EFFECTS OF DIFFERENT DOSES OF ARSENIC LEVELS IN GROWTH AND YIELD OF RICE

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EFFECTS OF DIFFERENT DOSES OF ARSENIC LEVELS IN GROWTH AND YIELD OF RICE

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Dedicated

To

My Beloved Parents and Younger Brother

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CERTIFICATE

This is to certify that the thesis entitled **“EFFECTS OF DIFFERENT DOSES OF ARSENIC LEVELS IN GROWTH AND YIELD OF RICE”** submitted to the **Faculty of Agriculture,** Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE (M.S.) IN SOIL SCIENCE,** embodies the results of a piece of bonafide research work carried out by **SUMYEA AKHTER** Registration. No. 10-04156, under my supervision and guidance. No part of this thesis has been submitted for any other degree or diploma.

I further certify that such help or source of information as has been availed of during the course of this investigation has duly been acknowledged.

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EFFECTS OF DIFFERENT DOSES OF ARSENIC LEVELS IN GROWTH AND YIELD OF RICE

ABSTRACT

The pot experiment was conducted at the Sher-e-Bangla Agricultural University, Dhaka, Bangladesh during the period from December 2016 to March 2017 to study the effect of arsenic on growth and yield of rice. The experiment comprised of two factors. Factor A: Arsenic level (4 levels): A_1: Control (No arsenic); A_2: 1 ppm As pot^{-1}, A_3: 2 ppm As pot^{-1} and A_4:4 ppm As pot^{-1}. Factor B: Nitrogen doses: (2 Nos.); T_1: recommended dose of nitrogen; T_2: 50% more than recommended dose of N.The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. In case of arsenic, at harvest,the tallest rice plant (92.00 cm), highest effective tillers per plant (24.0), the largest panicle length (23.93 cm), the highest filled grain per plant (880.67) , the highest filled grain per panicle (43.66),the highest 1000-grain weight (28.26 g), the highest straw yield (28.10 g), the highest grain yield (28.00 g) were found in A_1 treated pot & the highest un-filled grain per panicle (36.00),the highest un-filled grain per plant (298.33) were found in A_4 treated pot.The shortest rice plant (61.90 cm) , lowest effective tillers per plant (12.0) , smallest panicle length (11.48 cm),and lowest filled grain per plant (99.67), and lowest straw yield (8.3 g), lowest grain yield (13.00 g) were found in A_4 treated pot and lowest un-filled grain per plant (188.67),lowest un-filled grain per panicle (22.66) were found in A_1 treated pot and lowest filled grain per panicle (31.00),lowest 1000-grain weight (27.30 g) were found in A_3 treatment.In case of nitrogen, tallest rice plant(92.00), highest effective tillers(24.00), largest panicle length(23.93), , highest straw yield(28.10)were found in T_1 treatment & highest filled grain per plant(880.67) ,highest un-filled grain per plant(298.33), highest filled grain per panicle(43.66), highest un-filled grain per panicle(36.00) ,highest 1000-grain weight(28.26), highest grain yield(28.00) were found in T_2 treatment.On the other hand ,shortest rice plant (61.90 cm), smallest panicle length (11.48 cm),lowest 1000-grain weight (27.30 g), lowest straw yield (8.3 g), lowest grain yield (13.00 g) were found in T_2 treatment & lowest effective tillers per plant (12.0), lowest filled grain per plant (99.67), lowest un-filled grain per plant (188.67), lowest filled grain per panicle (31.00),lowest un-filled grain per panicle (22.66) were found in T_1 treatment.Interaction effect of arsenic & nitrogen doses,highest plant height(92.00 cm), highest effective tillers per plant (24.0), largest panicle length (23.93 cm), highest filled grain per plant (880.67), highest straw yield (28.10 g) found in A_1T_1. The highest filled grain per panicle (43.66),highest 1000-grain weight (28.26 g), highest grain yield (28.00 g) found in A_1T_2.The highest un-filled grain per panicle (36.00), highest un-filled grain per plant (298.33) were found in A_4T_2. On the other hand shortest rice plant (61.90 cm) , lowest effective tillers per plant (12.0) , smallest panicle length (11.48 cm), lowest straw yield (8.3 g), lowest grain yield (13.00 g) were found in A_4T_2 & lowest un-filled grain per plant (188.67), lowest un-filled grain per panicle (22.66) found in A_1T_1.

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LIST OF ACRONYMS

AEZ	=	Agro-Ecological Zone
BARI	=	Bangladesh Agricultural Research Institute
BRRI	=	Bangladesh Rice Research Institute
BBS	=	Bangladesh Bureau of Statistics
DAS	=	Days after sowing
et al.	=	And others
N	=	Nitrogen
TSP	=	Triple Super Phosphate
MoP	=	Muriate of Potash
Ca	=	Calcium
Mg	=	Magnesium
K	=	Potassium
P	=	Phosphorous
Fe	=	Iron
DAT	=	Days after transplanting
ha^{-1}	=	Per hectare
g	=	Gram
kg	=	Kilogram
SAU	=	Sher-e-Bangla Agricultural University
SRDI	=	Soil Resources and Development Institute
HI	=	Harvest Index
No.	=	Number
Wt.	=	Weight
LSD	=	Least Significant Difference
^{0}C	=	Degree Celsius
NS	=	Non-significant
%	=	Percent
CV%	=	Percentage of coefficient of variance
T	=	Ton
viz.	=	Videlicet (namely)

INTRODUCTUION

CHAPTER I

INTRODUCTION

Rice (*Oryza sativa L.*) belongs to the family Poaceae is the most widely cultivated cereal crop in the world. It is the central to the lives of billions of people around the world. Possibly the oldest domesticated grain (~10,000 years), rice is the staple food for 2.5 billion people (1) and growing rice is the largest single use of land for producing food, covering 9% of the earth's arable land. Rice provides 21% of global human per capita energy and 15% of per capital protein (2). Calories from rice are particularly important in Asia, especially among the poor, where it accounts for 50-80% of daily caloric intake (3). It plays a vital role in the economy of Bangladesh providing significant contribution to the GDP, employment generation and food availability. The geographical, climatic and edaphic conditions are favorable for year round rice cultivation for Bangladesh. Among the rice growing countries, Bangladesh occupies third position in rice area and fourth position in rice production (BRRI, 2012). Rice alone contributes 95 % of food production in Bangladesh (Julfiquar *et al.*, 1998). About 77.07 % of total cropped area of Bangladesh is used for rice production, with annual production of 33.54 million tons from 11.52 million ha of land (BBS, 2015). Rice alone contributes 11 % of GDP and accounts for 55 % labour employment in its production, processing, and marketing (BBS, 2013). More than 94 % of population derives 76 % of its daily calories and 66 % of its protein needs from rice (BBS, 2013). In Bangladesh three distinct classes of rice namely Aus, Aman and Boro, are cultivated during the period April to July, August to December and January to May, respectively. Among them, *boro* rice covers about 35.72% of total rice and it contributes to 44.13% of the total rice production (BBS, 2003). Thus, rice plays a vital role in the livelihood of the people of Bangladesh but the national average rice yield (2.34 t ha^{-1}) is very low compared to that of other rice growing countries. For instance, the average rice yield in China is about 6.30t ha^{-1}, Japan is 6.60t ha-1 and Korea is 6.30t ha^{-1} (FAO, 2002).

Now-a-days, food protection mainly reaching self-sufficiency in rice production is a burning trouble in Bangladesh. In such condition, increasing rice production can play a crucial function to feed the steadily growing people of this country. The multiplied rice manufacturing has been feasible largely via the adoption of modern varieties and technologies. Several high yielding varieties has been developed by different organization and researchers. These high-yielding rice variety has resulted in an increase in rice production but environmental pollution like arsenic presence in soil in several concentration makes it difficult to giving high yield.

Arsenic is one of the toxic environmental pollutants which have recently attracted mass attention because of its chronic and epidemic effects on human health. Arsenic naturally occurs in water, soil and rocks, but its levels may be higher in some areas than others. It readily enters the food chain and may accumulate in significant amounts in both animals and plants, some of which are eaten by humans. The greatest threat to public health from arsenic originates from contaminated ground water. Inorganic arsenic is naturally present at high levels in the groundwater of a number of countries, including Argentina, Bangladesh, Chile, China, India, Mexico, and the United States of America. Drinking-water, crops irrigated with contaminated water and food prepared with contaminated water are the sources of exposure of As.

Arsenic inside the floor water and its shipping to the air appear to be a superb difficulty in Bangladesh. Except home use, large portions of water from shallow aquifers are getting used within the dry season especially in irrigating boro rice. About 50% of usual ground water withdrawn is used for irrigating crop mainly boro rice. Immoderate arsenic awareness in irrigation water may moreover cause accelerated cognizance of arsenic in soil and sooner or later in rice grain & straw.

Rice accumulates more arsenic than other food crops. In fact, it is the single biggest food source of inorganic arsenic, which is the more toxic form. Paddy rice is particularly susceptible to arsenic contamination, for three reasons: Firstly, It is grown in flooded fields (paddy fields) that require high quantities of irrigation water. In many areas, this irrigation water is contaminated with arsenic. Secondly, Arsenic may accumulate in the soil of paddy fields, worsening the problem. Thirdly Rice absorbs more arsenic from water and soil compared to other common food crops.

In Bangladesh, arsenic concentrations in agricultural soils have been reported to be between 4.0 and 75 8.0 mg kgP-1P where the underground irrigation water does not contaminated with high level of arsenic. However, about 83 mg of As kgP^{-1} P has been reported in agricultural soils of those areas, where the underground irrigation water is contaminated with very high level of arsenic (Ullah, 1998). Kabata- Pendias and Pendias (1992) recommended 20 mg of As kgP-1P soil as the safe level of arsenic in agricultural soil for crops.

Consequently, widespread use of arsenic contaminated groundwater for irrigation in rice field could elevate its concentrations in surface soil and eventually into rice plant and rice grain (Abedin et al., 82 2002; Rahman et al., 2007a; Rahman et al., 2007b). Arsenic uptake and accumulation in rice plant from irrigation water and contaminated soil might depend on cultivars (Xie and Huang, 1998; Meharg and Rahman, 2003). The availability of arsenic to the rice plant might also be subjected to the geographic location, soil properties, redox condition and cropping season (Meharg and Rahman, 2003). However, limited literatures are available on arsenic accumulation in different rice varieties. Detail information is needed to make rice cultivation sustainable in an arsenic containing soil, it is important to know how different doses of nitrogen can contribute to the improvement of rice growth. Recently, arsenic has become an important subject to analysis as its concentration is increasing in underground water. Thus it get enter into the food chain through rice grain. Considering the above fact, the present study is carried out with the following objectives:

- To assess the probable yield of rice in arsenic containing soil.
- To find out the relation of rice yield with different doses of N in such area.

REVIEW

AND

LITERATURE

Chapter 2

REVIEW AND LITERATURE

Yield and yield contributing characters of rice are considerably depended on manipulation of basic ingredients of agriculture. The basic ingredients include variety, environment, agronomic practices and hazards factors. Among the above factors As is now a considerable matter for rice growing in context of production and also health hazards. Varieties in respect of local, MV and hybrid are generally more adaptive to appropriate and they greatly affect the return of rice cultivation. But the available relevant reviews related to As and variety in respect of their performance is very limited in the context of Bangladesh as well as the World. Some of the recent past information on As and variety performance on rice have been reviewed under the following headings:

2.1 Arsenic and its occurrence

The name 'Arsenic' is derived from the Greek word "*arsenikon*" meaning potent (Frost, 1984). Arabian alchemist, Geber discovered arsenic during the eighth century when he heated orpiment (As_2S_3) (Mellor, 1954). In 1775, a famous Swedish chemist, Scheele discovered arsine (AsH_3) (Nriagu, 2002), however its deadly nature was not known until the death of a chemistry professor in Munich, who inhaled a minor quantity of AsH_3, in 1815. Arsenic is a metalloid (element that has properties of both metals and non-metals), and belongs to the Group VA in the periodic table of elements (Allen, 1989; Emsley, 1991; Smith et al., 1998). Arsenic has an atomic number 33, atomic mass 74.9216 $gmol^{-1}$ and an electronic configuration of $4s^2$ $3d^{10}$ $4p^3$ (Smith *et al.*, 1998; Grafe and Sparks, 2006). Arsenic can show either electro-positive or electro-negative valence in its compound. The valences of arsenic are 0, -3, +3 and +5. Under aerobic conditions arsenic exists as As (+5) where as reducing environment is congenial for existence of elemental Arsenic (0), Arsenite (+3) and Arsine (-3). Arsenical, both trivalent and pentavalent, are soluble over a wide pH range and are found routinely in surface as well as in ground water. Elemental arsenic is crystalline and exists in yellow, black, or grey allotropic forms (grey being most stable). The oxidation states and electron orbitals are similar between arsenic and phosphate (Tamaki and Frankenberger, 1992).

Arsenic found in environment are classified into three major groups namely inorganic arsenic compounds, organic arsenic compounds, and arsine gases. Arsenic is widely dispersed in rocks, soils, waters, air, plants, and animals (Cullen and Reimer, 1989). Although arsenic is found in the environment to a small extent in its elemental form, it occurs mostly in inorganic and organic compounds.

Inorganic arsenic is usually found to combine with other elements such as cobalt ($CoAs_2$), nickel (NiAs), iron ($FeAs_2$). However, arsenic is found concentrated in magmatic sulphides and iron ores, leading to the fact that most important ores of arsenic are arsenopyrites or mispickel (FeAsS), realgar (As_4S_4), and orpiment (As_2S_3) (Nriagu, 1994). Organic form of arsenic can be encountered attributes to the biological methylation of inorganic arsenic by microorganism (biotransformation). Arsenic is found as methylated forms such as monomethylarsonic acid (MMAA), dimethylarsinic acid (DMAA), trimethylarsine oxide (TMAO). These species are well known to be found in living organisms (Nriagu, 1994).

The primary sources of arsenic include natural processes, such as weathering of rocks, volcanic emissions and discharge from hot springs, and various anthropogenic activities like mining, smelting, and the use of As-containing pesticides, herbicides, wood preservatives, and feed additives. These contribute to the regional background base level of arsenic and to abnormal geochemical arsenic conditions in some local areas. Historically, the use of arsenic-based pesticides has led to considerable contamination of domestic and agricultural land, through their use as lawn herbicides, and insecticides for rice, orchards and cotton (Woolson et al., 1971).

2.2 Causes of arsenic contamination in Bangladesh

Presently, two hypotheses are prevailing to describe the cause (mobilization) of arsenic into groundwater. These are: i) Pyrite Oxidation and ii) Oxy-hydroxide Reduction.

