increasing As concentration in culture solution. Results showed that arsenic antagonised absorption of copper in both root and shoot of rice plants (Table 4). Lonergan and Asher (1967) found the existence of P-Cu interaction regarding the uptake of Cu by the root.

Table 4. The concentration of micronutrients in shoot and root of rice plants at different levels of As and P.

As level (mg kg^{-1})	Shoot & root	Phosphorus (0 $mgkg^{-1}$)				Phosphorus (15 $mgkg^{-1}$)				Phosphorus (30 $mgkg^{-1}$)			
		Fe (mg kg^{-1})	Cu (mg kg^{-1})	Zn (mg kg^{-1})	Mn (mg kg^{-1})	Fe (mg kg^{-1})	Cu (mg kg^{-1})	Zn (mg kg^{-1})	Mn (mg kg^{-1})	Fe (mg kg^{-1})	Cu (mg kg^{-1})	Zn (mg kg^{-1})	Mn (mg kg^{-1})
0*	Shoot	699^{c}	2412^{a}	1054^{a}	333^{d}	699^{d}	2412^{a}	1054^{a}	333^{d}	699^{d}	2412^{a}	1054^{a}	333^{d}
	Root	29118^{a}	68^{a}	226^{a}	582^{a}	29118^{a}	68^{a}	226^{a}	582^{a}	29118^{ab}	68^{a}	226^{a}	582^{a}
0.1	Shoot	958^{a}	2212^{b}	981^{b}	721^{a}	922^{a}	2532^{a}	890^{b}	653^{a}	918^{b}	2322^{b}	870^{b}	828^{a}
	Root	20938^{b}	71^{a}	193^{b}	532^{b}	12918^{b}	32^{b}	114^{b}	513^{b}	31245^{a}	29d	120^{b}	550^{b}
1	Shoot	614^{d}	1923^{c}	779^{c}	526^{b}	821^{c}	2102^{b}	750^{c}	573^{b}	759^{c}	2243^{c}	740^{c}	588^{b}
	Root	28658^{a}	30^{b}	164^{c}	487^{c}	17218^{b}	23^{c}	94^{c}	423^{c}	27317^{ab}	54^{b}	99^{c}	530^{c}
2	Shoot	807^{b}	1610^{d}	679^{d}	446^{c}	830^{b}	2032^{b}	650^{d}	538^{c}	1047^{a}	1965^{d}	634^{d}	398^{c}
	Root	23034^{b}	25^{c}	159^{d}	334^{d}	15617^{b}	21^{c}	83^{d}	354^{d}	24214^{b}	35^{c}	82^{d}	337^{d}

[a b c d] data bearing different superscripts within the same column differ significantly at 5% level; * Control.

Zinc concentration in rice root and shoot was affected by arsenic treatments (Tables 4). The results differed significantly ($p<0.05$). Zinc concentration varied in rice root and shoot from 82 to 226 $mgkg^{-1}$ and 1054 to 634 $mgkg^{-1}$. The maximum concentration of Zn in rice root (226 $mgkg^{-1}$) was obtained at 0 $mgkg^{-1}$As treatment where 0 $mgkg^{-1}$P was applied. The lowest concentration of zinc in rice root (82 $mgkg^{-1}$) was recorded at 2 $mgkg^{-1}$As treatment where 30 $mgkg^{-1}$ P was used. It was observed that Zn concentration in root was significantly different with different doses of As treatment and zinc concentrations in the shoot of rice plants differed significantly ($p<0.05$). The maximum concentration of Zn in rice shoot (1054 $mgkg^{-1}$) was obtained at 0 $mgkg^{-1}$As treatment where 0 $mgkg^{-1}$ dose of P was applied. The lowest concentration of zinc in rice shoot (634 $mgkg^{-1}$) was measured at 2 $mgkg^{-1}$As treatment where 30 $mgkg^{-1}$P was added. It was observed that Zn concentrations in shoot varied significantly ($p<0.05$).The antagonistic effect of As on Zn was reported by Barrachina *et al.* (1994) in tomato plants. Heidaryan *et al.* (2011) observed an antagonistic interaction of Zn and P. Yoshida and Tanaka (1969) reported that normal rice plants became zinc deficient with the addition of 0.5% cellulose to the soil. Experiments of Forno *et al*. (1975), and Mikkelsen and Brandon (1972) also showed that addition of readily decomposable organic materials may aggravate zinc deficiency and reduce zinc uptake by rice plants.

Manganese concentrations in rice root and shoot were affected by different levels of arsenic and are presented in Table 4. Results of root and shoot varied significantly ($p<0.05$). The ranges of Mn concentration in root and shoot were 334 to 582 $mgkg^{-1}$ and 333 to 828 $mgkg^{-1}$, respectively. It was found that Mn concentration declined with increasing levels of As in rice root and shoot. Manganese concentration in the shoot of rice plants was reduced from 0.1 $mgkg^{-1}$As to 2 $mgkg^{-1}$As dose significantly ($p<0.05$). Manganese concentration also reduced from 0.1 $mgkg^{-1}$As to 0 $mgkg^{-1}$As dose application in the shoot of rice plants. The highest concentration of Mn was found 582 $mgkg^{-1}$ in the root of rice plants where 0 $mgkg^{-1}$As and 0 $mgkg^{-1}$ P was applied. Arsenic (As) treatments differed significantly with the control, while 2 $mgkg^{-1}$As treatment differed significantly ($p<0.05$) with all other treatments and caused a decrease in Mn concentration in the root of rice plants. In rice shoot, the maximum concentration of Mn was obtained again at 0.1 $mgkg^{-1}$As treatment, then decreased in Mn concentration with increase in As concentration. Arsenic concentration of 1 $mgkg^{-1}$ differed significantly from 0.1 $mgkg^{-1}$ treatment, while 2$mgkg^{-1}$As differed significantly compared to the control and 0.1 $mgkg^{-1}$ arsenic treatment. Such antagonistic effect of As on Mn uptake was reported in tomato plants by Barrachina *et al.* (1994) and in rice plants by Yamare (1989).

The experiment revealed that arsenic reduced the growth of rice plants and the concentrations of nitrogen, potassium, sulphur, iron, copper, zinc and manganese were antagonized by arsenic. The concentration of micronutrients was affected more severely than those of the macronutrients. Therefore, the concentration of arsenic in the soils might be an additional strategy for a more rational agricultural program.

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