ISSN: 1394-7900
Malaysian Journal of Soil Science Vol.12 : 87-102 (2008) Malaysian Society of Soil Science

Amelioration of Cheringa Acid Sulfate Soil and Screening of Acidity-Salinity Tolerant Rice Varieties in a Simulation Study

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ABSTRACT

A simulation study was conducted to evaluate the effects of basic slag (BS_{10}: basic slag 10 t ha^{-1} and BS_{20}: basic slag 20 t ha^{-1}), aggregate size (A_{20}: aggregate sizes of soil less than 20 mm and A_{30}: aggregate sizes of soil, 20-30 mm) and groundwater depth (Gw_0: no influence of groundwater and Gw_{50}: groundwater beneath 50 cm of the soil surface) in pre-leached Cheringa acid sulfate soil (Typic Sulfic Halaquept) in relation to the production and screening of the acidity-salinity tolerance of 18 rice cultivars. The results obtained from the study showed that the physico-chemical properties of the pre-leached acid sulfate soil were strongly ($p \leq 0.05$) influenced by the application of basic slag, aggregate size and maintenance of groundwater depth. Among the individual treatments, the application of BS_{20} ranked first with regard to the reclamation of soil and production of rice, followed by $Gw_{50} > A_{30}$. The average soil data of all the treatments at post harvesting of rice cultivars were increased by 1.6 units for soil $pH_{(water;\ 1:2.5)}$ and 34 to 1803% for the contents of N, P, Ca and Mg, while the saturations of Fe, Al and Na were decreased by 24 to 88% compared with the initial soil. The maximum quantity (6.9 t/ha) of rice grain was attained by the local (Cox' Bazar) Kajashail, followed by the Bangladesh rice (BR) line 5828-11-1-4 (6.7 t ha^{-1}) > BR 23 (6.6 t ha^{-1}). Among the rice varieties, the BR lines were found to be the most effective for rice production in the soil, followed by the local varieties > BR varieties > international rice (IR) varieties. Almost similar and significant ($p \leq 0.05$) effects were observed for plant height, tiller production, straw yield and yield components of the rice cultivated in the soil.

Keywords: Acid sulfate soil, aggregate size, basic slag, groundwater depth, tolerant rice cultivars

INTRODUCTION

It is estimated that acid sulfate soils (ASSs) affect some 100 million hectares (M ha) of land world-wide (Sheeran 2003). Van Mensvoort and Dent (1998) claimed that for about 24 M ha of ASSs, of which about 0.7 M ha are located in inundated

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areas in Bangladesh, have high agricultural potential (Khan 2000). These ASSs can cause severe environmental degradation. Neutralising them with lime and/or leaching leads to the deterioration of soils, related ecosystems and to permanent soil acidification (Khan and Adachi 1999). Runoff and leachate from ASSs can adversely affect aquatic communities, agriculture, engineering works and beneficial use of the environment (*http://www.epa.vic.gov.au*). The reclamation of these soils may be difficult, but essential, due to the severe acidity and salinity problems (from flooding by saline sea water) during the dry periods of the year, which not only hinders crop growth but also destroys aquatic organisms. Moreover, there is a need to increase food production but the availability of land for growing crops is limited. It may become inevitable to utilise marginal and problem soils or to improve yield potential for various crops per unit land under various soil stresses. It has also been demonstrated that the reclamation and improvement of ASSs through leaching cannot be an effective and sustainable method of crop production, unless these practices are followed by the addition of materials rich in basic cations such as basic slags (Khan *et al*. 1994). Takai *et al*. (1992), based on studies carried out in Thailand over a period of nine years, reported that nutrient deficiency is an important factor when reclamation and improvement practices are performed in ASSs. Khan *et al*. (2006) reported that the application of basic slag (BS) in ASSs significantly increased soil pH, Ca and Mg with an associated decrease in Na, Fe and Al concentrations over time. Successful reclamation of ASSs may result in the development of productive fields for crop growth. While poor soil reclamation may lead to creation of unfavorable soil conditions for crop growth and formation of actual ASSs, the real problem lies in the coastal tidal flat plain areas (Khan *et al*. 2007). Basic slag as a byproduct from the steel industry in Bangladesh can be collected almost free of charge and the processing cost which depends on the amount of basic slag to be processed and the availability of a processing factory nearby is relatively low. The basic slag had a very high pH of 9.6 and contained 20.8% Ca, 9.8% Mg, and 12.8% SiO_2 (Khan *et al*. 2006). They also stated that the use of basic slag was found to be harmless in Bangladesh since 1985. Elawad and Green (1979) reported that Si contained in basic slag decreases Mn toxicity, enhances insect and disease resistance, and increases the water-use efficiency and oxidation power of rice roots and the efficiency of phosphorus utilisation in low pH soils. In ASSs, water management is the key to soil management and proper water management can limit acidification. To achieve the highest rate of oxidation and effective drainage of sulfudic materials in the heavy-textured ASS, the soil aggregate size should be smaller than the conventional sizes, which may enhance rice production by allowing a higher rate of release of toxic elements like Al, Fe and salts. Moreover, screening of acidity-salinity tolerant rice varieties for the ASS plays a very important role for the right selection of suitable tolerant varieties of rice for the peculiar characters of the ASS. Considering the above facts, the objectives of the present simulation study were to reduce the acidity and salinity problems of ASS through leaching and to evaluate the effects of basic slag application rate, aggregate size and groundwater depth as physico-chemical amendments of ASS in relation to the production and screening of acidity-salinity tolerant rice cultivars.