2.2.1 Pyrite oxidation hypothesis

Arsenic is assumed to be present in certain sulphide minerals (pyrites) that are deposited within the aquifer sediments. Due to the lowering of water table below deposits, the newly-introduced O_2 oxidizes the arsenopyrite in the vadose zone and releases arsenic and arsenic is adsorbed on iron hydroxide. During the subsequent recharge period, iron hydroxide releases arsenic into groundwater (Fig. 2.1). According to this hypothesis, groundwater contamination with arsenic is man-made, which has a relationship with excessive groundwater withdrawal. The pyrite oxidation hypothesis came from West Bengal, a state of India bordering to Bangladesh that has similar geological and environmental factors. West Bengal has also a serious arsenic problem. In West Bengal, it is believed by several authors that the source of arsenic in groundwater is geological and the cause of contamination is pyrite oxidation. The intensive irrigation development in the country supports the pyrite oxidation hypothesis. Irrigation development in Bangladesh, using DTWs and STWs, started in the early 1960s and rapidly expanded in the early 1980s. The contribution of groundwater to total irrigated area increased from 41 percent in 1982/1983 to over 75 percent in 2004/05 with an increasing tendency in each year, while the contribution of surface water steadily declined from 59 to <25 percent over the same period (Rashid, 1997 and Rashid and Islam, 2006).

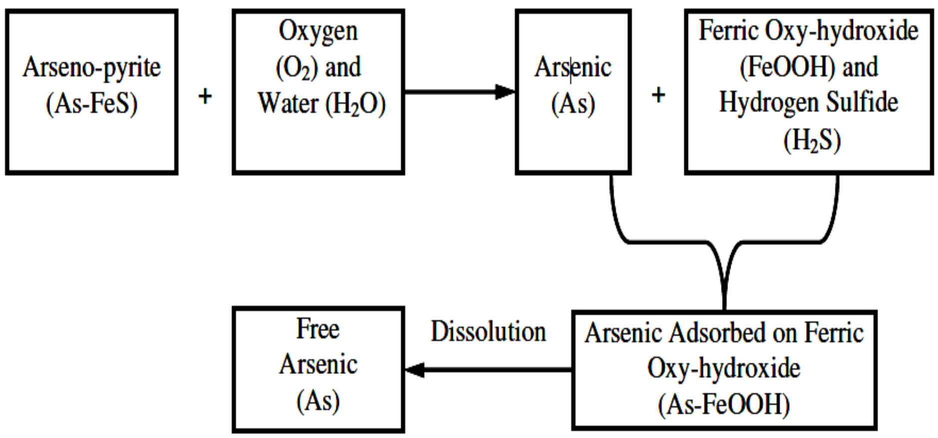

Fig. 2.1 Arsenic release according to pyrite oxidation hypothesis (Adapted from Safiuddin and Karim, 2001).

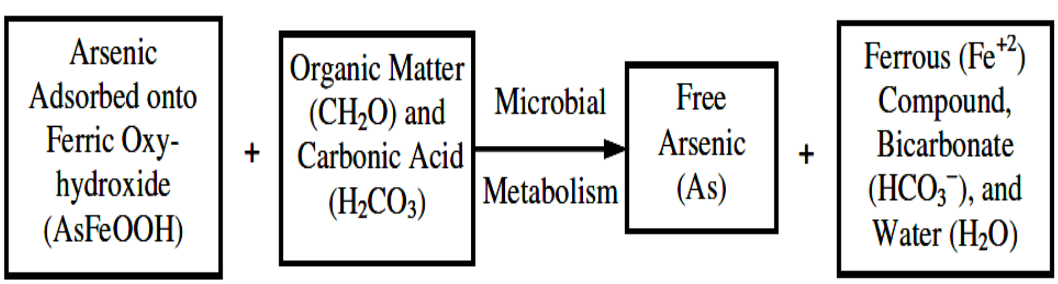

Fig. 2.2 Arsenic release according to hydroxide reduction hypothesis (Adapted from Safiuddin and Karim, 2001).

2.2.2 Oxy-hydroxide reduction hypothesis

Arsenic is assumed to be present in alluvial sediments with high concentrations in sand grains as a coating of iron hydroxide. The sediments were deposited in valleys eroded in the delta when the stream base level was lowered due to the drop in sea level during the last glacial advance. The organic matter deposited with the sediments reduces the arsenic-bearing iron hydroxide and releases arsenic into groundwater (Fig. 2.2). According to this hypothesis, the origin of arsenic-rich groundwater is due to a natural process, and it seems that the arsenic in groundwater has been present for thousands of years without being flushed from the delta. This hypothesis was first proposed by Nickson et al., (1998). BGS accepted this hypothesis and considered that groundwater arsenic contamination has no relation with the excessive groundwater withdrawal.

2.3 Arsenic in the environment and human exposure

2.3.1 Arsenic in air

Arsenic is released to atmosphere from both natural and anthropogenic sources. The principal natural source is volcanoes. Man-made emission to air arises from the smelting of metals, the combustion of fuels, especially of low-grade brown coal, and the use of pesticides. Arsenic in air is present mainly in particulate forms as inorganic arsenic like arsenic trioxide (As_2O_3) (Leonard, 1991). Moreover, recent studies has shown the presence of arsine (AsO_3) and methylated arsenic ($MeAsH_2$, Me_2AsH, and Me_3As) as trace component of the air sample, particularly over sites of higher biological activity (Feldmann and Grumping, 1994; Feldmann and Hirner, 1995; Hirner et al., 1998). Particulate arsenic compounds may be inhaled, deposited in the respiratory tract and absorbed into blood. Inhalation of arsenic from ambient air is usually a minor exposure route for the general population.

2.3.2 Arsenic in water

Arsenic is mainly transported in the environment by water. Arsenic is found at low concentration in natural water. The unpolluted fresh water has a level of arsenic ranging from 1-10 μgL^{-1}, rising to 100-5000 μgL^{-1} in areas of sulphide mineralization and mining (Mandal and Suzuki, 2002). The World Health Organization (WHO, 1981) recommends that the As concentration in drinking water should not exceed 10 $\mu g\ L^{-1}$. However, the permissible limit of As in drinking water in many countries, including Bangladesh and the United States, is up to 50 $\mu g\ L^{-1}$. Higher levels of arsenic are found in groundwater sources than in surface-water sources. Arsenic in groundwater is mainly inorganic with arsenate comprising about 50% of the total (Abedin et al., 2002b).

Arsenic contamination in the groundwater has been reported from many countries, with the most severe problems occurring in Asia, namely Bangladesh (Dhar et al., 1997; Biswas et al., 1998; Chowdhury et al., 1999), West Bengal, India (Mandal et al., 1997), China (Huang et al., 1992; Liangfang and Jianghong, 1994), Vietnam (Winkel et al., 2011) and Taiwan (Chen et al., 1995). In the United States, arsenic-contaminated groundwater has been reported in New England (Peters et al., 1999), the Mid-west (Welch et al., 2000), Oklahoma (Schlottmann and Breit, 1992), Nevada (Welch and Lico, 1998) and California (Wilkie and Hering, 1998). In South East Asia, drinking (ground) water is mainly contaminated by geogenic arsenic. As a result, millions of people have been exposed to As placing their health at risk. It has been reported that approximately 42 million people are exposed to As containing potable water with a concentration of more than 50 μg L^{-1} and more than 100 million people worldwide are affected by As contaminated water with a concentration of more than 10 μgL^{-1}.

Groundwater in Bangladesh is currently contaminated by up to 2 mg/L As with reports of widespread arsenic-related health effects on millions of people (Abedin et al., 2002b). This problem is at its worst in the Bengal Delta region (encompassing Bangladesh and West Bengal, India), where tube-wells were installed to provide "safe" drinking water free from microorganisms causing gastrointestinal diseases, without prior knowledge of As contamination. The geochemical and hydrological conditions causing this As contamination are still being debated, but it is clear that elevated As concentrations are linked to the reducing environment developed in Holocene alluvial and deltaic deposits (BGS/DPHE, 2001). Use of this contaminated water for irrigation to crops has led to elevated concentrations of arsenic in agricultural soils.

2.3.3 Arsenic in soil

The global average concentration of As in soil is about 5 $mgkg^{-1}$. Uncontaminated soils typically contain <10 $mgkg^{-1}$ total As, but the concentration can reach hundreds or thousands of $mgkg^{-1}$ in contaminated environments (Kabata-Pendias and Pendias, 1992). Anthropogenic sources of As have elevated the background concentration of As in soils (Adriano, 1986). For example, in areas near As mineral deposits, As levels in soils may reach up to 9300 $mgkg^{-1}$ (Ashley and

Lottermoser, 1999). Depending on the nature of the geogenic and anthropogenic sources, As concentration in soils can range from <1 to 250,000 mg kg^{-1}. Due to soil parent material, a large fluctuation was found among countries; for example, calcareous soils can be expected to have higher levels of As than noncalcareous soils (Aichberger and Hofe, 1989). Although the dominant source of As in soils is geological, additional inputs may also be derived locally from industrial sources, such as smelting and fossil fuel combustion products and agricultural sources, namely pesticides and phosphatic fertilizers.

The soluble As concentration in soil is largely determined by redox conditions, pH, biological activity, and adsorption reactions. The adsorption and mobility of As in soil are affected more strongly by the presence of $H_2PO_2^-$ ion than any other anions. Arsenic is subject to both chemical and biological transformations in soils, resulting in the formation of various species.

Marin et al., (1992) reported that anthropogenic activities, such as pesticide accumulation and herbicide applications, mining and irrigation with the contaminated groundwater have significantly enhanced As levels in agricultural soils in many parts of the world.

Meharg and Rahman (2003) and Loeppert et al., (2005) stated that the natural soil-As concentrations are generally less than 10 $mgkg^{-1}$ in the surface soils of Bangladesh, but the concentrations can be significantly higher and sometimes greater than 40 mg kg^{-1} in soils that have been intensively irrigated with the As contaminated water.

Dittmar et al., (2005) reported that the highest concentration of As in soil receiving irrigation from a shallow tube well (0.077 mg AsL^{-1}). At this site, the sub-surface soil contained about 3 $mgkg^{-1}$ As. Arsenic concentration in the topsoil of a paddy field has been reported to be approaching 100 $mgkg^{-1}$. These indicate that the As added to the soil through irrigation is mostly concentrated in the top 0-150 mm layer. This layer corresponds to the main root zone depth for most cultivated crops.

2.3.4 Arsenic in plants

Arsenic is detected in low concentrations (< 1.5 μgkg^{-1}) in plants grown in the uncontaminated soils (McLaren et al., 2006). Several studies on the arsenic contamination in crop plants reveal an alarming situation in Bangladesh. A very extensive study conducted by Ullah et al., (2009) reported the extent and severity of arsenic poisoning in the food chain. They examined arsenic contents in soil and plant samples collected from arsenic contaminated areas under 11 districts of

Bangladesh. They selected 40 plant species with majority of crop plants from these sites. Their results showed that vegetables such as amaranth, red amaranth, arum, coriander, and spinach as well as rice and wheat were found to contain arsenic in the edible parts above the upper permissible limit.

Das et al., (2004) conducted a survey among different crop plants including rice and vegetables on the contamination of arsenic. Though they did not find arsenic concentration in rice grain samples above the upper permissible limit of 1.0 $mgkg^{-1}$ but they found that roots had a significantly higher concentration of arsenic (2.4 $mgkg^{-1}$) compared to stem (0.73 $mgkg^{-1}$) and rice grains (0.14 $mgkg^{-1}$).

Meharg and Rahman (2003) reported rice grain As contents ranging between 0.058 and 1.835 $mgkg^{-1}$ in 13 rice varieties tested from Bangladesh. The comparative levels were 0.20–0.46 $mgkg^{-1}$ in the US and 0.063-0.20 $mgkg^{-1}$ in Taiwan varieties.

Rice has been studied substantially for the determination of their level of contamination. A number of studies analyzed together 788 rice samples (USAID, 2003; Duxbury et al., 2003; Hironaka and Ahmad, 2003; Meharg and Rahman, 2003; Shah et al., 2004). Their studies revealed that daily arsenic intakes from 84% of the Bangladeshi rice samples would exceed daily arsenic intake from water at the US and European drinking water standard of 10 ppb. This estimated data of arsenic consumption from only rice indicate that arsenic from rice alone is an important source of exposure in the Bangladeshi food system.

2.4 Arsenic chemistry in the rice rhizosphere

Arsenic chemistry in the rhizosphere is complex and is controlled by several factors (Fitz and Wenzel, 2002). Under paddy field conditions, inorganic As is inter-converted between the reduced inorganic species arsenite (As(III)) and the oxidized species arsenate (As(V)) (Marin, 1993). Soil microbes can also methylate inorganic As to produce monomethylarsonic acid (MMAA) and dimethylarsinic acid (DMA) (Fig. 2.3) (Turpeinen et al., 1999). In roots, oxygen transported within the root aerenchyma is consumed by adjacent tissue cells, or diffused towards the root apex or the rhizosphere; the transfer of oxygen from aerenchyma to the rhizosphere is termed radial oxygen loss (ROL) (Colmer, 2003a). ROL can oxidize rhizosphere soil elements (e.g. Fe^{2+} to Fe^{3+}) and cause precipitation of toxic metals in rhizosphere soil and on root surfaces (Otte et al., 1989; Smolders and Roelofs, 1996), subsequently altering rhizosphere metal mobility. Rice plants develop aerenchyma to transfer O_2 from the aerial parts of the plant to the roots, resulting in the oxidation of ferrous iron (Fe^{2+}) to ferric iron (Fe^{3+}), and the precipitation of Fe oxides or hydroxides (Fe-plaque) on the root surfaces (Chen et al., 1995). Iron plaque can sequester metals on wetland plant roots (Hansel et al., 2001; Blute et al., 2004) and prevent translocation of As from roots to shoots (Liu et al., 2005, 2007). Therefore rhizosphere interactions play a key role in controlling As bioavailability to crop plants (Fitz and Wenzel, 2002).

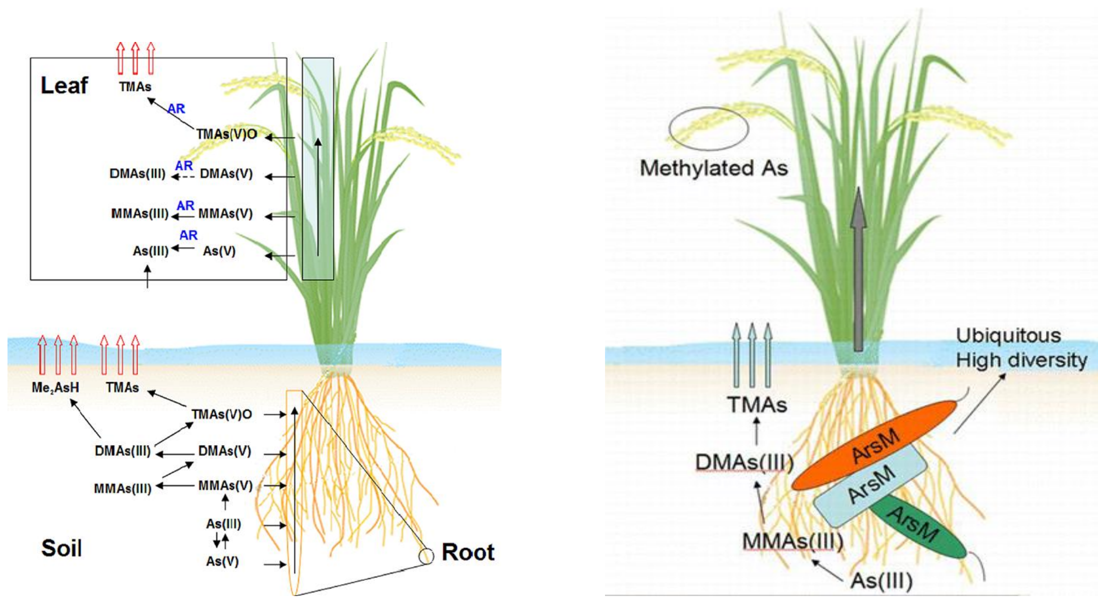

Fig. 2.3 Arsenic speciation in rice rhizosphere under paddy field condition in presence of bacteria in rhizosphere

2.5 Arsenic transport and metabolism

Arsenic is taken up by plants inadvertently through the pathways of essential or beneficial nutrients and detoxified via a variety of mechanisms. Along its route from soil to plants, As interacts with a number of elements, most noticeably with iron (Fe), phosphorus (P), silicon (Si), and sulphur (S). Zhao et al., (2009) reviewed the pathways of As uptake and metabolism in plants as shown in Fig. 2.4.

