

**EFFECTS OF SELECTED TREATMENTS AND TECHNIQUES FOR
THE RECLAMATION AND IMPROVEMENT OF CHERINGA
ACID SULFATE SOIL UNDER RICE PRODUCTION IN THE
COASTAL PLAIN OF COX'S BAZAR**

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Abstract

Modified-Plain-Ridge-Ditch techniques (Tech 1: pyrite layer at top, jarosite layer at middle and top soil at the bottom of ridge; Tech 2: top soil at top, pyrite at middle and jarosite layer at the bottom of ridge) were used under field condition for the reclamation and improvement of the pre-leached Cheringa acid sulfate soil manipulated by basic slag (BS₂₀ and BS₃₀: basic slag 20 and 30 t ha⁻¹) and aggregate size (A₂₀ and A₃₀: aggregate sizes of soil less than 20 and 20-30 mm) treatments. The initial soil had very low pH (3.4), high E_{Ce} (1.6 S m⁻¹) and pyrite content (76 g kg⁻¹). Magnesium content (water soluble + exchangeable = 5.38 c mol kg⁻¹) of the soil was about 3 fold than that of Ca (1.71 c mol kg⁻¹), and Al content (9.22 c mol kg⁻¹) was highly toxic level. The pre- and post harvested soil data revealed that the properties of the soil was strongly (p≤0.05) influenced by the different treatments. The average soil data of all the treatments at post harvesting of rice cultivars were increased by 1.5 units for soil pH_(dry) and 12 to 463% for the contents of N, P, Ca and Mg, while decreased the concentrations of Fe, Al, Na, Cl⁻ and SO₄²⁻ by 27 to 93% compared with the initial soil. The maximum growth and yield of rice grain (5.4 t ha⁻¹) were attained by the local cultivar Pizam compared with the high yielding variety BR 14 (5.1 t ha⁻¹) by the A₂₀BS₃₀ treatment in the ridges of the Tech 2. The lowest grain yields of 0.03 (BR 14) and 0.07 (Pizam) t ha⁻¹ were recorded for the control plots (where no amendment was applied). The other treatments also resulted in a significant (p≤0.05) improved performance on plant production compared with the control.

Key words: Aggregate size, Basic slag, Growth performance, Modified-plain-ridge-ditch techniques, Reclamation, Improvement of acid sulfate soil

Introduction

Acid sulfate soils (ASSs) affect more than 100 million hectares (M ha) of land worldwide of which about 0.7 M ha occurs in the coastal areas where crop production is very low; somewhere the lands are unproductive, though the lands have high agricultural potential (Van Mensvoort and Dent 1998 and Khan 2000). Runoff and leachate from ASSs can adversely affect the aquatic communities, agricultural and engineering works and beneficial use of environment (Khan 2016). Crop production on salt-affected soils is

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adversely affected due to salt toxicity, nutritional imbalances, poor soil physical and chemical properties (Murtaza *et al.* 2011 and Khan 2015). In the ASS areas, massive fish kills and ulcerative diseases have been reported by several scientists (Lin and Melville 1994 and Sammut *et al.* 1996). Losses due to fish killing from such situations in the coastal plains of Bangladesh were about US\$ 3.4 million during 1988-1989 (Callinan *et al.* 1993). Moreover, as the availability of land for growing crops is limited, it may become inevitable to utilize marginal and problem soils. Among the problem soils in Bangladesh, the ASSs have been causing severe environmental degradation (Khan 2016).