MATERIALS AND METHODS

Soil Collection

Cheringa ASS occurs in the coastal old mangrove floodplain area of Cox' Bazar (Latitude 1206.2 rad or 21°3' N, Longitude 5220.0 rad or 91°6' E) in Bangladesh. For the simulation study using concrete tanks, bulk soils from the 1st layer (0-20 cm), 2nd layer (20-40 cm) and 3rd layer (40-60 cm) of fallow land (crop production impossible due to severe acidity and salinity) of Cheringa ASS were collected from Ringbong Sarishaghata (Dulhazara) in the Cox' Bazar district in Bangladesh. The samples obtained from the soil were stored for a couple of days under field-moist conditions (by putting the soil samples into polyethylene bags in an air-tied box) just prior to laboratory analyses, when the sub-samples were air-dried and crushed to 2 mm before analyses. After treatment with 1M CH_3COONH_4 (pH 5.0) and with 30% H_2O_2 to remove free salts and organic matter, respectively, particle size distribution was determined by the pipette method (Day 1965). Soil pH was measured for the oven dried soil in soil-water (1:2.5) suspension using a Corning pH meter Model-7 as described by Jackson (1973). For saturation extract of soil, the electrical conductivity (Richards 1954), water soluble Na^+ and K^+ (flame photometry: Black 1965), water soluble SO_4^{2-} and Cl^- contents (Jackson 1973); Ca^{2+}, Mg^{2+}, Fe^{3+} and Al^{3+} (atomic absorption spectrometry - AAS: Hesse 1971) were determined. Organic matter content was determined (Nelson and Sommers 1982) by wet combustion with $K_2Cr_2O_7$. Available N (1.3M KCl extraction, Jackson 1973), available P (0.002N H_2SO_4, pH 3 extraction, Olsen *et al*. 1954) were determined. Cation exchange capacity was determined by saturation with CH_3COONH_4(pH 7.0), ethanol washing, NH_4^+ displacement with acidified 10% NaCl, and subsequent analysis by steam (Kjeldhal method) distillation (Chapman 1965). Exchangeable Na^+, K^+, Ca^{2+} and Mg^{2+} were extracted with 1M CH_3COONH_4 (pH 7.0) and determined by flame photometry (Na^+, K^+) and AAS. Exchangeable Al^{3+} (1M KCl, Thomas 1982) and Fe^{3+} (1M CH_3COONH_4: pH 4.8, Black 1965) were determined by AAS. Pyrite (FeS_2) content was estimated from the total content of Fe {(Fe content/46.7) x 100, i.e. FeS_2 was considered to contain 46.7% Fe; other Fe-containing minerals were ignored for this study} in the ASS. The soil had a silty clay texture and contained pyrite, high Al and Fe, and low base saturation (Table 1). Selected physical and chemical properties of the initial soil (depth: 0-60 cm) and the average (18 treatments having 3 replications) soil (0-60 cm) data of all the treatments at post harvesting of rice are presented in Table 1. Based on the field and laboratory investigations (Kabir 2005), the soil was classified as Typic Sulfic Halaquept (Soil Survey Staff 1999).

Preparation of Simulation Tanks

The soil samples from 1st, 2nd and 3rd layers were air-dried and crushed into two different aggregate sizes of <20 and 20-30 mm, to prepare a 60-cm soil bed by arranging the soil layers in the same order as that under field conditions. Effects of the basic slag application rate (BS_{10} and BS_{20}: basic slag 10 and 20 t ha^{-1}), aggregate size (A_{20} and A_{30}: aggregate sizes of soils, less than 20 and 20-30 mm, respectively) and groundwater depth (Gw_0: no influence of groundwater and Gw_{50}: groundwater beneath 50 cm of the soil surface) as physico-chemical amendments in the pre-