2.5.1 Arsenic transport

The most common forms of As in soil solution available for plant uptake are arsenate, arsenite, MMA (Monomethylarsonic acid), and DMA (Dimethylarsenic acid). Their uptake mechanisms are described below:

2.5.1.1 Uptake of arsenate

With dissociation constants (p*K*a) of 2.2, 6.97, and 11.5, most arsenic acid (H_3AsO_4) is dissociated as the oxyanions $H_2AsO_4^-$ or $HAsO_4^{2-}$ under normal pH conditions (pH 4-8), and they are the chemical analogs of corresponding phosphate ions.

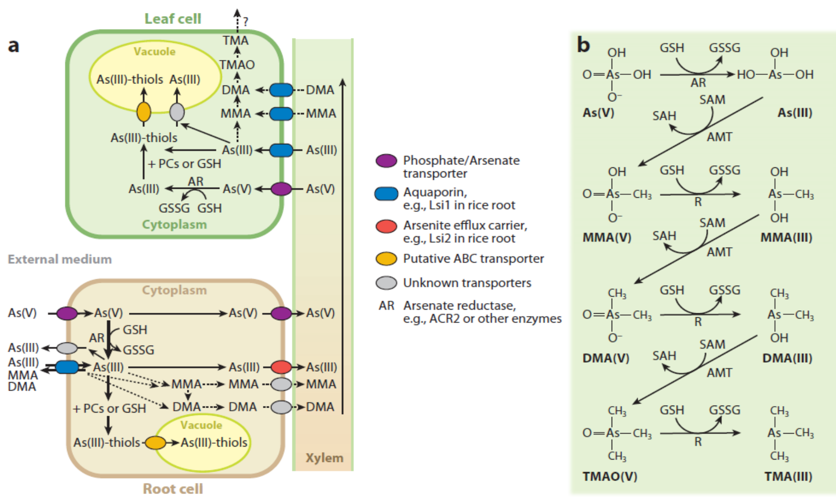

Fig. 2.4 Arsenic uptake and metabolism in plants. (*a*) A simplified schematic diagram of arsenic transport and metabolism in plants. The thickness of arrow lines is indicative of the relative flux. **(*b*)** The Challenger pathway of arsenic methylation in microorganisms. AR: arsenate reductase; R: reductase; AMT: arsenic methyltransferase; GSH, reduced glutathione; GSSG, oxidized glutathione; SAM, *S*-adenosylmethionine; SAH, *S*-adenosylhomocysteine **(**Zhao et al., 2009**).**

Arsenate is taken up by plant roots via phosphate transporters. Physiological and electrophysiological studies proved that a potent inhibition of phosphate on arsenate uptake (Abedin et al., 2002c; Asher and Reay, 1979; Ullrich-Eberius et al., 1989) and recent reports showed that *Arabidopsis thaliana* mutants defective in phosphate transport are more tolerant to arsenate (Catarecha et al., 2007; Gonzalez et al., 2005; Wang et al., 2002).

2.5.1.2 Uptake of arsenite

In contrast to arsenate, arsenous acid (H_3AsO_3, p*K*a = 9.2, 12.1, and 13.4) is mostly undissociated at normal pH conditions (>94% undissociated at pH <8.0). Therefore, plant roots take up arsenite mainly as the neutral molecule $As(OH)_3$. Arsenic (As) in microorganisms and mammalian tissues (Bhattacharjee and Rosen, 2007), arsenite enters plant root cells via some aquaglyceroporin channels. In higher plants, the nodulin 26-like intrinsic proteins (NIPs) are the structural and functional equivalents of the microbial and mammalian aquaglyceroporins (Wallace et al., 2006). NIPs are a subfamily of the plant major intrinsic proteins (MIPs), collectively known as aquaporins or water channels (Maurel et al., 2008).

In rice roots, *Lsi1* (OsNIP2:1), which is highly expressed in the distal side of the plasma membranes of the exodermis and endodermis cells where *Casparian* strips are formed, is a major entry route for silicic acid (Ma et al., 2006) and arsenite (Ma et al., 2008); mutation in this protein resulted in a 60% loss of the arsenite influx in the short term. However, the effect of *Lis1* mutation on As accumulation in rice shoots is relatively small over a longer growth period (Ma et al., 2008). *Lsi2* is localized to the proximal side of the plasma membranes of the exodermis and endodermis cells, allowing solute efflux toward the stele for xylem loading (Ma et al., 2007). This process is a crucial step in the accumulation of As in rice shoot and grain; it is also the step in which Si exerts a strong inhibitory effect. Transport of Si mediated by *Lsi2* is an active process driven by the proton gradient (Ma et al., 2007). *Lsi2* has a low degree of homology (18%) with the arsenite efflux transporter ArsB in *Escherichia coli* (Ma et al., 2007).

2.5.1.3 Uptake of methylated arsenic:

MMA and DMA have lower dissociation constants than arsenite (p*K*a = 4.2 and 6.1, respectively). The permeability of MMA and DMA across liposomes was estimated to be 1.4×10^{-13} and 4.5×10^{-11} cms^{-1}, respectively (Cullen and Reimer, 1992). Undissociated pentavalent MMA and DMA are also taken up by rice aquaporin *Lsi1* (Li et al., 2009a); the uptake capacity for MMA and DMA through the rice *Lsi1* mutant was observed to decreased by 80% and 50%, respectively, compared with the wild-type rice. At pH 5.5, uptake by rice roots decreases in the order of arsenite > MMA > DMA (Abedin et al., 2002c). The substrate properties that may explain this order are: (*a*) the extent of dissociation within the normal pH range, and (*b*) the number of hydroxyl groups; formation of the hydrogen bonds between the hydroxyl group of a substrate and the aquaporin protein along the pore structure greatly facilitates the flux through the channel (Wu and Wong, 2007). In contrast to arsenite, the rice *Lsi2* is not involved in the efflux of MMA or DMA, possibly because most MMA and DMA are dissociated at the cytoplasmic pH (Li et al., 2009a). Despite its limited uptake (Abedin et al., 2002c and Raab et al., 2007), for unknown reasons, DMA is more efficiently translocated from roots to shoots (Li et al., 2009; Marin et al., 1992 and Raab et al., 2007).

2.6 Arsenic metabolism

Two aspects of As metabolism are discussed here:

2.6.1 Arsenate reduction:

The dominance of trivalent As in plant tissues is found when arsenic is supplied to the plants in the form of arsenate (Dhankher et al., 2002, Pickering et al., 2000, Xu et al., 2007, Zhao et al., 2009) indicates a higher capacity of arsenate reduction. Both roots and shoots of rice exhibit arsenate reduction activities (Duan et al., 2007), but roots may be quantitatively more important because arsenite is the main form found in the xylem sap of a number of plant species (Zhao et al., 2009). The plant homologues of the yeast arsenate reductase *Acr2p* have recently been isolated from *A. thaliana* (Dhankher et al., 2006), *Holcus lanatus* (Bleeker et al., 2006), rice (Duan et al., 2007), and *P. Vittata* (Ellis et al., 2006). The plant *ACR2* proteins are CDC25- like (cell division cycle) tyrosine phosphatises that have both phosphatase and arsenate reductase activities; PvACR2 from *Pteris vittata* appears to be an exception with only the activity of an arsenate reductase (Ellis et al., 2006). Purified recombinant proteins of plant *ACR2s* are able to reduce arsenate in vitro using GSH and glutaredoxin as reductants. However, the role of *ACR2* remains unresolved, since there are conflicting reports on the phenotype of the *ACR2* knockout or knockdown lines of *A. thaliana* with regard to arsenate tolerance and As translocation from roots to shoots in plant (Bleeker et al., 2006; Dhankher et al., 2006). Furthermore, the As speciation in the *Arabidopsis ACR2* knockout mutants is still dominated by As (III) (Zhao et al., 2009), suggesting a functional redundancy of *ACR2*. The possible existence of other arsenate reductases or nonenzymatic reduction mechanisms warrants further investigation.

2.6.2 Arsenic methylation:

Arsenic is metabolised from inorganic to organic forms by a wide range of organisms, with limited evidence that this occurs in plants (Nissen and Benson, 1982). In a range of organisms, metabolism typically occurs through biomethylation to give MMA, DMA, tetramethylarsonium ions (TETRA) and trimethylarsonium oxide (TMAO) (Cullen and Reimer, 1989). A number of organisms have also been found in some terrestrial plants that metaboliseinorganic arsenic to arsenocholine, arsenobetaine and arseno-sugars (Tamaki and Frankenberger, 1992 and Kuehnelt et al., 2000). Gosio (1897), as cited in Cullen and Reimer, (1989) was the first to establish that fungi could generate methylated As. Challenger proposed a scheme in which As(+5) was eventually transformed to TMAs. In this scheme, As (+5) is first reduced to As (+3) then methylated, and each methylation step results in the reoxidation of the As, thus requiring a reductive step to As (+3) prior to further methylation.

2.7 Arsenic toxicity and detoxification mechanism in plants

2.7.1 Arsenic toxicity in plants

Phytotoxicity of arsenic species is affected considerably by the chemical form in which it occurs in the soil and concentration of the metalloid. Production of reactive oxygen species (ROS) like superoxide anions, singlet oxygen, hydroxyl radicals and hydrogen peroxide by plants exposed to environmental stresses causes damage to DNA, proteins and lipids (Singh et al., 2006). Plants exposed to either arsenate or arsenite produce ROS (Srivastava et al., 2007). The primary cause of As^{3+} toxicity is its interference with a variety of enzymes because it has high affinity to sulfhydryl groups found on many enzymes, whereas being a phosphate analogue, As^{5+} can substitute inorganic phosphate in a plethora of biochemical processes, thus affecting key metabolic processes in the cell. Arsenate and arsenite are also toxic to plants by disturbing central cellular functions. Arsenate is transported across the plasma membrane via phosphate co-transport systems (Ullrich-Eberius et al., 1989). Once arsenate enters inside the cytoplasm it competes with phosphate, for example replacing phosphate in ATP to form unstable ADP-As, generates reactive oxygen species (ROS) in plant tissues, induces oxidative stress such as lipid peroxidation (Ahsan et al., 2008; Mylona et al., 1998 and Hartley-Whitaker et al., 2001) and leads to the disruption of energy flows in cells (Meharg, 1994).

The primary impact of arsenic toxicity on plants is a reduction in growth (Kabata-Pendias and Pendias, 1991). The thorough review by Punz and Sieghardt (1993) outlined the important responses of plant roots to heavy metals, which can be applied to arsenic. Other responses of heavy metal: changes in root biomass - typically a reduction in weight; changes in the root system architecture increased lateral root growth leading to a compacted system; changes in growth rate; inhibition of root elongation-largely due to a disruption of cell division and mitosis.

They also noted other important morphological changes, including root discolouration, decreased root hair density, vessel diameter, and vessel number and structural changes to hypodermis, endodermis, and pericycle. Further physiological responses include damage to root cell membrane, decreased water permeability of the plasmalemma, decreased turgor or plasmolysis, reduced root respiration, reduced water uptake, and increased water flow resistance (Punz and Seighardt, 1993). At higher concentration, arsenic is toxic to most plants. It interferes with metabolic processes and inhibits plant growth and development through arsenic induced phytotoxicity (Marin et al., 1993b). Smith et al. (1998) reported that rice, bean, oats can suffer from phytotoxicity at a soil concentration of 20 $mgkg^{-1}$ As, whereas for maize and radish this is 100 $mgkg^{-1}$ As. Certainly, the reduction of rice plant growth, in terms of tillering, plant height, root length, shoot and root biomass production, was the ultimate result of arsenic phytotoxicity at high soil arsenic concentrations (Jahan et al., 2003; Rahman et al., 2004; Xie and Huang, 1998) though the phytotoxicity at lower soil arsenic concentrations was not significant. High As concentrations in soils can reduce crop yield, since it inhibits plant growth and under stringent conditions may be lethal to the plant (Nriagu et al., 2007).

2.7.2 Arsenic detoxification mechanism

For non-hyperaccumulator plants, As toxicity often occurs at a shoot As concentration varying between 1 and 100 $mgkg^{-1}$ (Kabata-Pendias and Pendias, 1992), whereas the As hyperaccumulator *P. Vittata* can withstand 5000–10,000 $mgkg^{-1}$ of As in the frond tissue without suffering from toxicity (Lombi et al., 2002 and Tu and Ma, 2002). In general, a high level of tolerance to heavy metals could rely on either reduced uptake or increased plant internal sequestration, which is manifested by an interaction between a genotype and its environment (Macnair et al., 2000 and Hall, 2002). A variety of tolerance and resistance mechanisms including avoidance or exclusion, which minimizes the cellular accumulation of metals, and tolerance, which allows plants to survive while accumulating high concentrations of metals, have been identified in plants. These include: (i) decreased uptake of As^{5+} due to suppression of the high-affinity phosphate uptake system; (ii) binding to the cell wall; (iii) detoxification of As^{5+} by reduction to As^{3+}, which subsequently complexes with thiols, particularly phytochelatins (PCs), metallothioneins, and metal-binding proteins and remains sequestered in roots; (iv) rapid efflux of As^{5+} and As^{3+} from plant roots back to the medium; (v) repair of stress-damaged proteins; and (vi) the compartmentation of metals in the vacuole by tonoplast-located transporters (Hall, 2002).

Arsenic hyperaccumulator plants take up and sequester exceptionally high concentrations of arsenic in the aboveground parts and hence offer a great promise to phytoremediation of arsenic. Tolerance in these plants appears to involve increased As^{5+} uptake, decreased As^{3+} -thiol complexation and As^{3+} efflux to the external medium, greatly enhanced xylem translocation of As^{3+}, and vacuolar sequestration of As^{3+} in fronds.