Conventional reclamation of ASSs through liming and flash leaching is not sustainable. Because, soil acidity produced by 1% oxidizable sulfur requires about 30 t of $\text{CaCO}_3 \text{ ha}^{-1}$ (van Breemen 1993). Usually ASSs contain 1-5% oxidizable sulfur and the use of more than 10 t lime ha^{-1} showed antagonistic effect on micronutrient levels as well as on the balance of basic cations in plants (Khan *et al.* 1994). Neutralization of ASSs with lime and/or leaching led to the deterioration of the soils, related ecosystems and to permanent soil acidification (Khan and Adachi 1999). Takai *et al.* (1992) reported that nutrient deficiency is an important factor when reclamation and improvement practices are performed in ASSs. Khan *et al.* (1994) reported the reclamation and improvement of ASSs require addition of materials rich in basic cations such as basic slag. The composition and use of basic slag were found to be harmless in Bangladesh since 1985 (Khan *et al.* 2006). Tri *et al.* (1993) revealed that construction of raised bed is the most important land management practices for ASSs. However, this practice has not achieved enough success. Its success depends on several factors of the soils, their position and environmental conditions (AARD and LAWOO 1992, Khan 2000). Construction of raised bed is important in sustainable reclamation and management practices of the soils. This type of reclamation of ASSs may be difficult but very essential due to the formation of acidity through the natural phenomenon of oxidation-reduction processes in the coastal soils (Khan 2015). Potential ASSs may have high pH like 6 to 7 under wet condition, but it does not mean that the soils are safe because at that situation it may create H_2S , Fe and some organic acid problems (Moore *et al.* 1990). Successful reclamation of the 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 in the coastal tidal flat plain areas (Khan *et al.* 2007). With this background, the objectives of the present study were to evaluate the effects of basic slag, aggregate size and different techniques for the reclamation and improvement of ASS in relation to rice production.

Materials and Methods

Site condition: The experiment was conducted in a fallow land at Cheringa ASS occurring in the coastal old mangrove floodplain area in the Cox's Bazar district of Bangladesh. The site enjoys tropical monsoon climate and has three main seasons, namely, the

monsoon or rainy season, the dry or winter season and the pre-monsoon or summer season. The study site was once occupied for centuries by dense mangrove forest. Now about 95% of the areas have been cleared for agricultural cultivation. As a result, the potential ASSs have become actual ASSs with very poor yields. They generate H_2SO_4 that brings their pH from 6-7 to below 4, sometimes to as low as 2. This acid leaks into drainage and floodwaters, corrodes steel and concrete, and attacks clay liberating elements in toxic concentrations. Eight series of ASSs were studied in the field and among these the Cheringa ASS at Sarisabari was selected for further studies in relation to crop production.

Experimental design and field preparation: The experiment was set up in a completely randomized block design with three replications. There was an approximately 1.5 m wide and 1.0 m deep drain around the experimental field, about a 0.5 and 0.3 m boundary around each main plot and subplot, respectively for protecting the individual plot from the contamination of the treatments. The field of about 0.75 ha was divided into 12 main plots each having 10 x 5 m² size. In each main plot of plain or ridge, there were 6 subplots of 1 x 1 m² but there was no subplot in the ditch, which was about 10 x 5 m² wide and 0.4 to 0.6 m deep. The subplots of 1 x 1 m² were then used for individual treatment. These plots were irrigated mainly by using rainwater (yearly rainfall >4000 mm) collected from the local rain-fed channels through the irrigation pump. Pond water was also used for irrigation during the dry period. Saline water intrusion and drainage water were controlled through dikes and flap gates. Basic slag was collected from a steel industry and then grounded to less than 1 mm sizes in order to apply in the field. The rates of BS₁₀ and BS₂₀ (basic slag at 10 and 20 t ha⁻¹) were incorporated into the topsoil (depth: 0-20 cm) by broadcasting during ploughing. For in-situ neutralization of acidity arising from jarosite and pyrite layers in the modified-plain-ridge-ditch techniques (Fig. 1), the same doses of BS were incorporated into the subsoil (0.2-0.4 m) by using a soil slitter (5 cm diameter) at every 0.2 m of distance.

Modified-Plain-Ridge-Ditch Techniques

Plain: The area of each main plain (flood plain land) plot was 10 x 5 m² and the particle size of the plain plot soil was grounded manually into two aggregate sizes of about less than 20, and 20 to 30 mm (A₂₀ and A₃₀). The grounded soils were then processed under the sun and open air for maximum oxidization within 2 days. The plain land was considered to reclaim by the application of flash leaching (5-7 times washing within a week: till the pH becomes >4.5 and lower ECe values) followed by the application of BS treatments. The drainage waters from the plain plots under the Modified-Plain-Ridge-Ditch techniques were disposed to the nearby ditches where the water was treated by BS as required to raise the water pH till 5.5.