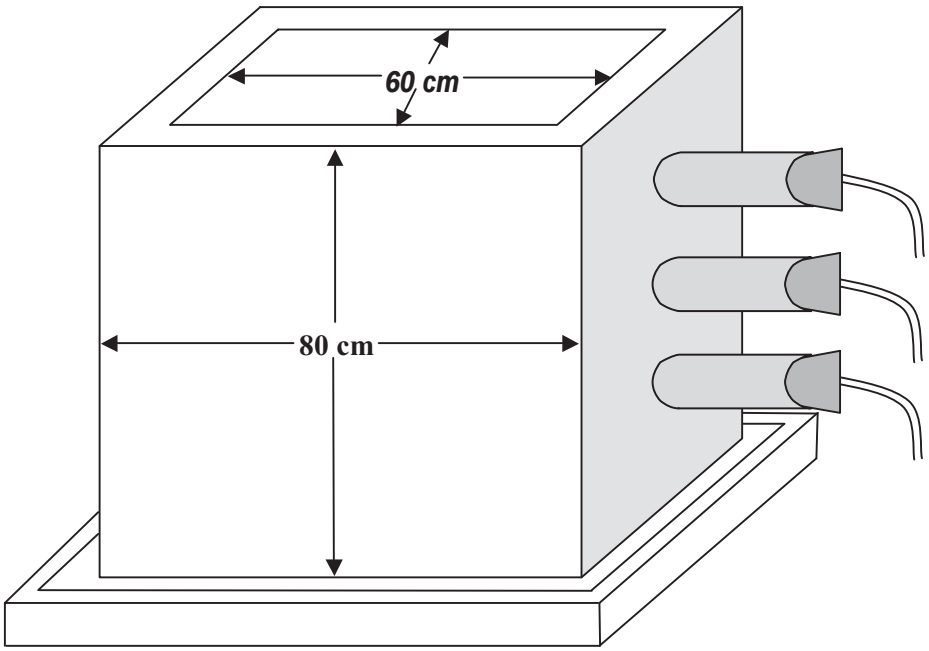

Fig. 1: Design of concrete tank used for the simulation study

leached ASS of the Cheringa series were evaluated in a simulation experiment in relation to the production and screening of salt tolerant rice varieties. The size of the concrete tank was 0.6 m X 0.6 m X height 0.8 m, that is, the inside area of each tank was about 0.4 m^2 (*Fig. 1*). The absolute control ($A_0Gw_0BS_0$) treatment of the experiment has been excluded due to not having data on agronomic parameters of rice which was attributed to the severe acidity and salinity problems of the soil. It was also mentioned earlier that the soil was collected from the fallow land, where crop production was nil. Moreover, Khan *et al*. (1994; 1996; 2006) reported that the use of BS at the rate of 10 to 20 t/ha would be economic for these ASSs of Bangladesh. Furthermore, the maintenance of A0 sizes (no till) was not an effective measure for this soil. Therefore, the $A_{20}Gw_0BS_{10}$ (T_1) treatment was used as experimental control for the present simulation study. The experiment was conducted in the polyethylene house at the premises of the Department of Soil, Water and Environment, University of Dhaka during the period for September to December, 2002. The experiment was set up in a completely randomised design with three replications for each treatment. The temperatures during experiment were 29±5°C.

About 10 kg of air-dried coarse sand, which was previously treated with tap water followed by 1M HCl, and distilled water was placed at the bottom of each of the concrete tanks. Thereafter, the soil layers were placed in the concrete tanks according to the following field arrangement: 1st layer at the top of the concrete tank, followed by the 2nd and 3rd layers. The soils amounting to about 70, 30 and 30 kg from the 1^{st}, 2^{nd} and 3^{rd} layers, respectively, that is, a total of 130 kg soils with aggregate sizes of <20 and 20-30 mm were placed in the concrete tanks for

the treatments. Some of the concrete tanks were designed with facilities aimed at analysing the effect of groundwater at a depth of 50 cm beneath the soil surface. All the concrete tanks were heavily coated with cement in order to prevent any release of materials. Prior to the transplanting operation, the soil in each tank was leached through tap water of about 10 L m^{-2} each time and this practice was done 10 times within a week to remove excess salts, that is, to increase the initial $pH(_{dry\ 1:2.5})$ of the soil from 3.6 to 4.1 and to decrease the initial ECe value from 17 to 2.1 dS m^{-1} during transplantation.

Then to the topsoil in each tank, fertilisers containing N, P and K at rates of 100, 60 and 40 kg ha^{-1} as urea, triple super phosphate (TSP) and muriate of potash (MP), respectively, were applied. The full dose of TSP and MP and half of the urea dose were mixed with soil during tank preparation. The remaining half of urea was applied in two equal splits, one at the maximal growth stage of the rice tillers and the other at the panicle initiation stage. The top soils in the concrete tanks were also subjected to the application of basic slag at rates of 10 and 20 t ha^{-1} during soil preparation. Thirty-day-old healthy and uniform seedlings of 18 varieties of rice (six International Rice Research Institute's - IRRI varieties: IR 42, IR 44, IR 46, IR 50 and IR 54; five Bangladesh rice research institute's - BRRI varieties: BR 1, BR 4, BR 10, BR 11 and BR 23; two BRRI lines: BR 5331-93-2-8-3 and BR 5828-11-1-4; and five local (Cox' Bazar area) high yielding varieties - HYVs: Nonashail, Latishail, Nazirshail, Rajashail and Kajalshail) were transplanted at a rate of 2 plants per hill, 3 hills in a row and 6 rows in the tank (that is, 18 hills per unit of 0.4 m^2 tank). The distance between the hills and rows were 16 and 10 cm, respectively. The soils in the tanks were irrigated with tap water, whenever necessary to maintain the topsoil under moist to wet conditions for rice production on ASSs. The Gw level was also maintained regularly by using tap water when required.

Sample Collection and Analysis

Plant height, number of tillers and straw dry matter yield were determined after harvesting the rice at maturity from about 110 to 125 days after transplanting. The straw and grain yields of the rice cultivars were determined. The level of significance of the different treatments was determined using Duncan's New Multiple Range Test (DMRT) and least significant difference (LSD) techniques (Zaman *et al*. 1982). The typical analyses of selected parameters of the rice and soils, as determined after harvesting at maturity stage of the rice, are presented in Tables 2 and 3.

RESULTS AND DISCUSSION

Conditions of Pre- and Post Harvesting Soils

The Cheringa ASS showed a silty clay loam texture, initially low pH of 3.1 to 3.8 as determined by the different conditions, low base saturation (20.3%), high ECe (17 dS m^{-1}) and high Fe and Al saturations (Table 1). The soil was subjected to physico-chemical amelioration in relation to rice cultivation by the application of basic slag, aggregate size and groundwater treatments after leaching. The pH

TABLE 1
Some selected properties of the initial Cheringa acid sulfate soil (depth: 0-60 cm) and the average (18 treatments having 3 replications) soil (0-60 cm) data of the all treatments at post harvesting of the rice cultivars under a simulation study