2.8 Arsenic concentration in rice straw and grain

Arsenic contamination in the Bangladeshi staple food, rice, showed presence of high levels of arsenic 1700 $mgkg^{-1}$ (Meharg and Mazibur, 2003). A greenhouse study was conducted to examine the effects of arsenic-contaminated irrigation water on the growth of rice and uptake and speciation of arsenic. Increasing the concentration of arsenate in irrigation water significantly decreased plant height, grain yield, the number of filled grains, grain weight, and root biomass, while the arsenic concentrations in root, straw, and rice husk increased significantly. Concentrations of arsenic in rice grain did not exceed the food hygiene concentration limit (1.0 mg of As kg^{-1} dry weight). The concentrations of arsenic in rice straw (up to 91.8 mg kg^{-1} for the highest As treatment) were of the same order of magnitude as root arsenic concentrations (up to 107.5 $mgkg^{-1}$), suggesting that arsenic can be readily translocated to the shoot (Abedin et al., 2002).

Das et al., (2004) determined the level of contamination in 100 samples of crop, vegetables and fresh water fish collected from three different regions in Bangladesh. They reported that, no samples of rice grain had arsenic concentrations more than the recommended limit of 1.0 $mgkg^{-1}$. Rice plants, especially the roots had a significantly higher concentration of arsenic (2.4 $mgkg^{-1}$) compared to stem (0.73 $mgkg^{-1}$) and rice grains (0.14 $mgkg^{-1}$).

Abedin et al. (2002a) reported that significant increase of arsenic concentration in rice root, straw and husk with the increase of arsenate concentration in irrigation water. He found 3.9 $mgkg^{-1}$ arsenic in straw at the lowest arsenate treatment (0.2 mgL^{-1}), which increased progressively with increasing arsenate application and reached to 91.8 $mgkg^{-1}$ in the highest arsenate treatment (8.0 mgL^{-1}).

Jahiruddin et al., (2004) spiked silt loam soil with As. First, a Boro rice cultivar developed by the Bangladesh Rice Research Institute "BRRI dhan29" and then an Aman cultivar "BRRI dhan3" were grown. For Boro rice, the first significant effects occurred at 10 mg kg^{-1} soil, causing a grain yield reduction of more than 45 percent.

Abedin et al. (2002) and Meharg and Rahman (2003) have reported about the rice samples with As accumulation much above the WHO recommended permissible level (1.0 $mgkg^{-1}$). Meharg and Rahman (2003) reported that Bangladesh rice grain accumulate As up to 2.0 $mgkg^{-1}$.

Delowar et al., (2005) reported the accumulation of As in rice grain in the range 0.0-0.14 $mgkg^{-1}$ which was cultivated with 0.0-20.0 mgL^{-1} As contaminated water. Arsenic accumulation in rice straw at very high levels indicates that the cattle populations are in direct threat for their health and also, indirectly, human population, via consuming contaminated bovine meat and milk (Abedin et al., 2002).

Delowar et al., (2005) and Williams et al., (2006) noticed that some of the rice varieties (IR 50, White Minikit, Red Minikit) are high accumulator of As (0.24, 0.009-0.31, 0.005 $mgkg^{-1}$) with respect to varieties (Nayanmani, Jaya, Ratna, Ganga-kaveri, Lal Sanna) with low accumulation(0.14, 0.002-0.20, 0.005 $mgkg^{-1}$).

Williams et al., (2006) reported that daily consumption of rice with a total As level of 0.08 mg kg^{-1} would be equivalent to drinking contaminated water with As level of 0.01 mg/L. Arsenic uptake and accumulation in different rice parts found in the order roots > stem > leaf> grain (Abedin et al., 2002). 2400μgkg^{-1} As in roots, 730 μgkg^{-1} in stems and leaves, and 140μgkg^{-1} in grain (Das et al., 2004 and Islam et al., 2004).

Rice grain has been reported to accumulate arsenic upto 2.0 $mgkg^{-1}$ by Meharg et al., (2003), Islam et al., (2004) and Delowar et al. (2005), which is much above the permissible limit in rice (1.0 mgkg) according to WHO recommendation.

Rahman et al., (2007), Abedin et al., (2002) and Das et al., (2004) reported that the concentration of arsenic in the grain of all the studied rice samples was found to be between 0.25±0.014 to 0.73±0.009 $mgkg^{-1}$ dry weight of arsenic, which did not exceed the permissible limit in rice (1.0 $mgkg^{-1}$) according to WHO recommendation.

Rahman et al., (2007a,b) conducted glasshouse and field-level experiments to investigate the concentrations of arsenic in different parts of rice plant and found that arsenic concentration in grain (0.2–0.7 $mgkg^{-1}$ dry weight), straw (0.9–23.7 $mgkg^{-1}$ dry weight), husk (0.2–1.6 $mgkg^{-1}$ dry weight), and root (46.3–51.9 $mgkg^{-1}$ dry weight).

Rahman et al., (2007a) and Tsutsumi et al., (1980) reported that 23.7 and 149 mg of As kg^{-1} dry weight, respectively was found in rice straw when the soil arsenic concentrations were 60 and 313 $mgkg^{-1}$ dry weight, separately.

Abedin et al., (2002) also found 25 mg of As kg^{-1} dry weight in rice straw when the rice was irrigated by 2 mg of As l^{-1} water. The study revealed that the highest level of arsenic in root at 40.3 ± 57 $mgkg^{-1}$ dry weight As (n = 4) was located at the RS1 field with the arsenic content of 43.8 $mgkg^{-1}$ dry weight in topsoil.

Das et al., (2004) also stated that the highest concentrations of arsenic in rice grain (0.27 $mgkg^{-1}$), shoot (1.58 $mgkg^{-1}$), root (9.71 $mgkg^{-1}$), and soil (27.28 $mgkg^{-1}$) were found in samples collected from the irrigated fields of Kachua Upazila of Chandpur in Bangladesh.

Patel et al., (2016) found that the concentration of As in the rice grain, husk, straw and root (n = 20) was ranged from 0.17 - 0.72, 0.40 - 1.58, 2.5 - 5.9 and 204 - 354 $mgkg^{-1}$ with mean value of 0.47 ± 0.07, 0.83 ± 0.15, 4.2 ± 0.5 and 276 ± 21 $mgkg^{-1}$, respectively.

2.9 Plant responses to arsenic toxicity

2.9.1 Effect of arsenic in seed germination of rice

Marked decreases in germination percentage and shoot and root elongation were recorded with As treatments in rice seedlings. The germination of rice seed decreased significantly with the higher concentrations of As in water and the adverse effect was different among the varieties.

Abedin et al., (2002) reported that plant height ranged between 91.1 and 84.1 cm with lower ranges of arsenate doses (0-1.0 mg As L^{-1}), while with higher arsenate doses (2.0 - 8.0 mg of As L^{-1}) plant height decreased to 79.2 - 63.8 cm. Leaf number $plant^{-1}$ was less affected by As in water. Similar to germination of seeds, the adverse effect of As on seedling height was different among the varieties.

Carbonell et al., (1997) suggested that root length decreased with increasing arsenic concentration but the present study showed no regular pattern of variation in root length in Barisal soil series while in Sara series an increasing trend of root length was observed up to 5 ppm showed and decreased thereafter.

The germination decreased significantly with the increase in As concentration. Root length, shoot length, root and shoot fresh weight of rice seedlings were greatly inhibited at 50 mM As (III) and 500 mM As (V) (Shri et al., 2009).

Li et al., (2007) observed that germination performance of the plant was better in lower concentrations and with the increase of concentration germination was adversely affected. At an As concentration of 0.5 $mgkg^{-1}$ the germination energy and germination index increased by 104.33% and 101.97%, respectively.

The vitality index increased by 6.56% at an As concentration of 1 $mgkg^{-1}$. Germination energy, germination percentage, germination index and vitality index reduced significantly in rice, by 9.60%, 4.04%, 10.73% and 46.61%, respectively, with higher As concentration of 20 $mgkg^{-1}$ (Li et al., 2007).

2.10 Effect of arsenic in growth of rice plant

Rahman et al., (2012) reported germination percentage (GP), germination speed (GS) and vigor index (VI) of rice varieties decreased significantly ($p>0.01$) with increasing As(V) concentrations. Abedin and Meharg, (2002) also studied germination on rice seeds and a short-term toxicity experiment with different concentrations of arsenite and arsenate on rice seedlings. Percent germination over control decreased significantly with increasing concentrations of arsenite and arsenate. Arsenite was found to be more toxic than arsenate for rice seed germination.

Shaibur et al., (2006), conducted an experiment to observe the effect of arsenic (As) on a number of physiological and mineralogical properties of rice (*Oryza sativa* L. cv. Akihikari) seedlings. Seedlings were treated with 0, 0.5, 1.0 and 2.0 mg As L^{-1} for 14 days in a greenhouse. Shoot dry matter yield decreased by 23, 56 and 64%; however, the values for roots were 15, 35 and 42% for the 0.5, 1.0 and 2.0 mg As L^{-1} As treatments, respectively. Shoot height decreased by 11, 35 and 43%, while that of the roots decreased by 6, 11 and 33%, respectively. These results indicated that the shoot was more sensitive to As than the root in rice. Leaf number and width of leaf blade also decreased with As toxicity. Arsenic toxicity induced chlorosis symptoms in the youngest leaves of rice seedlings by decreasing chlorophyll content.

Delowar et al., (2005) conducted a study aims at assessing the extent of accumulation of arsenic in rice plants and its effects on growth and yield of rice. Arsenic concentrations in paddy soils (irrigated with 0, 2.5, 5, 10, 15 and 20 mgL^{-1} of arsenic water) were 0-0.2, 0-0.95 and 0-0.27 mg kg^{-1} at tillering, heading and ripening stages. The growth and yield of rice plants were reduced significantly with increased doses of arsenic but the grain weight was not affected.

Abedin et al., (2002) found that increasing the concentration of arsenate in irrigation water significantly decreased plant height, grain yield, the number of filled grains, grain weight, and root biomass, while the arsenic concentrations in root, straw, and rice husk increased significantly.

Azad et al., (2009) conducted a pot-culture experiment in open-field conditions in Bangladesh with highly cultivated locally transplanted aman rice cv. BR22 in arsenic (As)-amended soil (0, 1.0, 5.0, 10.0, 20.0, 30.0, 40.0 and 50.0 $mgkg^{-1}$) to determine the effect of As on the growth, yield of rice. They found arsenic affect the plant height, tiller and panicle numbers, grain and straw yield of T. aman rice significantly.

Panaullah et al., (2009) reported the growth of rice plant was restrained due to the toxicity of inorganic As (iAs). Haq et al., (2006) observed different symptoms in the rice plants due to phytotoxicity of arsenic. The symptoms were: delayed seedling emergence; reduced plant growth; yellowing and wilting of leaves; and finally, reduced grain yield. Brown necrotic spots were also found on old leaves of the plants growing at 20 and 40 mg kg^{-1} As treatment in both BRRI dhan28 and BRRI dhan29 rice varieties.

Islam and Jahiruddin (2010) found the grain yield of rice was reduced by 20.6 % for 15 mg kg^{-1} As treatment and 63.8 % due to 30 $mgkg^{-1}$ As. Such reductions for straw yield were 21.0 and 65.2 % with these two As treatments, respectively.

Khan et al., (2010) reported arsenic addition in either irrigation water or as soil-applied As resulted in yield reductions from 21 to 74 % in *Boro* rice and 8 to 80 % in T. *Aman* rice, the latter indicating the strong residual effect of As on subsequent crops.

Hossain et al., (2008) assessed effect of arsenic on growth and yield of rice. They reported that the growth and yield of rice plants were reduced significantly with increased doses of arsenic but the grain weight was not affected. Among the different yield components, the number of tillers per pot, number of effective tillers per pot and grain yield per pot reduced greatly with the higher dose (20 mgL^{-1}) of arsenic applied. Yield reduction of more than 60 and 40% for Iratom-24 and BRRI dhan28, was found with 20 mg L^{-1} of arsenic as compared to control. The reduction in straw yield was also significantly higher for both of rice varieties with the 20 mgL^{-1} arsenic application.

Abedin et al., (2002b) reported a reduction of 20% of crop (cereal) production from approximately 20 mgL^{-1} of arsenic in the plant body. Arsenic concentration in irrigation water (0.1 to 2.0 mgL^{-1}) and soil (5 to 50 $mgkg^{-1}$) could result in lower yield of a local rice variety. Rice production is reported to decrease by 10% at a concentration of 25 mg kg^{-1} As in soil.

Marin et al., (1992) found significant reduction of rice shoot height when arsenite or monomethyl arsenic acid was applied at the relatively low dose of 0.8 mg As L^{-1}.

Abedin and Meharg (2002) reported that germination and early seedling growth of rice decreased significantly with increasing concentrations of As. The inhibition was stronger in the root than in the shoot when treated with As (Wang et al., 2002). When uptake of nutrition was inhibited in roots, the growth of the whole plant was constrained, and the plant biomass decreased finally. The reason is that plant roots were the first point of contact for these toxic arsenic species in the nutrient media (Abedin and Meharg, 2002).

2.11 Effect of arsenic in yield of rice

Abedin et al., (2002) also observed that tillers number of rice plant was reduced significantly with increase of arsenic concentration in irrigation water up to 8 mgL^{-1}. Khan et al., (2010) also found that the addition of arsenic significantly reduced tillering in rice plant.

Abedin (2002) found that presence of arsenic as arsenate at a higher concentration in irrigation water significantly reduced the 1000 grain weight. Tsutsumi (1980) also reported that arsenic could reduce 1000 grain weight.

Hossain et al., (2009) reported that grain yield of rice was decreased as the level of arsenic addition was increased, and the yield was reduced drastically with the 30 mg $Askg^{-1}$ addition.

Arsenic application in rice significantly reduced yield and different yield-contributing parameters including the number of panicles per plant, panicle dry weight, the number of spikelets and full grains per plant and 1000-grain weight (Vromman et al., 2013).

MATERIALS AND METHODS

CHAPTER 3
MATERIALS AND METHODS

The pot experiment was conducted at the Sher-e-Bangla Agricultural University, Dhaka, Bangladesh during the period from December 2016 to April 2017 to study the effect of different doses of arsenic on yield of rice. The details of the materials and methods have been presented below:

3.1 Description of the experimental site

3.1.1 Location

The present piece of research work in pot was conducted in the experimental area of Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka. The location of the site is 23^0 74′ N latitude and 90^0 35′ E longitude with an elevation of 8.2 meter from sea level.

3.1.2 Soil

The soil of the experimental area that used in the pot for rice grown belongs to “The Modhupur Tract”, AEZ – 28 .Pot soil was silty clay in texture. Soil pH was 5.6 and has organic carbon 0.45%. The experimental area was flat having available irrigation and drainage system. The details of the pot soil have been presented in Appendix I.

3.1.3 Climate

The geographical location of the experimental site was under the subtropical climate, characterized by three distinct seasons, winter season from November to 20 February and the pre-monsoon period or hot season from March to April and monsoon period from May to October (Edris *et al.*, 1979). Details of the meteorological data of air temperature, relative humidity, rainfall and sunshine hour during the period of the experiment was collected from the Weather Station of Bangladesh, Sher-e Bangla Nagar, Dhaka and has been presented in Appendix II.

3.2 Experimental details

3.2.1 Treatments

The experiment comprised of two factors.

Factor A: Arsenic level (4 levels):

i. As_1:Control (No arsenic)

ii. As_2: 1 ppm As/ kg soil

iii. As_3: 2 ppm As/ kg soil

iv. As_4: 4 ppm As/ kg soil

Factor B: N doses(2 levels)

i. T_1: Recommended dose of N

ii T_2: 50% more than recommended dose of N

Factro C: Saturated condition

As such there were 8 treatments combinations viz. A_1T_1, A_2T_1, A_3T_1, A_4T_1, A_1T_2, A_2T_2, A_3T_2, A_4T_2.

3.2.2 Experimental design and layout

The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. There were 24 pots for 8 treatment combination in each of 3 replications. The 8 treatment combinations of the experiment were assigned at random in 8 pots of each replication.

3.3 Growing of crops

3.3.1 Raising seedlings

3.3.1.1 Seed collection

The seeds of the test crop i.e. BRRI dhan 36 is collected from Bangladesh Rice Research Institute (BRRI), Joydevpur, Gazipur .

3.3.1.2 Seed sprouting

Healthy seeds were selected by specific gravity method and then immersed in water bucket for 24 hours and then they were kept tightly in gunny bags. The seeds started sprouting after 48 hours and were sown after 72 hours.

3.3.1.3 Preparation of seedling nursery bed and seed sowing

According to BRRI recommendation seed bed was prepared with 1 m wide seed bed adding nutrients as per the requirements of soil. Seeds were sown in the seed bed on December 8, 2016, in order to transplant the seedlings in the pot as per experimental treatment.

3.3.2 Preparation of the pot

The pot for the experiment was filled up with soil at 2 January, 2017. Weeds and stubble were removed from the soil and finally obtained a desirable tilth of soil for transplanting of seedlings.

3.3.3 Fertilizers and manure application

The fertilizers N, P, K, S, Zn and B in the form of urea, TSP, MoP, gypsum, zinc sulphate and borax, respectively were applied. The entire amount of TSP, MoP, gypsum, zinc sulphate and borax were applied during the final preparation of pot land. Urea was applied in two equal installments at tillering and before panicle initiation. Different concentration of As was mixed the soil as per treatment. The dose and method of application of fertilizers are shown in Table 1.

Table 1. Dose and method of application of fertilizers

Fertilizers	Dose (kg/ha)	Application (%)		
		Basal	1 st installment	2 nd installment
Urea	150	33.33	33.33	33.33
TSP	100	100	-	-
MoP	100	100	-	-
Gypsum	60	100	-	-
Borax	10	100	-	-

Source: Anon., 2010, BRRI, Joydevpur, Gazipur

3.3.4 Uprooting of seedlings

The nursery bed was made wet by application of water one day before uprooting of the seedlings. The seedlings were uprooted on January 8, 2017 without causing much mechanical injury to the roots.

3.3.5 Transplanting of seedlings in the pots

The rice seedlings were transplanted in the pot at 9 January, 2017 and 2 healthy seedlings were transplanted in the pot in a hill.

3.3.6 After care

After establishment of seedlings, various intercultural operations were accomplished for better growth and development of the rice seedlings.

3.3.6.1 Irrigation and drainage

Sprinkler irrigation was provided to maintain a constant level of standing water upto 6 cm in the early stages to enhance tillering and 10-12 cm in the later stage to discourage late tillering. The pot was finally dried out at 15 days before harvesting.

3.3.6.2 Gap filling

First gap filling was done for all of the pots at 10 days after transplanting (DAT) by planting same aged seedlings.

3.3.6.3 Weeding

Weedings were done to keep the pots free from weeds, which ultimately ensured better growth and development. The newly emerged weeds were uprooted carefully at tillering stage and at panicle initiation stage by manual means.

3.3.6.4 Top dressing

After basal dose, the remaining doses of urea were top-dressed in 2 equal installments in the soil.

3.3.6.5 Plant protection

Furadan 57 EC was applied at the time of final land preparation and later on other insecticides were applied as and when necessary.

3.4 Harvesting, threshing and cleaning

The rice was harvested depending upon the maturity of plant and harvesting was done manually from each pot. The harvested crop of each pot was bundled separately, properly tagged and brought to threshing floor. Enough care was taken during harvesting, threshing and also cleaning of rice seed. Fresh weight of grain and straw were recorded pot wise. The grains were cleaned and finally the weight was adjusted to a moisture content of 13%. The straw was sun dried and the yields of grain and straw pot^{-1} were recorded and converted to t/ ha.

3.5 Data recording

3.5.1 Plant height

The height of plant was recorded in centimeter (cm) at the time of 0,15,30, 45, 60, 90 DAT (Days after transplanting) and at harvest. The height was measured from the ground level to the tip of the tiller.

3.5.2 Number of tillers hill^{-1}

The number of tillers hill-1 was recorded at the time of 15, 30, 45, 60, 90 DAT by counting total tillers in a hill.

3.5.3 Total tillers hill^{-1} (at harvest)

The total number of total tillers hill^{-1} was counted as the number of panicle bearing and non bearing tillers hill^{-1}. Data on total tillers hill-1 were counted at harvest and value was recorded.

3.5.4 Effective tillers hill^{-1}

The total number of effective tillers hill^{-1} was counted as the number of panicle bearing tillers plant^{-1} . Data on effective tiller hill^{-1} were counted and value was recorded.

3.5.5 Length of panicle

The length of panicle was measured with a meter scale from 5 selected panicles and the average value was recorded.

3.5.6 Number of penicle

The number of total penicle per pot are counted.

3.5.7 Filled grain hill^{-1}

The total number of filled grain per hill are counted manually.

3.5.8 Un-filled grain hill^{-1}

The total number of unfilled grain per hill are counted manually.

3.5.9 Filled grains panicle^{-1}

The total number of filled grains was collected randomly from selected 3 panicles of a pot on the basis of grain in the spikelet and then average number of filled grains panicle^{-1} was recorded.

3.5.10 Unfilled grains panicle^{-1}

The total number of unfilled grains was collected randomly from the same 3 panicles where filled grains were counted of a pot on the basis of no grain in the spikelet and then average number of unfilled grains panicle^{-1} was recorded.

3.5.11 Weight of 1000 seeds

One thousand seeds were counted randomly from the total cleaned harvested seeds of each individual pot and then weighed in grams and recorded.

3.5.12 Plant sterility %

The plant sterility % is measured through dividing the unfilled grain number by the total grain number.It is measured in case of each hill separately.

3.5.13 Grain yield

Grains obtained from each unit pot were sun-dried and weighed carefully. The dry weight of grains of each pot was measured and grain yield pot^{-1} .

3.5.14 Straw yield

Straw obtained from each unit pot were sun-dried and weighed carefully. The dry weight of the straw of each pot was measured .

3.6 Statistical Analysis

The data obtained for different characters were statistically analyzed using MSTAT software to observe the significant difference among the treatments. The mean values of all the characters were calculated and factorial analysis of variance was performed. The significance of the difference among the treatment means was estimated by the Least Significant Difference Test (LSD) test at 5% level of probability (Gomez and Gomez, 1984).

RESULTS

AND

DISCUSSIONS

Chapter 4

RESULTS AND DISCUSSION

The present investigation included the response of rice variety (BRRI dhan36, susceptible to arsenic) to different levels of arsenic (As) and nitrogen fertilizers. The results presented in tables and figures are discussed systematically under the following heads:

Effect of arsenic levels and nitrogen fertilizers on yield and yield contributing characters of rice plant

4.1 Plant height at harvest

Plant height was affected markedly due to the effects of arsenic (As) and nitrogen fertilizers in BRRI dhan36. A significant ($p<0.05$) variation in plant height was observed in respect of different arsenic levels and nitrogen fertilizers (Table 1). The tallest rice plant (92.00 cm) was found in As_1T_1 treated pot and lowest rice plant (61.90 cm) was found in As_4T_2 treated pot (Table 1). Plant height might be reduced due to increase in arsenic concentration in soil. Abedin et al., (2002a) reported that As affect the root development and reduced the plant height of rice. Similar findings was also reported by some other researchers and they have also reported that plant roots are unable to accumulate the essential nutrients from soil in presence of excess arsenic because As (III) reacts with sulfhydryl groups of proteins (Speer, 1973) causing disruption of root functions of plants (Orwick et al., 1976). These results are in agreement with previous researches such as Biswas et al., (2009), Abedin et al., (2002) and Azad et al., (2009). In linear relationship, significant and negative correlation were observed in rice plant height (R^2= 0.610) (Fig. 1). And, also, in linear relationship, plant height were found statistically significant ($p<0.05$) and negatively correlated with straw yield (R^2= 0.430) in BRRI dhan36 (Fig. 9).

Table 1. Effect of arsenic and nitrogen on the different growth parameters of rice

Treatments	Plant height (cm)	Effective Tillers plant^{-1}	Non-effective Tillers plant^{-1}	Panicle Length (cm)
A_1T_1	92.00 a	24.0 a	6.66 a	22.84 a
A_2T_1	82.00 ab	20.0 ab	3.66 ab	20.14 ab
A_3T_1	74.20 bc	16.0 ab	2.33 bc	16.07 bcd
A_4T_1	66.70 bc	14.0 ab	1.33 bc	11.48 d

A_1T_2	80.20 ab	22.0 ab	4 ab	23.93 a
A_2T_2	74.00 bc	18.0 ab	2 bc	18.57 abc
A_3T_2	71.00 bc	14.0 ab	0.33 c	14.64 cd
A_4T_2	61.90 c	12.0 b	0.0 c	11.49 d
LSD	**8.158**	**5.446**	**1.490**	**2.578**
CV (%)	**13.28**	**18.12**	**17.83**	**18.15**

Means in a column followed by same letter (s) are not significantly different at 5% level of significance (A_1T_1= As0+N recommended dose, A_2T_1= As1+N recommended dose, A_3T_1=As2+N recommended dose,A_4T_1=As4+N recommended dose,A_1T_2=As0+50% more N than recommended dose,A_2T_2=As1+50% more N than recommended dose,,A_3T_2=As2+50% more N than recommended dose,A_4T_2=As4+50% more N than recommended dose.)

4.2 Effective tillers plant^{-1}

The concentration of soil As showed remarkable effect on the number of effective tillers per plants in rice variety BRRI dhan36. It was observed that number of effective tillers of rice plant decreased significantly ($p<0.05$) with increasing soil As concentration. Effective tillers plant^{-1} was affected markedly due to the effects of different arsenic (As) levels in BRRI dhan36 (Table 1). The maximum effective tillers per plant (24.0) was found in A_1T_1 treated pot and minimum effective tillers per plant (12.0) was found in A_4T_2 treated pot (Table 1). Similar results were in agreement with Islam and Jahiruddin (2010), who reported that arsenic treatment resulted in a marked decrease in effective tillers per pot, filled grains per panicle and 1000-grain weight; these together contributed reduced grain yield. Rice grain yield was reduced by 20.6% for 15 mgkg^{-1} As treatment and 63.8% due to 30 mgkg^{-1} As. In linear relationship, the effective tillers per plant of rice variety BRRI dahn36 were observed negatively and strongly correlated (R^2= 0.472) (Fig. 2).

4.3 Non-effective tillers plant^{-1}

Regarding the number of non-effective tillers plant^{-1} in response diiferent doses of arsenic and nitrogen were found statistically significant ($p<0.05$) variation in rice variety of BRRI dhan36. A significant ($p<0.05$) variation in non-effective tillers per plant was observed in respect of different arsenic levels and nitrogen (Table 1). The highest number of non-effective tillers per plant (6.6) were found in A_1T_1 treated pot and lowest number of non-effective tillers per plant (0.0) of rice was found in A_4T_2 treated pot (Table 1). Results reflected similar correlation with some researchers, such as, Islam and Jahiruddin (2010), who reported that 15 mgkg^{-1} As treated rice soils significantly reduced the effective tillers per pot, filled grains per panicle and 1000-grain weight; these together contributed reduced grain yield. Similarly, Abedin et al., (2002) also observed that tillers number of rice plant was reduced significantly with increase of arsenic concentration in irrigation water up to 8 mgL^{-1}. Khan et al., (2010) also found that the addition of arsenic significantly reduced tillering in rice plant. In linear relationship, the non-effective tillers per plant of rice variety BRRI dhan36 were observed negatively and strongly correlated (R^2= 0.674) (Fig. 3).

3.4 Panicle length (cm)

Panicle length of rice variety BRRI dhan36 were decreased significantly with increasing soil As levels in soils. Panicle length of rice plant was affected markedly due to the effects of arsenic (As) and nitrogen fertilizers applications in BRRI dhan36 (Table 1). A significant ($p<0.05$) variation in panicle length was observed in respect of different arsenic levels and nitrogen fertilizers. The panicle length of rice plant was significantly affected by arsenic contamination of soil. Each successive levels of soil arsenic concentration significantly decreased the panicle length of BRRI dhan36. The largest panicle length (23.93 cm) was found in A_1T_2 treatment and smallest panicle length (11.48 cm) was found in A_4T_1 treatment (Table 1). Arsenic application in rice soils significantly reduced yield and different yield-contributing parameters including the number of panicles per plant, panicle dry weight, the number of spikelets and full grains per plant and 1000-grain weight (Vromman et al., 2013). Azad et al., (2009) reported that the panicles number of rice plant were not affected at low doses of As in soil but significantly affected the panicles number at higher doses. A positive and strong correlation of panicle length was found (R^2= 0.280) (Fig. 4).

Table 2. Effect of arsenic and nitrogen on the different yield parameters of rice

Treatments	**Filled grain plant^{-1}**	**Un-filled grain plant^{-1}**	**Filled grain panicle^{-1}**	**Un-filled grain panicle^{-1}**
A_1T_1	880.67 a	188.67	38.00	22.66
A_2T_1	515.67 bc	197.00	43.00	30.33
A_3T_1	266.33 cd	207.67	31.00	30.00
A_4T_1	99.67 d	214.00	37.00	27.66

A_1T_2	810.00 ab	155.00	43.667	22.66
A_2T_2	448.00 cd	228.00	36.667	24.00
A_3T_2	393.33 cd	253.33	34.333	28.00
A_4T_2	183.33 cd	298.33	32.667	36.00
LSD	**168.33**		**9.871**	**9.483**
CV (%)	**15.85**	**16.54**	**23.64**	**14.98**

Means in a column followed by same letter (s) are not significantly different at 5% level of significance

(A_1T_1= As0+N recommended dose, A_2T_1= As1+N recommended dose, A_3T_1=As2+N recommended dose,A_4T_1=As4+N recommended dose,A_1T_2=As0+50% more N than recommended dose,A_2T_2=As1+50% more N than recommended dose,,A_3T_2=As2+50% more N than recommended dose,A_4T_2=As4+50% more N than recommended dose.)