Soil properties	Initial soil	Post harvested soil	% IOC[a]
Texture		Silty clay loam	
Water content at Field Capacity (%)	51	53	4
Soil pH (Field, 1:2.5)	3.8	5.5	45
Soil pH (water, 1:2.5)	3.6	5.2	44
Soil pH (0.02 M $CaCl_2$, 1:2.5)	3.1	4.8	55
Pyrite content (g kg^{-1})	82	33	- 60
ECe (dS m^{-1})	17	2.3	- 86
Organic Carbon (g kg^{-1})	21.7	25.1	16
Available N (1.3 M KCl: mM kg^{-1})	3.53	5.61	59
Avail. P (0.002N H_2SO_4, pH 3: mM kg^{-1})	0.10	0.21	110
CEC (1 M NH_4Cl: $cmol_c$ kg^{-1})	18.7	19.4	4
Base saturation at pH 7.0 (%)	20.3	61.3	202
Al-saturation (1 M KCl: %)	44.5	5.46	- 88
Fe-saturation (1 M NH_4Cl: %)	9.1	4.27	- 53
Na-saturation (1 M NH_4Cl: %)	12.1	9.22	- 24
K-saturation (1 M NH_4Cl: %)	1.3	2.33	79
Ca-saturation (1 M NH_4Cl: %)	1.2	22.83	1803
Mg-saturation (1 M NH_4Cl: %)	5.4	26.93	399
Water-soluble ions:			
Sodium (flame photometer: $cmol_c$ kg^{-1})	4.25	2.67	- 37
Potassium (flame photomet.: $cmol_c$ kg^{-1})	0.21	0.35	67
Calcium (AAS*: $cmol_c$ kg^{-1})	0.29	3.79	1207
Magnesium (AAS: $cmol_c$ kg^{-1})	3.47	4.66	34
Aluminum (AAS: $cmol_c$ kg^{-1})	2.23	0.29	- 87
Iron (AAS: $cmol_c$ kg^{-1})	0.33	0.31	- 6
Chloride (0.05N $AgNO_3$: $cmol_c$ kg^{-1})	3.75	2.51	- 33
Sulfate ($BaCl_2$: $cmol_c$ kg^{-1})	5.03	2.56	- 49

[a]IOC = Increase over control (initial soil).*AAS=Atomic Absorption Spectrophotometer

TABLE 2
Comparison of post harvested soil pH and exchangeable K, Ca, Mg, Fe and Al as affected by basic slag (BS), groundwater level (Gw) and aggregate size (A) treatments in the Cheringa acid sulfate soil under a simulation study

Treatment	Soil pH			Exchangeable K ($cmol_c$ kg^{-1})		
	BS_{10}	BS_{20}	Gw $M^{\#}$	BS_{10}	BS_{20}	Gw $M^{\#}$
Gw_0			5.0 q			0.42 q
A_{20}	4.8 [a$]	5.5 [a]		0.33 [b]	0.41 [b]	
A_{30}	4.6 [a]	5.2 [b]		0.42 [a]	0.53 [a]	
Gw_{50}			5.3 p			0.48 p
A_{20}	5.2 [a]	5.8 [a]		0.37 [b]	0.49 [a]	
A_{30}	4.8 [b]	5.4 [b]		0.46 [a]	0.60 [a]	
BS Mean	4.9 n	5.5 m		0.40 n	0.051 m	
L.S.D. at 5% level =			0.3			0.06
Exchangeable Ca ($cmol_c$ kg^{-1})				Exchangeable Mg ($cmol_c$ kg^{-1})		
Gw_0			4.4 p			5.2 p
A_{20}	4.2 [a]	4.4 [a]		4.8 [a]	5.1 [b]	
A_{30}	4.3 [a]	4.6 a		5.0 [a]	5.8 [a]	
Gw_{50}			4.5 p			5.3 p
A_{20}	4.2 [a]	4.6 [a]		4.8 [b]	5.4 [b]	
A_{30}	4.4 [a]	4.8 [a]		5.1 [a]	5.9 [a]	
BS Mean	4.3 n	4.6 m		4.9 n	5.6 m	
L.S.D. at 5% level =			0.3			0.3
Exchangeable Fe ($cmol_c$ kg^{-1})				Exchangeable Al ($cmol_c$ /kg^{-1})		
Gw_0			0.97 p			1.04 p
A_{20}	1.19 [a]	0.97 [a]		1.26 [a]	0.79 [a]	
A_{30}	1.10 [b]	0.61 [b]		1.28 [a]	0.84 [a]	
Gw_{50}			0.69 q			1.08 p
A_{20}	1.09 [a]	0.48 [a]		1.49 [a]	0.96 [a]	
A_{30}	0.78 [b]	0.41 [b]		1.23 [b]	0.63 [b]	
BS Mean	1.04 m	0.62 n		1.32 m	0.81 n	
L.S.D. at 5% level =			0.06			0.08

$M^{\#}$ = Mean,
[$]In a column and row, means followed by a common letter are not significantly different at 5% ($p \leq 0.05$) level

values in different conditions of the average soil data of all the treatments at post-harvesting of rice were found to have increased from 4.8 to 5.5, that is, by 1.6 to 1.7 units higher compared with the control (initial value), while the ECe value of the soil decreased to 2.3 dS m^{-1}, which was 14.7 units lower than the initial ECe value (86% decrease from control: Table 1). The contents of N, P, Ca and Mg in the average soil data at post-harvesting were found to have increased (IOC = increase from control) from 34 to 1803% IOC. The saturations of Al, Fe and Na in the soil were found to have decreased by 24 to 88% (Table 1). The results also indicate that the physico-chemical properties of the ASS were strongly influenced by the application of basic slag, aggregate size and groundwater treatments after leaching practices.

The analyses of the post harvested soil data of pH, exchangeable K, Ca, Mg, Fe and Al contents were found to be affected significantly ($p \leq 0.05$) by the individual application of the basic slag, groundwater level and aggregate size treatments (Table 2). In most cases, the interactions of these treatments were more effective than the individual treatments for the increase in soil pH, K, Ca and Mg contents. The contents of Al, Fe and Na were found to decrease significantly by the treatments (Table 2). Among the individual treatments, the application of BS_{20} ranked first, followed by the $Gw_{50} > A_{30}$ treatments for the increments of soil pH, exchangeable K, Ca and Mg, while these effects were found to be reversed for the contents of exchangeable Fe and Al in the post-harvested soil. Such a response of these parameters to the application of basic slag was due to the increase in soil pH and ultimate release of some elements such as K, Ca, Mg into the soil and the results agreed well with the findings of Khan *et al*. (1994; 1996).

Tiller Production

The maximum number of average tillers of 12.9/plant was recorded for the local variety Rajashail, followed by the Kajalshail (10.5) > BR line 5331-93-2-8-3 (9.8) > Nonashail (9.4), regardless of treatments (*Fig*. 2). Though the numbers of tillers for these treatments were high, a large number of these tillers were found unproductive, that is, inactive tillers. Among the rice cultivars, the local varieties ranked first (average 9.4 tillers/plant) in order of tiller production, the BR varieties came second (5.8), followed by the IR varieties (3.9), regardless of treatments. In most cases, the productions of tillers by the different rice cultivars was found to be significant ($p \leq 0.05$) by the individual application of basic slag, the groundwater level and aggregate size treatments. Most of the interactions of these treatments were more effective than the individual treatments for the increase in tiller production (*Fig*. 2). Khan *et al*. (1996) also reported almost similar effects of basic slag application on the vegetative growth of rice cultivated in two saline ASSs.

Straw and Grain Yield of Rice

The largest value of straw dry matter yield was obtained from the BR line of 5828-11-1-4 (6.9 t/ha), followed by the BR line 5331-93-28-3(6.8 t ha^{-1}) and the Kajalshail (6.8 t ha-1), and BR 23 (6.4 t ha^{-1}: *Fig*. 3). The lowest quantity of straw was recorded for the BR 4 (0.9 t ha^{-1}) preceded by BR 1 (1.0 t ha^{-1}) cultivars. The sequence of average straw yields as determined from the average values of all

the treatments for the different rice cultivars was: local variety > (5.7 t ha^{-1}) > BR variety (3.4 t ha^{-1}) > IR variety (2.0 t ha^{-1}). Despite the individual treatment in the soil, the order of effectiveness of the individual rice cultivar for the average straw yield was: 1. BR line 5828-11-1-4 (6.0 t ha^{-1}), 2. BR line 5331-93-28-3 (5.7 t ha^{-1}) = Kajalshail = BR 23, 3. Nonashail(4.8 t ha^{-1}), 4. Rajashail(4.3 t ha^{-1}), 5. Latishail(4.2 t ha^{-1}), 6. Nazirshail(3.0 t ha^{-1}), 7. IR 44 (2.7 t ha^{-1}), 8. BR 10 (2.4 t ha^{-1}), 9. IR 46 (2.2 t ha^{-1}), 10. IR 42 (2.0 t ha^{-1}), 11. IR 54 (1.9 t ha^{-1}) = IR 52, 12. BR 11 (1.7 t ha^{-1}), 13. IR 50 (1.6 t ha^{-1}), 14. BR 4 (1.2 t ha^{-1}), 15. BR 1 (1.1 t ha^{-1}) (*Fig. 3*).

The results obtained from the different rice cultivars showed remarkable variations on the grain yield performance of the rice. The maximum quantity (6.9 t ha^{-1}) of rice grain was attained by the local Kajashail, followed by the BR line 5828-11-1-4 (6.7 t ha^{-1}) and BR 23 (6.6 t ha^{-1}: *Fig. 4*), which are almost equal to the usual grain yields (5-7 t ha^{-1}) of these varieties cultivated in normal agricultural soils (BARC 1997). From the average grain yield obtained from all the treatments in the soil, the order of effectiveness of the individual rice cultivar was: 1. BR line 5828-11-1-4 (5.8 t ha^{-1}), 2. BR 23 (5.7 t ha^{-1}) = Kajalshail, 3. BR line 5331-93-28-3 (5.4 t ha^{-1}), 4. Nonashail (4.7 t ha^{-1}), 5. Rajashail (4.2 t ha^{-1}), 6. Latishail (4.1 t ha^{-1}), 7. Nazirshail (2.9 t ha^{-1}), 8. IR 44 (2.7 t ha^{-1}), 9. BR 10 (2.3 t ha^{-1}), 10. IR 46 (2.0 t ha^{-1}) = IR 42, 11. IR 54 (1.9 t ha^{-1}) = IR 52, 12. BR 11 (1.7 t ha^{-1}), 13. IR 50 (1.6 t ha^{-1}), 14. BR 4 (1.2 t ha^{-1}), 15. BR 1 (1.0 t ha^{-1}: *Fig. 4*).

In comparison with the straw and grain yields among the rice varieties, the BR lines were found to be the most effective in order of straw and grain production, followed by the local varieties, that is > BR varieties > IR varieties. BR 23 ranked third, while BR 1 produced the lowest yield preceded only by BR 4 and IR 50 in order of grain production among the selected 18 varieties of rice. Among the IR varieties, the best performance was recorded with the IR 44, followed by IR 46 and the lowest response was obtained from IR 50, which might be due to its having the shortest height amongst the varieties. The findings are partially in agreement with the results of Jugsujinda *et al*. (1998).

The straw dry matter production and grain yield of the 18 rice cultivars in the majority of the cases were found to increase significantly ($p \leq 0.05$) by the individual application of basic slag, and groundwater level and aggregate size treatments, while the combination of these treatments was more effective than the individual treatments for the increase in the straw and grain yields of the rice cultivars (Table 3). The application of BS_{20} was found to be the most effective among the individual treatments, followed by the Gw_{50} and A_{30} aggregate size treatments for the growth and yield performance of the tested rice cultivars. The application of basic slag was reported to be effective due to the increase in the soil pH and release of some elements such as Ca and Mg into the growing media as well as the large amounts of Si, which are beneficial to rice growth as reported by researchers (Khan *et al*. 1994; 1996). Khan *et al*. (2006) reported that the application of basic slag (BS) in ASSs significantly increased soil pH, Ca and Mg with an associated decrease in Na, Fe and Al concentrations over time. Successful reclamation of the ASSs may result in the development of productive fields for crop growth. Reclamation of poor soils may lead to creation of unfavorable soil conditions for crop growth and formation of actual ASSs, which is the real problem in the coastal tidal flat plain areas (Khan