3.5 Filled grain plant^{-1}

The number of filled grain per panicle of rice plant was varied significantly with increasing of soil As ocncentration. Filled grain per panicle was affected markedly due to the effects of arsenic (As) and nitrogen fertilizer in BRRI dhan36. A significant ($p<0.05$) variation in filled grain per panicle was observed in respect of different arsenic levels and nitrogen fertilizers (Table 2). The highest filled grain per panicle (880.67) was found in A_1T_1 treatment and lowest filled grain per panicle (99.67) was found in A_4T_1 treatment (Table 2). This results were found similar with the findings from Hussain et al., (2005), Islam and Jahiruddin (2010). Strong and negative correlation were observed in filled grain per plant (R^2= 0.194).

3.6 Un-filled grain plant^{-1}

Increasing soil As concentration not only decrease the filled grain per panicle but also the un-filled grain per panicle of rice plant. Un-filled grain per panicle was affected due to the effects of arsenic (As) and nitrogen fertilizer in BRRI dhan36 (Table 2). A non-significant ($p<0.05$) variation in un-filled grain per panicle was observed in respect of different arsenic levels and nitrogen fertilizer. The highest un-filled grain per plant (298.33) was found in A_4T_2 treated pot and lowest un-filled grain per plant (188.67) was found in A_1T_1 treated pot (Table 2). In linear relationship, the un-filled grain per plant of rice variety BRRI dahn36 were observed negatively and strongly correlated (R^2= 0.498) (Fig. 6).

3.7 Filled grain panicle^{-1}

The number of filled grain per panicle of rice plant was varied significantly with increasing of soil As ocncentration. Filled grain per panicle was affected markedly due to the effects of arsenic (As) and nitrogen fertilizer in BRRI dhan36. A significant ($p<0.05$) variation in filled grain per panicle was observed in respect of different arsenic levels and PGPRs (Table 2). The highest filled grain per panicle (43.66) was found in A_1T_2 treatment and lowest filled grain per panicle (31.00) was found in A_3T_1 treatment (Table 2). This results were found similar with the findings from Hussain et al., (2005), Islam and Jahiruddin (2010).

3.8 Un-filled grain panicle^{-1}

Increasing soil As concentration not only decrease the filled grain per panicle but also the un-filled grain per panicle of rice plant. Un-filled grain per panicle was affected due to the effects of arsenic (As) and nitrogen fertilizer in BRRI dhan36 (Table 2). A non-significant ($p<0.05$) variation in un-filled grain per panicle was observed in respect of different arsenic levels and nitrogen fertilizer. The highest un-filled grain per panicle (27.66) was found in A_4T_2 treated pot and lowest un-filled grain per panicle (22.66) was found in A_1 treated pot (Table 2).

Table 3. Effect of arsenic and nitrogen on the different yield parameters of rice

Treatments	1000-grain weight (g)	Grain yield (g)	Straw yield (g)
A_1T_1	28.1	27.1 a	28.1 a
A_2T_1	27.833	26.2 a	25.8 ab
A_3T_1	27.3	23.2 ab	16.7 bcd
A_4T_1	27.6	16.6 bc	9.2 cd
A_1T_2	28.267	28 a	22.3 ab
A_2T_2	27.567	23.1 ab	19.8 abc
A_3T_2	27.3	14 c	16.8 abcd
A_4T_2	28.067	13 c	8.3 d
LSD	**NS**	**4.058**	**5.376**
CV (%)	**4.37**	**23.33**	**15.64**

Means in a column followed by same letter (s) are not significantly different at 5% level of significance (A_1T_1= As0+N recommended dose, A_2T_1= As1+N recommended dose, A_3T_1=As2+N recommended dose,A_4T_1=As4+N recommended dose,A_1T_2=As0+50% more N than recommended dose,A_2T_2=As1+50% more N than recommended dose,,A_3T_2=As2+50% more N than recommended dose,A_4T_2=As4+50% more N than recommended dose.)

3.9 1000 grain weight

Increasing soil As concentration affected the 1000 grain weight of rice in As contaminated soils. 1000-grain weight was affected markedly due to the effects of arsenic (As) and nitrogen fertilizer in BRRI dhan36 (Table 3). A non-significant ($p<0.05$) variation in 1000-grain weight was observed in respect of different arsenic levels and nitrogen fertilizer because the grain weight is a stable characters of cereal crops. The highest 1000-grain weight (28.26 g) was found in A_1T_2treatment and lowest 1000-grain weight (27.30 g) was found in A_3T_2 treatment (Table 2). Similar findings were found from some researchers, such as, Abedin (2002) found that presence arsenic at a higher concentration in irrigation water significantly reduced the 1000 grain weight of rice plant. Tsutsumi (1980) also reported that arsenic could reduce 1000 grain weight. Arsenic application in rice significantly reduced yield and different yield-contributing parameters including the number of panicles per plant, panicle dry weight, the number of spikelets and full grains per plant and 1000-grain weight (Vromman et al., 2013).

3.10 Straw yield

The straw yield of rice was found negatively affected with increasing soil As concentration in soils. Straw yield was affected markedly due to the effects of arsenic (As) and nitrogen fertilizer in BRRI dhan36 (Table 3). A significant ($p<0.05$) variation in straw yield was observed in respect of different arsenic levels and nitrogen fertilizer. The straw yield of rice plant was found reduced drastically in soil arsenic treatments. The highest straw yield (28.10 g) was found in A_1T_1 treatment and lowest straw yield (8.3 g) was found in A_4T_2 treatment (Table 3). This might be due to the accumulation of As in rice leads to a disturbance of essential physiological processes, such as photosynthesis and respiratory activity. Recently reported with soil test-based soil arsenic concentration which could be reduced the grain yield of rice (Hossain et al., 2005; and Kang et al., 1996). Several studies have shown that soil arsenic concentration on irrigated rice-based cropping system may cause heavy depletion of straw yield of rice (Abedin et al., 2002; Yan et al., 2005; Hossain et al., 2005 and Islam et al., 2004).This results reflected similar correlation with the findings from some researchers, such as, Islam and Jahiruddin (2010) found that the grain yield of rice was reduced by 20.6 % for 15 mg kg^{-1} As treatment and 63.8 % due to 30 $mgkg^{-1}$ As. Such reductions for straw yield were 21.0 and 65.2 % with these two As treatments, respectively. Islam et al., (2004) reported that higher doses of arsenic with irrigation water significantly reduced of plant height, panicle length, grains panicle^{-1}, grain and straw yields of rice in boro season. Similar results were also found from others researchers, such as, Li et al., (1996); Azad et al., (2009) and Abedin and Meharg (2002). The straw yield were also found negatively correlated significantly with effective tillers (R^2= 0.431) (Fig. 7).

3.11 Grain yield

The yield of rice variety BRRI dhan36 were found adversely affected with different levels of soil As concentration in soils. Grain yield was affected markedly due to the effects of arsenic (As) and nitrogen fertilizer in BRRI dhan36 (Table 3) . A significant ($p<0.05$) variation in grain yield was observed in respect of different arsenic levels and nitrogen fertilizer. The highest grain yield (28.00 g) was found in A_1T_2 treated pot and lowest grain yield (13.00 g) was found in A_4T_2 treated pot (Table 3). These finding were in agreement with Jahiruddin et al. (2004) stated that the highest grain yield reduction was observed with the maximum dose of irrigation arsenic treatment. These results are in good agreement with the findings of .Due to arsenic toxicity in rice plant, grain yield reduction was reported by Hossain et al. (2005); Hossain et al. (2008) and Kang et al. (1996). Similar results were published by some another researchers, such as, Panaullah et al., (2009); Carbonell-Barrachina et al., (1997); Abedin and Meharg (2002); and Tsutsumi (1980). Another report was found from Islam et al., (2004), he reported that higher doses of arsenic with irrigation water significantly reduced of plant height, panicle length, grains panicle^{-1}, grain and straw yields of rice in boro season. Abedin et al., (2002) found that increasing the concentration in irrigation water significantly decreased plant height, grain yield, the number of filled grains, grain weight, and root biomass, while the arsenic concentrations in root, straw, and rice husk increased significantly. In linear relationship, the grain yield of BRRI dhan36 was observed negatively correlated (R^2= 0.518) (Fig. 8).

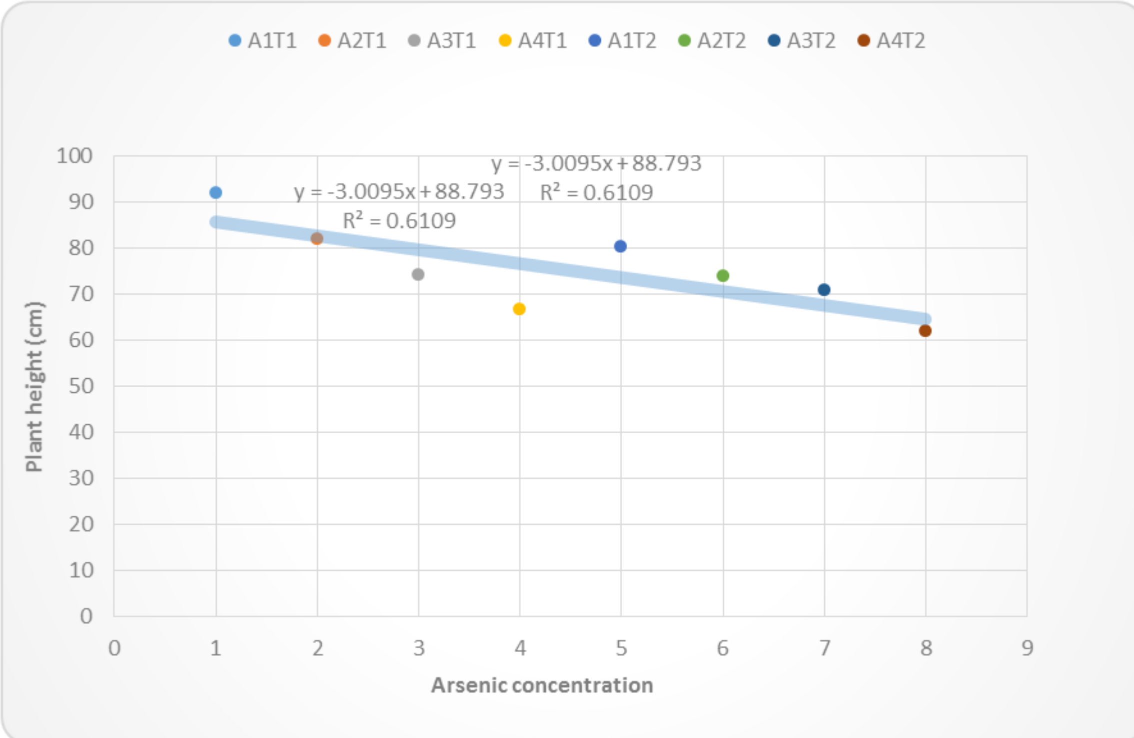

Fig. 1 Linear realtionship of plant height in response of arsenic and nitrogen fertilizers of BRRI dhan36.

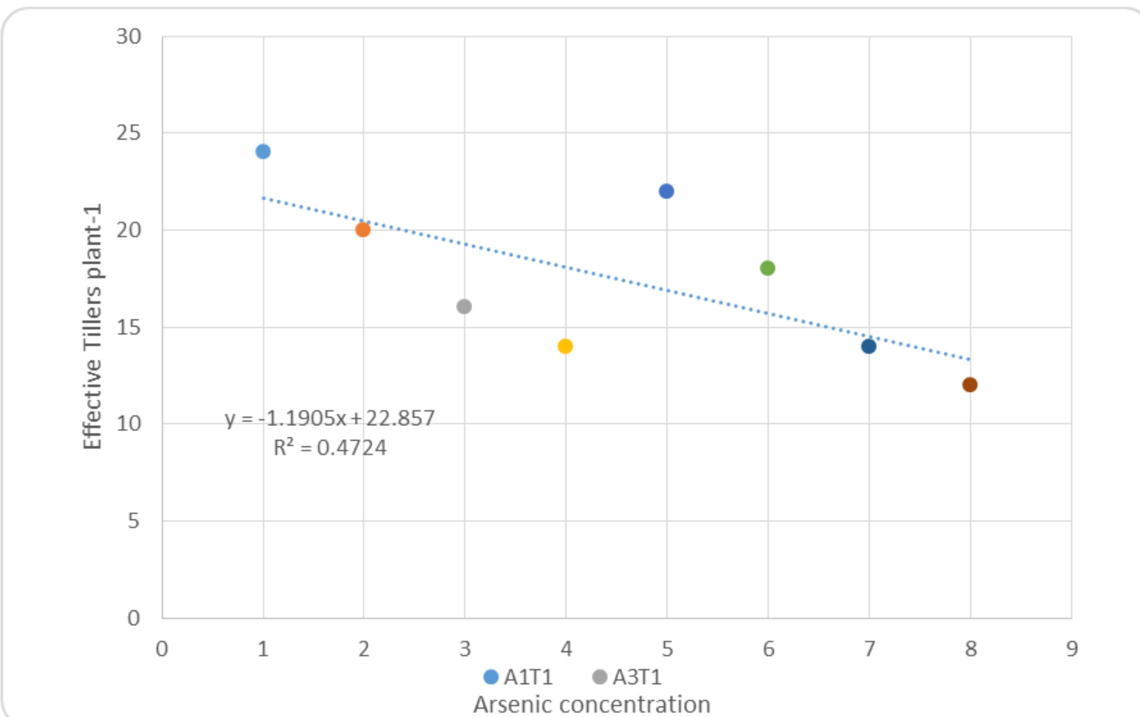

Fig. 2 Linear realtionship of effective tillers plant^{-1} in response of arsenic and nitrogen fertilizers of BRRI dhan36.