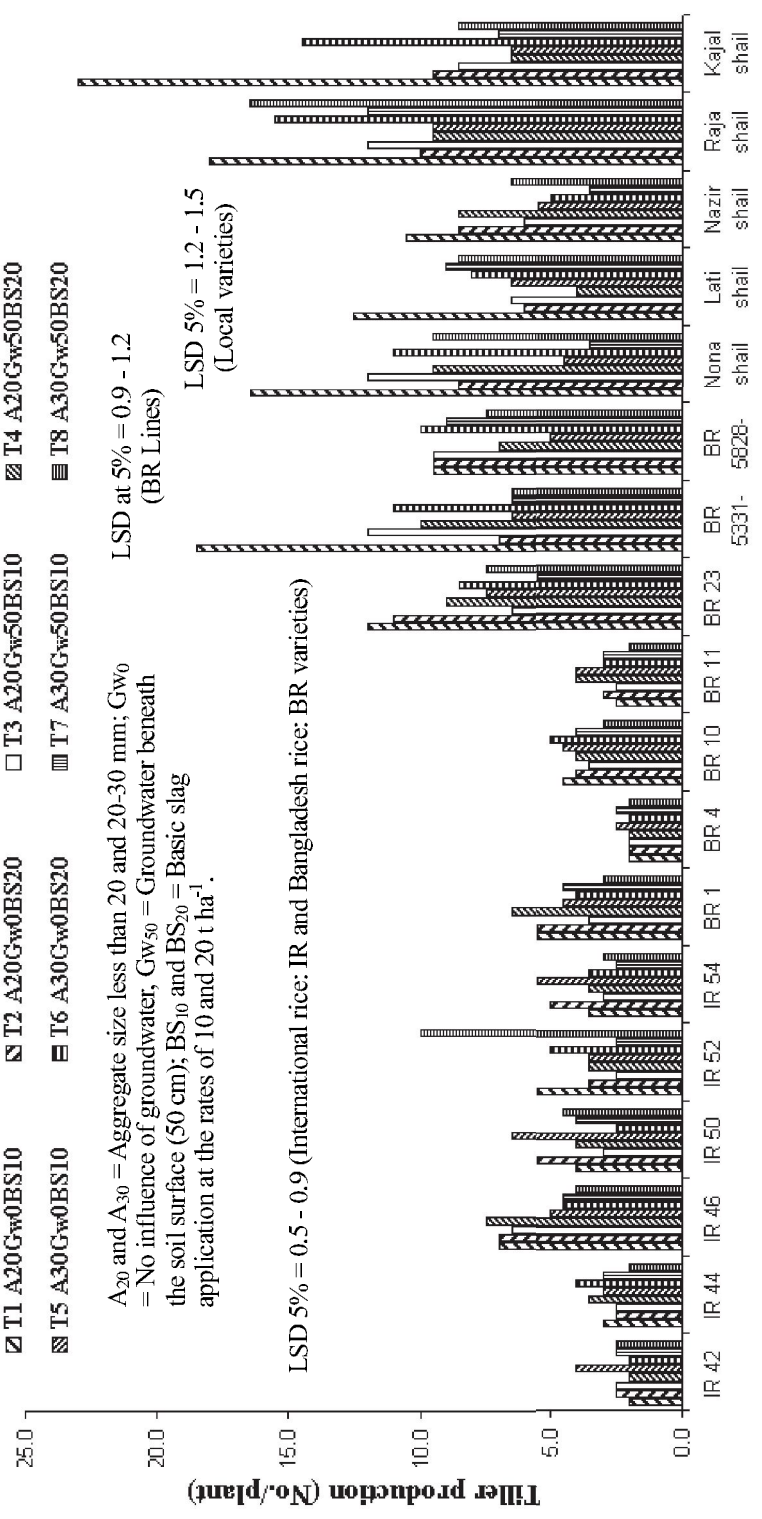

Fig. 2: Effects of basic slag application rate, aggregate size and groundwater management on tiller production (No./plant) of different rice varieties cultivated in the Cheringa acid sulfate soil under a simulation study