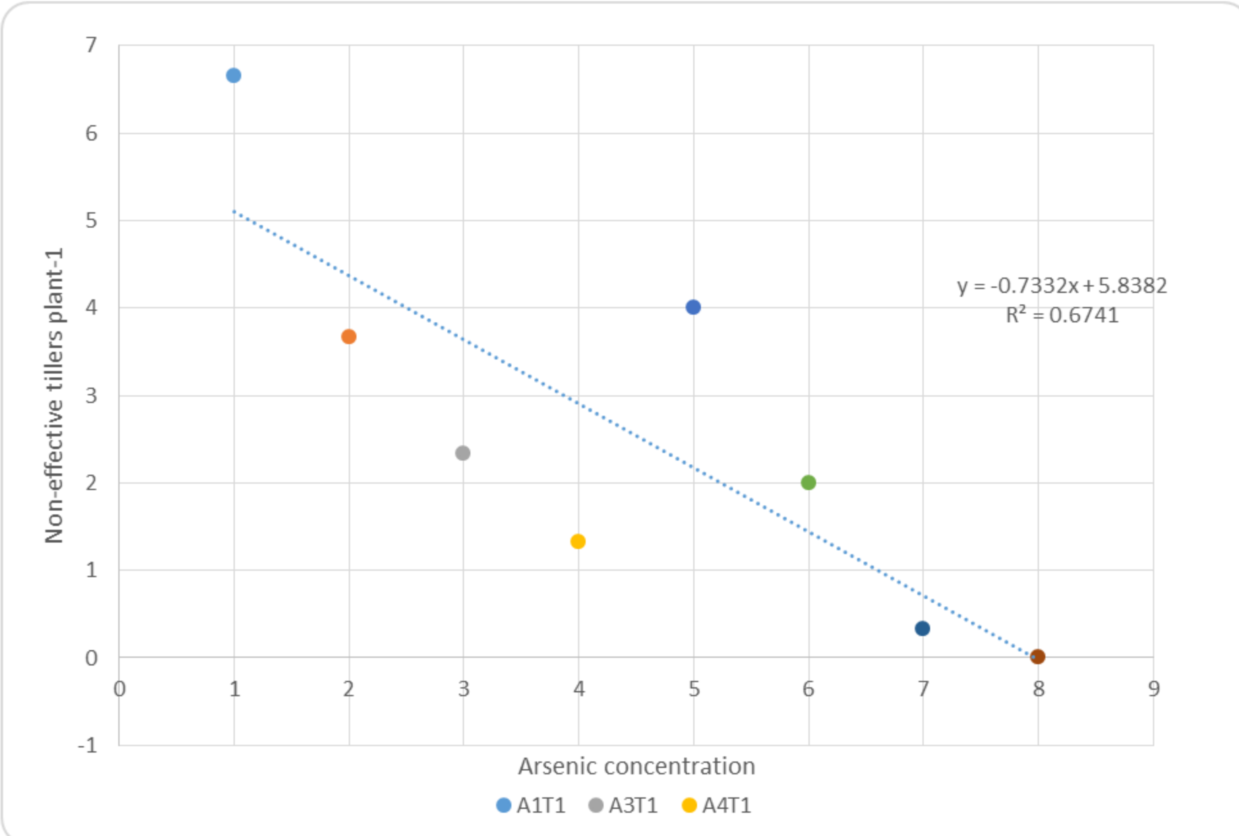

Fig. 3 Linear realtionship of non-effective tillers plant^{-1} in response of arsenic and nitrogen fertilizers of BRRI dhan36.

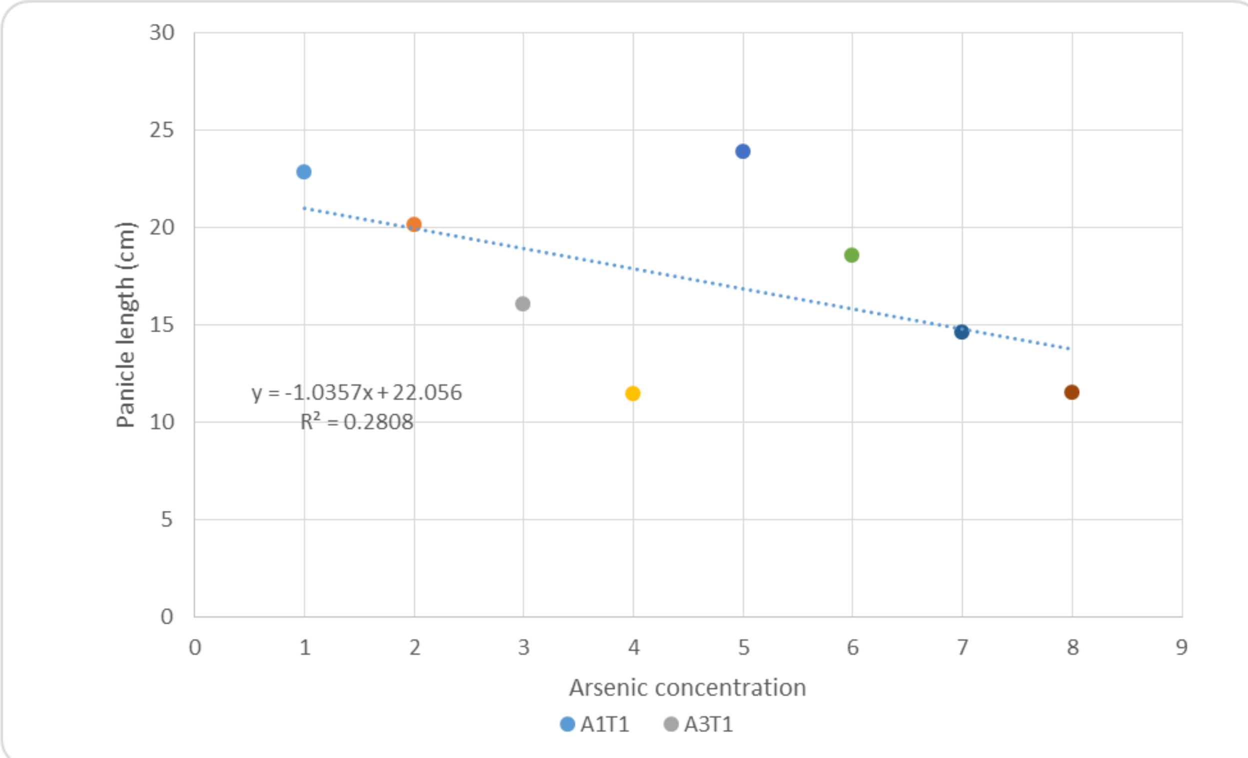

Fig. 4 Linear realtionship of panicle length in response of arsenic and nitrogen fertilizers of BRRI dhan36.

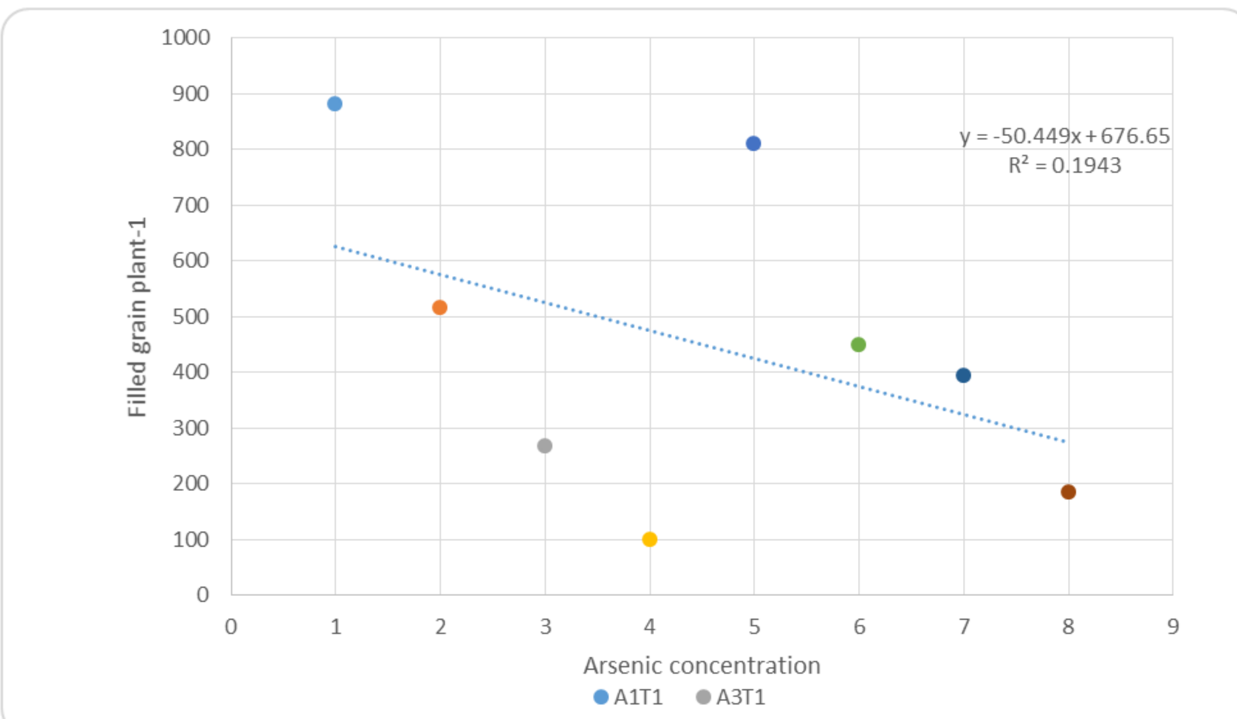

Fig. 5 Linear realtionship of filled grain plant^{-1} in response of arsenic and nitrogen fertilizers of BRRI dhan36.

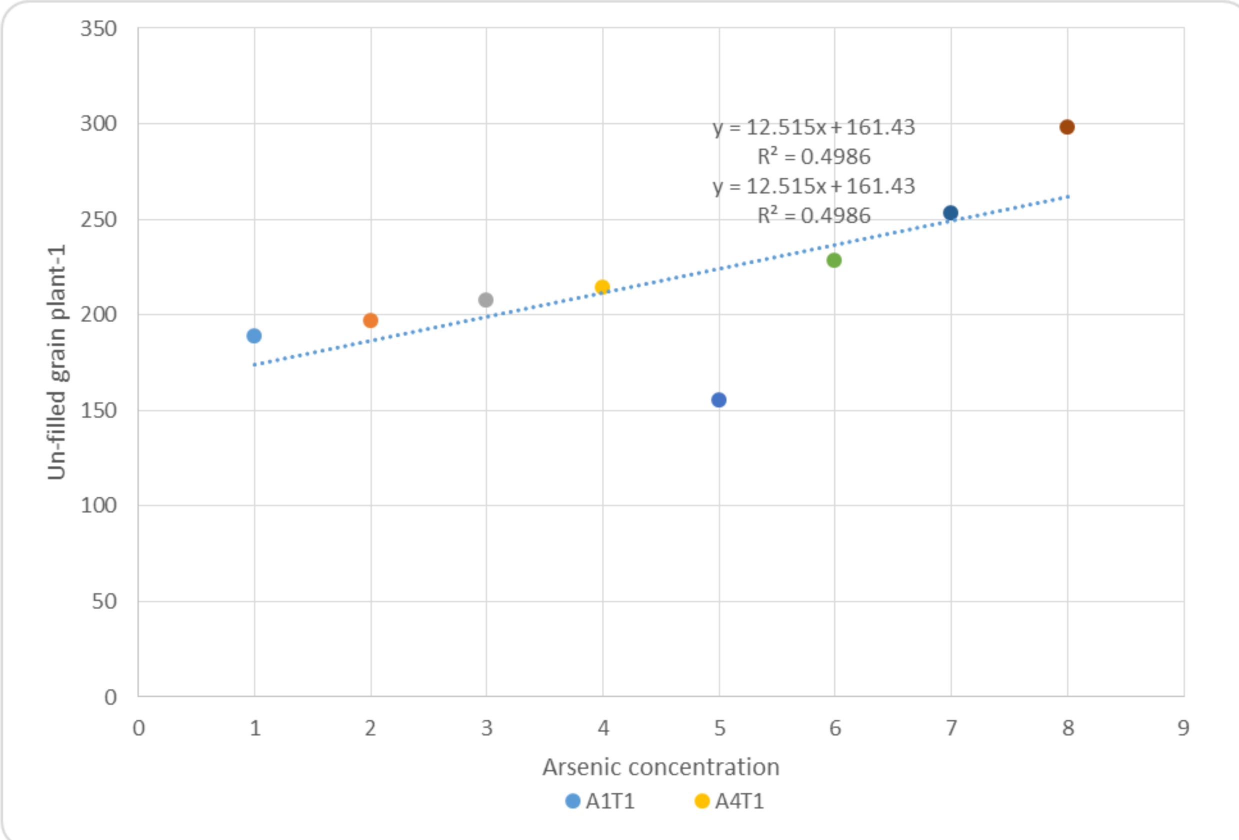

Fig. 6 Linear realtionship of un-filled grain plant^{-1} in response of arsenic and nitrogen fertilizers of BRRI dhan36.

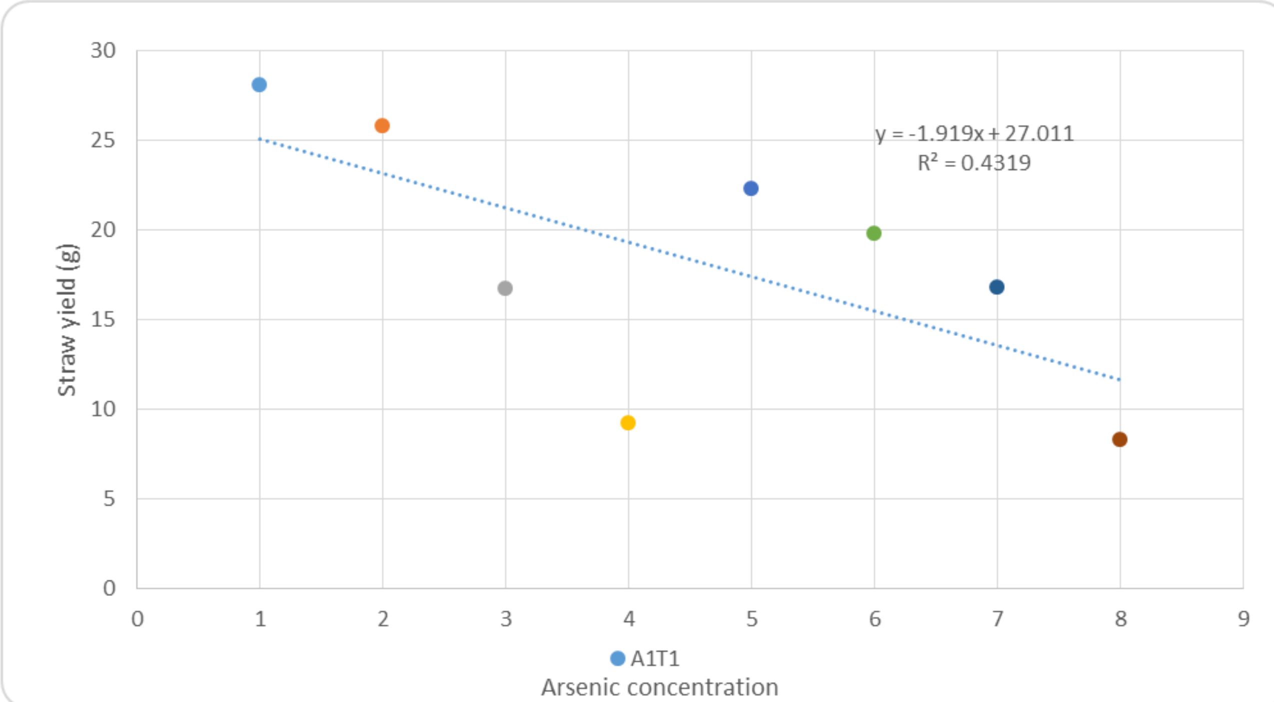

Fig. 7 Linear realtionship of straw yield in response of arsenic and nitrogen fertilizers of BRRI dhan36.

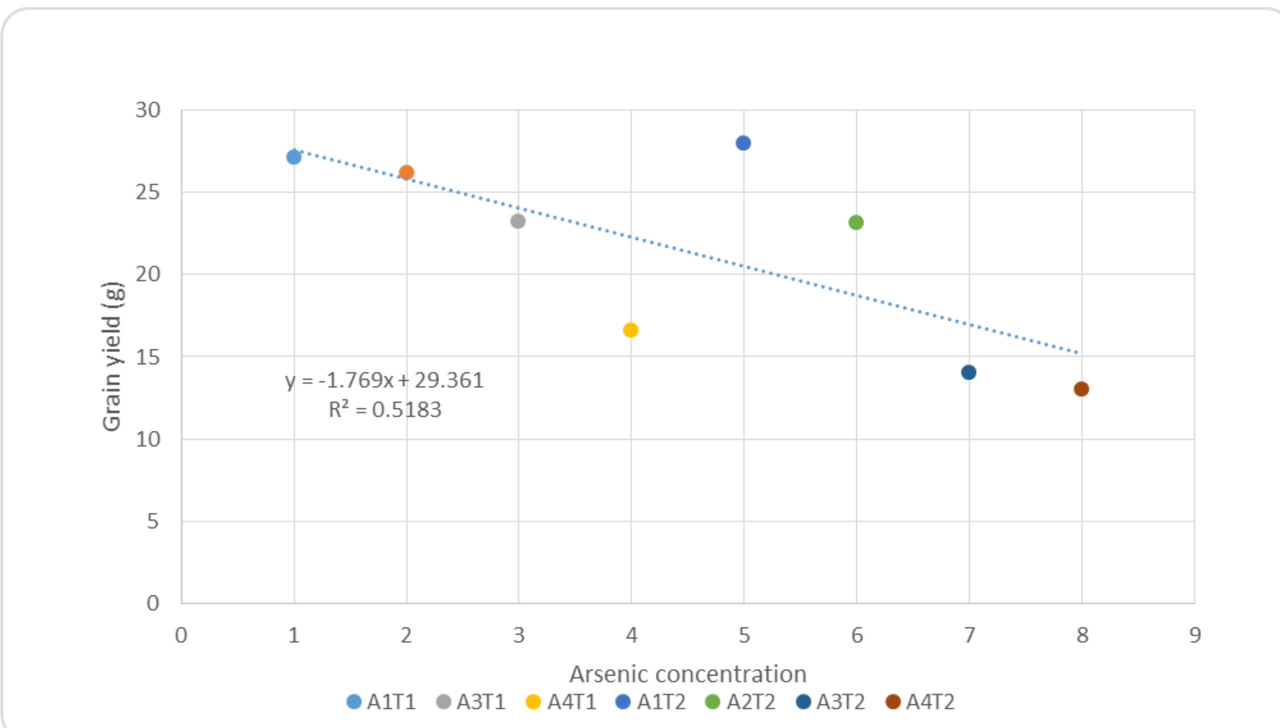

Fig. 8 Linear realtionship of grain yield in response of arsenic and nitrogen fertilizers of BRRI dhan36.

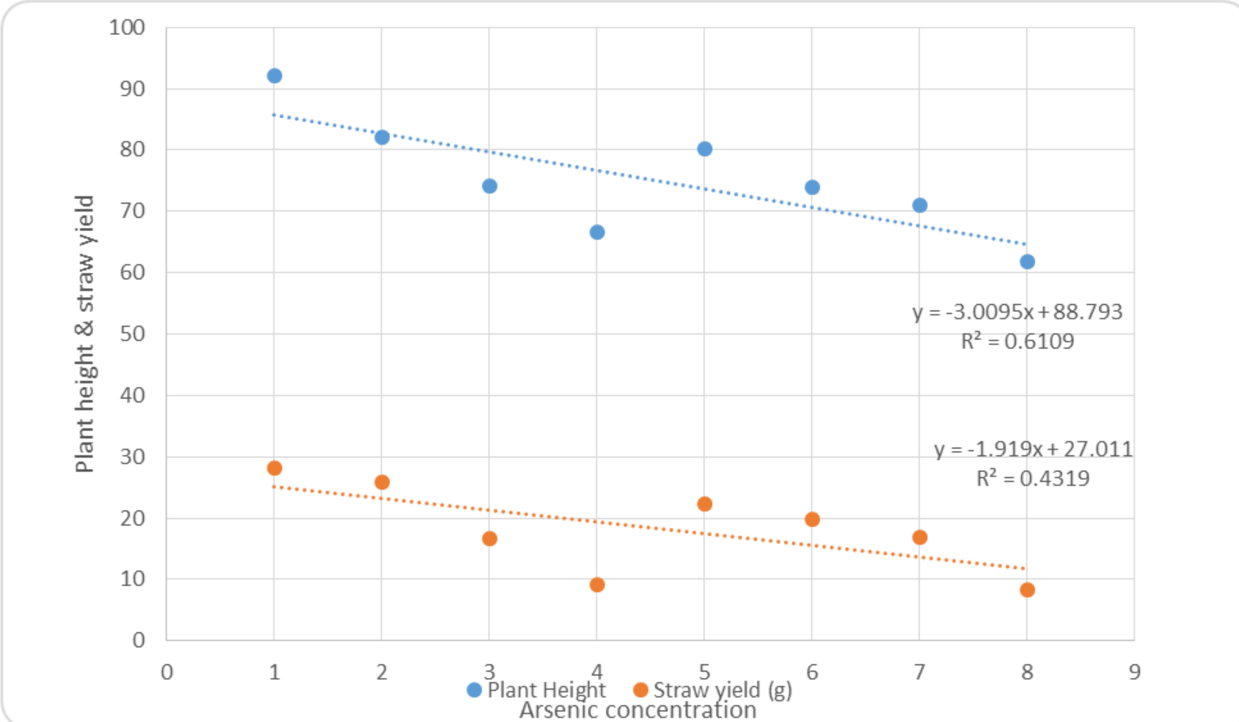

Fig. 9 Linear realtionship of plant height and grain yield in response of arsenic and nitrogen fertilizers of BRRI dhan36.

Arsenic (As), a toxic metalloid, is widely distributed in the environment, which results from both natural and anthropogenic sources. It is a human toxic and carcinogenic element that exists throughout the earth's crust and can be mobilized into water and subsequently incorporated into soil-water-plant system. Arsenic uptake and accumulation by plant is significantly influenced by As concentration in the soil or growth media and substantially increased with increasing As levels in soil solution. Soil microorganisms are capable of transforming As in the environment, thus impacting its solubility, mobility and bioavailability.

SUMMARY AND CONCLUSION

Chapter 5

Conclusion

The pot experiment was conducted at the Sher-e-Bangla Agricultural University, Dhaka, Bangladesh during the period in December 2016 to May 2017 to study the effect of arsenic on growth and yield of rice. The experiment comprised of two factors. Factor A: Arsenic level (4 levels): A_1: Control (No arsenic); A_2: 1 ppm As pot-1, A_3: 2 ppm As pot-1 and A_4:4 ppm As pot-1. Factor B: Nitrogen doses: (2 Nos.); T_1: recommended dose of nitrogen; T_2: 50% more than recommended dose of N.The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications.

In case of arsenic, at 30, 50, 70, 90 DAT and harvest the longest plant (42.1 cm, 70.1 cm, 78.4 cm, 83.4 and 92 cm), was recorded in A_1, whereas the shortest plant (29.5cm, 50.3 cm, 59.1 cm and 66.4 cm, 76.7 cm) in A_4. At 90 DAT the highest number of tillers hill-1 (26) was found in A_1 and while the lowest number (3) in A_4. The highest number of total tillers hill-1 at harvest (26) was found in A_1, whereas the lowest number (3) in A_4. The highest number of effective tillers hill-1 at harvest (24) was observed in A_1 and the lowest number (3) in A_4. The maximum length of panicle (20.82 cm) was recorded in A_1, again the minimum length (7.35) in A_4. The highest number of filled grains panicle-1 (58) was recorded in A_1, again the lowest number (20) in A_4. The lowest number of unfilled grains panicle-1 (13) was attained in A_1, while the highest number (41) in A_4. The highest weight of 1000 seeds (31.1g) was found in A_1 and the lowest weight (25.7 g) in A_4. The highest grain yield (32 gm hill-1) was recorded in A_1, while the lowest grain yield (12.2 gm hill-1) in A_3.The highest straw yield (28.1 gm hill-1) was attained in A_1, again the lowest straw yield (3.1 gm hill-1) in A_4.

At 30, 45, 60, 90 DAT and at harvest, the tallest plant (39 cm, 62 cm, 67 cm, 76.1 cm and 92 cm) was observed in T_1 again the shortest plant (28.5 cm, 46 cm, 58.2 cm, 66.3 cm and 71.9 cm) in T_2. At harvest, the highest number of tillers hill-1 (26) was obtained in T_1, again the lowest number (3) in T_2 at same stage. The highest number of effective tillers hill-1 at harvest (24) was found in T_1, whereas the lowest number (3) in T_2. The maximum length of panicle (28 cm) was recorded in T_1, whereas the minimum length (7.35 cm) in T_2. The highest number of filled grains panicle-1 (58) was observed in T_2, whereas the lowest number (20) in T_1. The lowest number of unfilled grains panicle-1 (45) was found in T_2, while the highest number (13) in T_1. The highest weight of 1000 seeds (28.8 g) was observed in T_1, while the lowest weight (25.7 g) in T_2. The highest grain yield (32 gm hill-1) was found in T_1 and the lowest grain yield (6 gm hill-1) in T_2. The highest straw yield (27.5 gm hill-1) was observed in T_2 , whereas the lowest straw yield (6.7 gm hill-1) in T_1 .

At 30, 45, 60, 90 DAT and at harvest the tallest plant (42.1 cm, 70.1 cm, 78.4 cm, 83.4 and 92 cm) was observed in A_1T_1, while the shortest (29.5cm, 50.3 cm, 59.1 cm and 66.4 cm, 76.7 cm) in A_4T_1. At harvest the highest number of tillers hill-1 (26) was recorded in A_1T_1 and the lowest number (3) in A_4T_2. The highest number of effective tillers hill-1 at harvest (24) was attained in A_1T_1, while the lowest number (3) in A_4T_2. The maximum length of panicle (28 cm) was attained in A_1T_2 and the minimum length of panicle (7.35 cm) in A_4T_2. The highest number of filled grains panicle-1 (54) was observed in A_2T_1 and the lowest number (22) in A_4T_2. The highest weight of 1000 seeds (31.1g) was found in A_1T_1, again the lowest weight (25.7 g) in A_4T_2. The highest grain yield (28.8 gm hill-1) was attained in A_1T_1, while the lowest grain yield (13 gm hill-1) in A_3T_1. The highest straw yield (28.5 gm hill-1) was recorded in A_1T_1,whereas the lowest straw yield (8.3 gm hill-1) in A_4T_2.

It may be concluded that growth, yield and yield contributing characters of rice were influenced by different levels of arsenic and nitrogen dose. Among the treatment combination applications of 0 ppm As/pot in BRRI dhan 36 produced longest plant, highest number of tillers, longest panicle, maximum number of filled grains panicle^{-1} and highest 1000 grains weight and ultimately provides maximum grain and straw yields. Considering the situation of the present experiment, further studies in the following areas may be suggested:

1. Such study is needed in different agro-ecological zones (AEZ) of Bangladesh for regional compliance and other performance.

2. More experiments may be carried out with other fertilizer doses.

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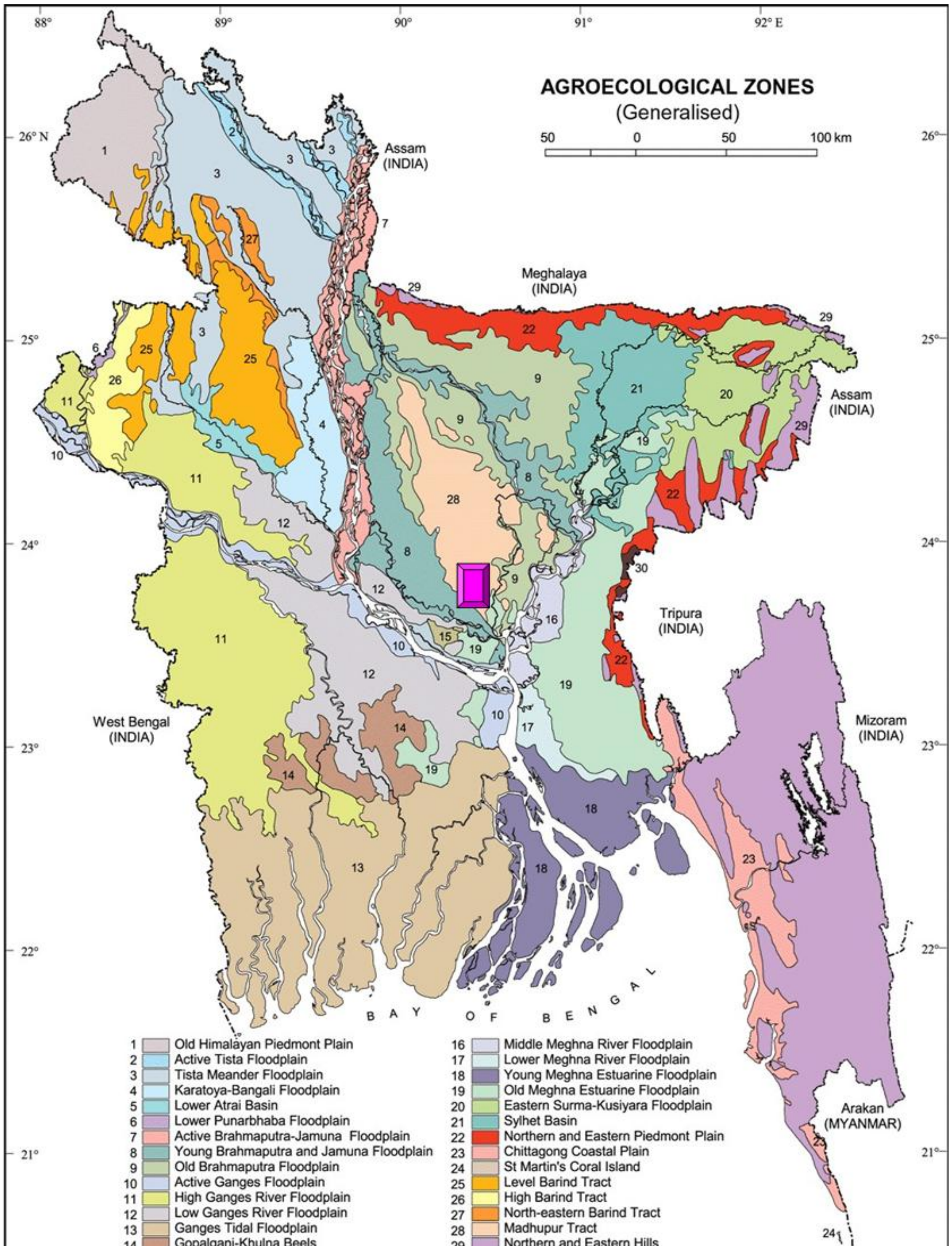
APPENDICES

APPENDICES

Appendix I. Photograph showing location of experimental site.



Appendix II. Characteristics of the soil of experimental field

Physical and chemical properties of the initial soil

Characteristics	Value
% Sand	27
% Silt	43
% Clay	30
Textural class	Silty-clay
pH	6.1
Organic matter (%)	1.13
Total N (%)	0.03
Available P (ppm)	20.00
Exchangeable K (me/100g soil)	0.10
Available S (ppm)	23

Source: Soil Resources Development Institute (SRDI), Farmgate, Dhaka