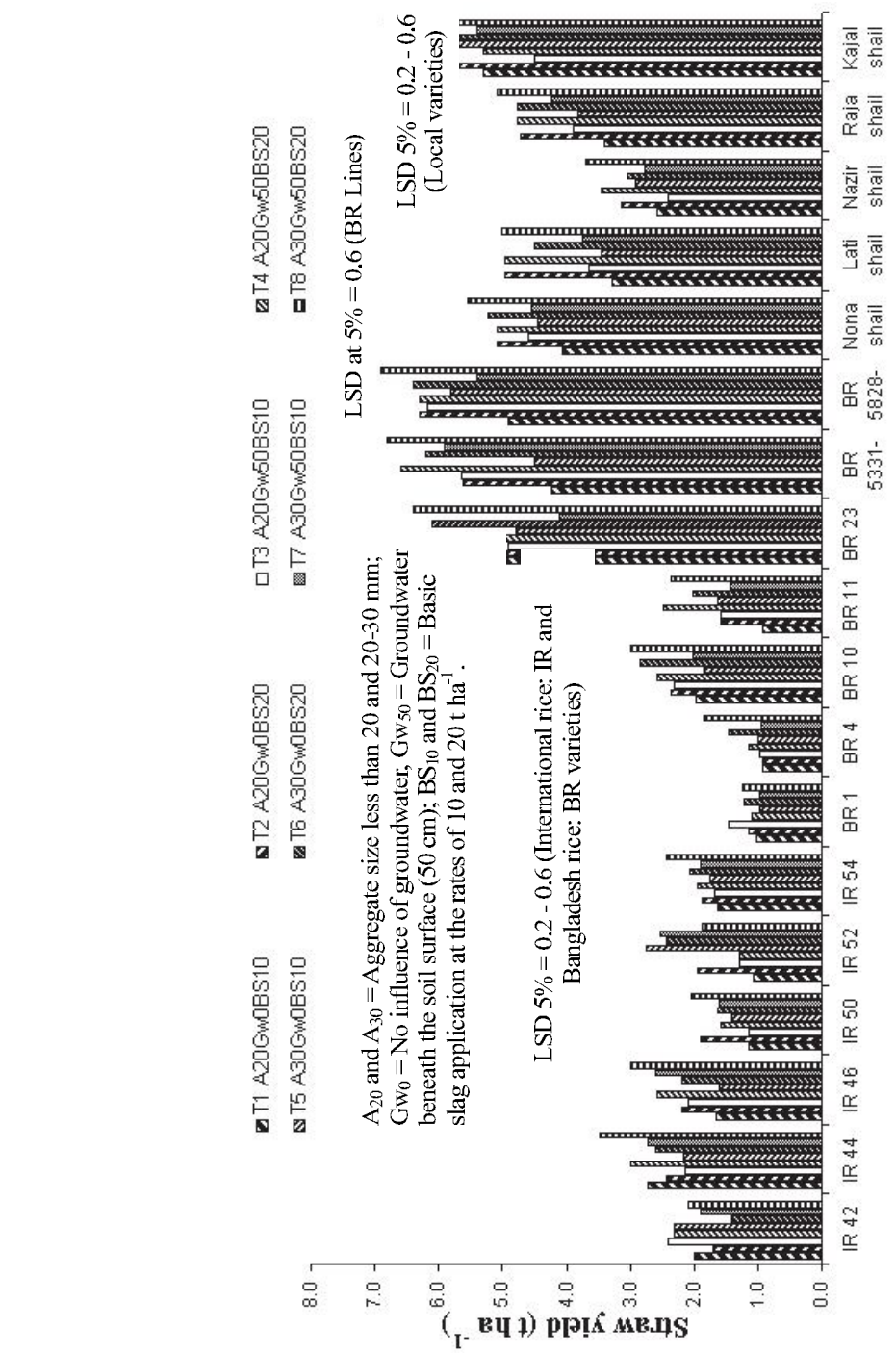

Fig. 3: Effects of basic slag application rate, aggregate size and groundwater management on straw yield (t/ ha) of different rice varieties cultivated in the Cheringa acid sulfate soil under a simulation study

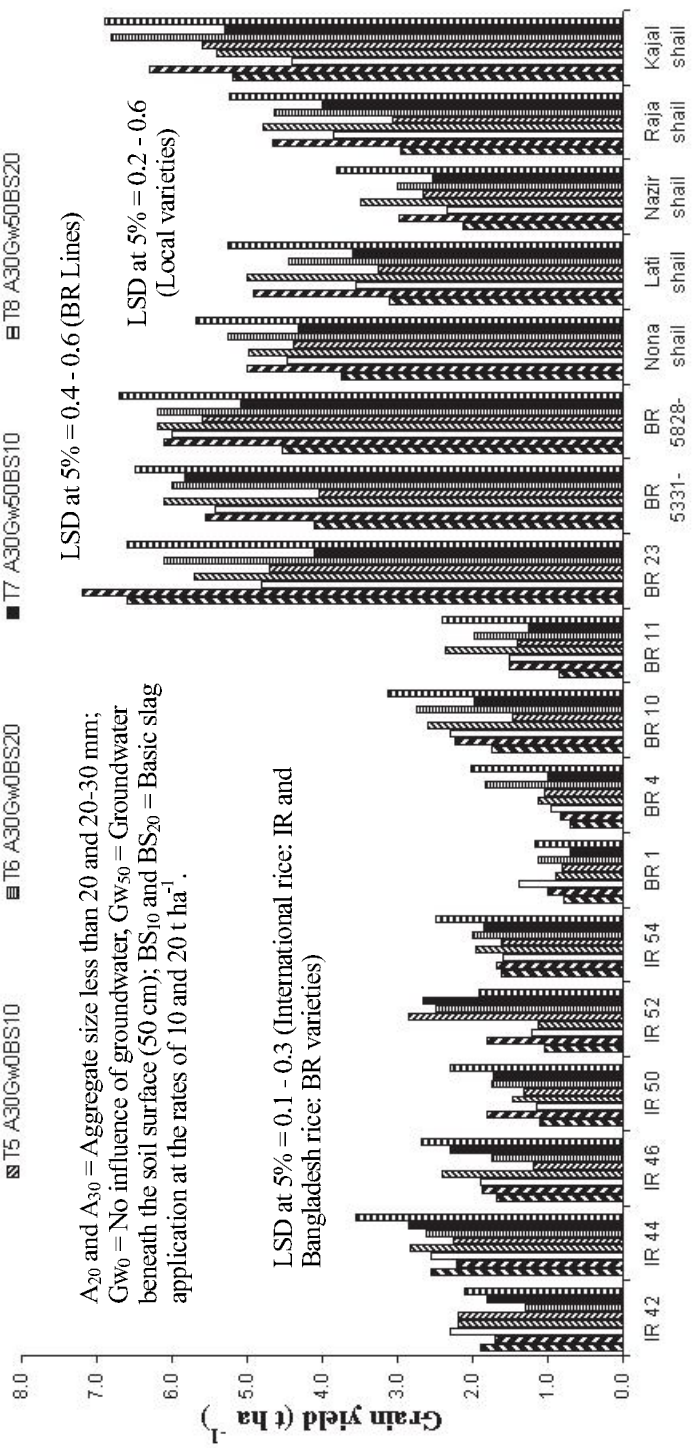

Fig. 4: Effects of basic slag application rate, aggregate size and groundwater management ongrain yield (t/ha) of different rice varieties cultivated in the Cheringa acid sulfate soil under simulation study

TABLE 3
Comparison of straw and grain yields of representative rice cultivars as affected by basic slag (BS), groundwater level (Gw) and aggregate size (A) treatments in the Cheringa acid sulfate soil under simulation study

Treatment	Straw yield (t ha^{-1})			Grain yield (t ha^{-1})		
	BS_{10}	BS_{20}	Gw $M^{\#}$	BS_{10}	BS_{20}	Gw $M^{\#}$
Rice cultivar: IR 44 (International Rice Variety)						
Gw_0			2.5 q			2.4 q
A_{20}	2.7 ^{a*}	2.4 ^{a}		2.6 ^{a}	2.2 ^{b}	
A_{30}	2.2 ^{b}	2.6 ^{a}		2.3 ^{b}	2.6 ^{a}	
Gw_{50}			2.9 p			3.0 p
A_{20}	2.2 ^{b}	3.0 ^{b}		2.6 ^{b}	2.8 ^{b}	
A_{30}	2.7 ^{a}	3.5 ^{a}		2.9 ^{a}	3.6 ^{a}	
BS Mean	2.5 n	2.9 m		2.6 n	2.8 m	
L.S.D. at 5% level =			0.3			0.2
Rice cultivar: BR Line- 5828-11-1-4 (Bangladesh Rice Variety)						
Gw_0			5.9 q			5.6 q
A_{20}	4.9 ^{b}	6.3 ^{a}		4.5 ^{b}	6.1 ^{a}	
A_{30}	5.8 ^{a}	6.4 ^{a}		5.6 ^{a}	6.2 ^{a}	
Gw_{50}			6.2 p			6.0 p
A_{20}	6.2 ^{a}	6.3 ^{b}		6.0 ^{a}	6.2 ^{b}	
A_{30}	5.4 ^{b}	6.9 ^{a}		5.1 ^{b}	6.7 ^{a}	
BS Mean	5.6 n	6.5 m		5.3 n	6.3 m	
L.S.D. at 5% level =			0.6			0.4
Rice cultivar: Kajalsail (Cox' Bazar local variety)						
Gw_0			5.9 p			6.0 p
A_{20}	5.3 ^{a}	6.2 ^{a}		5.2 ^{b}	6.3 ^{b}	
A_{30}	5.7 ^{a}	6.5 ^{a}		5.6 ^{a}	6.8 ^{a}	
Gw_{50}			5.5 p			5.5 q
A_{20}	4.5 ^{b}	5.3 ^{b}		4.4 ^{b}	5.4 ^{b}	
A_{30}	5.4 ^{a}	6.8 ^{a}		5.3 ^{a}	6.9 ^{a}	
BS Mean	5.2 n	6.2 m		5.1 n	6.4 m	
L.S.D. at 5% level =			0.6			0.3

$M^{\#}$ = Mean, *In a column and row, means followed by a common letter are not significantly different at 5% ($p \leq 0.05$) level

et al. 2007). Elawad and Green (1979) and Gashcho (1977) also reported that the yield of rice and sugar cane increased by the application of calcium silicate slag in low pH soil. The effect of a larger aggregate size (A_{30}: 20-30 mm) compared with a smaller (A_{20}: <20 mm) size was more significant for rice production of almost all the cultivars, which might be due to the maintenance of relatively more favourable conditions associated with the initial slow removal of acidity and also with the capillary rise of artificial groundwater (applied tap water) at a pH value of 6.8 used for the maintenance of the ground water level. Hence, the combined treatment of BS_{20}, Gw_{50} and A_{30} not only increased the vegetative growth, straw and grain yields of the majority of the 18 rice cultivars, but also exerted significant positive effects on the physico-chemical properties of the studied ASS (Table 1).

CONCLUSIONS

The results obtained from the tested 18 rice cultivars showed remarkable variations in growth and yield performance of the rice. The sequence of effectiveness in growth performance of the rice cultivars grown in the pre-leached ASS was: BR lines > Local > BR > IR –varieties. It is also concluded that the application of basic slag at 20 MG or t/ha, aggregate sizes of 20-30 mm and management of groundwater depth at 50 cm alone or in combination exerted significant ($p \leq 0.05$) positive effects not only on the production of the different rice cultivars but also induced soil pH by the introduction of exchangeable cations, while decreasing significantly ($p \leq 0.05$) the saturations of Al, Fe and Na in the soil. The application of basic slag to ASS after leaching proved to be an effective measure as it enabled the soil to be reclaimed and improved the growth of crops. It is also available at a reasonable price. Moreover, the management of groundwater and the use of aggregates with different sizes contributed to the reclamation of the soil and crop production. However, for a cost benefit analysis of these treatments in relation to the acid neutralisation capacity with time and frequency of liming under laboratory and field conditions, further studies on different soils under variable climatic conditions need to be carried out. The present findings suggest that the studied fallow land of ASS could be made productive by leaching the crushed soil on several occasions with A30 slag aggregates in order to quickly reduce the salinity and acidity problems. After leaching the soil, the use of BS or material rich in basic cations is a necessary option. It is advised to use the studied BR lines and local Kajalshail varieties for more grain yield from rice plants grown on this soil.

ACKNOWLEDGEMENTS

The study was carried out with the financial and technical support (1998-2005) of the Volkswagen (Ref: 1/73 802, dated 3 August 1998) and the Alexander von Humboldt (AvH) foundations respectively. We are also grateful to DAAD for providing two sandwich Scholarships for the Ph. D. programmes of S.M. Kabir and M.M.A. Bhuiyan.

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