Ridge: The ridge means raised bed of about 60 cm soil, stacked upon flood plain soil (plain land), which was made by raising different layers of soil through excavation and arranged as shown in the Fig. 1 (Tech 1 and Tech 2). These 60 cm high beds were

constructed to facilitate leaching of acids and salts of the soil. The area of the top of each ridge was $10 \times 5 \text{ m}^2$ same as the size of plain land plot. Particle sizes of the bed materials were grounded manually into two aggregate sizes of A_{20} and A_{30} . These smaller sizes of aggregates were considered in order to understand the effects of oxidation of sulfidic materials and their quick drainage from this heavy-textured ASS. Each plot on the ridge of the different techniques were brought into flash leaching followed by the application of BS treatments as practiced for the plain plot. The drainage water was neutralized by the use of BS into the nearby ditches. The arrangements of soil layers in different techniques were - **Technique 1:** Top layer (surface soil) was extended to about 20 cm thick layer (1st layer: 0-20 cm) first onto the adjacent plots and was ground into different aggregate sizes

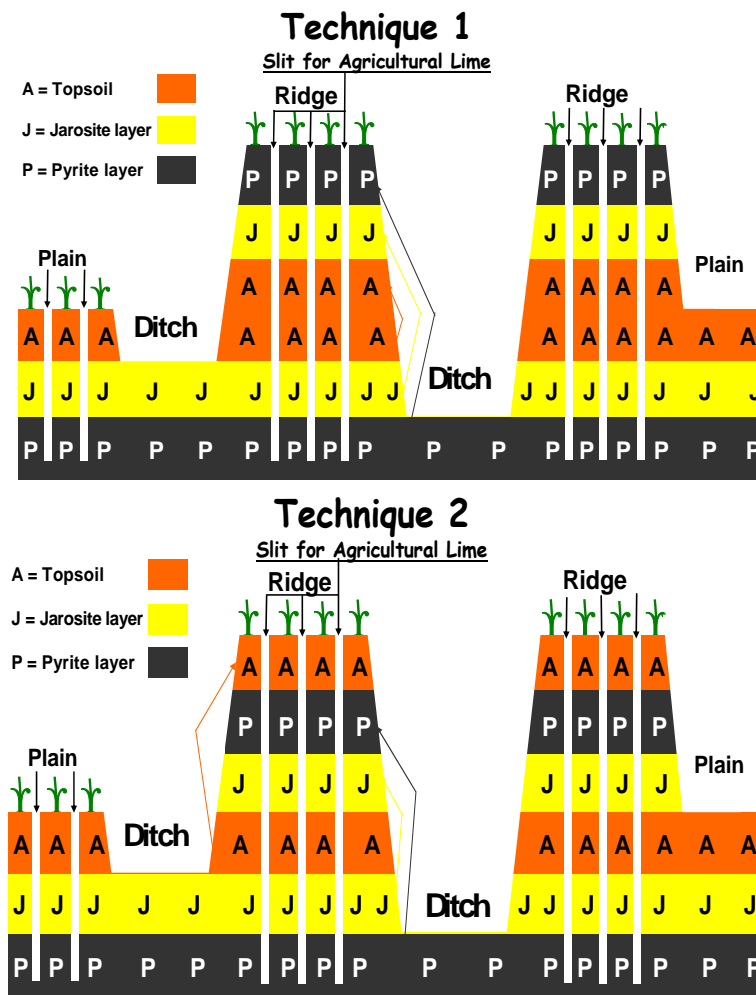


Fig 1. Modified-Plain-Ridge-Ditch techniques used in the field experiment for the reclamation and improvement of acid sulfate soil in relation to rice production.

(A₂₀ and A₃₀) as per treatment requirement and was kept open to air for oxidation within 2 days. Then second layer (20-40 cm layer: sub surface soil with jarosite material) was extended to about 20 cm thick layer onto that processed first layer. The soils of the second layer was also ground to the desired sizes of aggregates and kept for oxidation for 2 days. Finally the third layer (40-60 cm layer: deeper soil containing pyrite material) was placed at the top of the previously stacked layers. This third layer was also considered for the preparation of different sizes of aggregates and the oxidation of 2 days. After that, the prepared 60 cm raised beds were taken under extensive leaching (5-7 times washing within a week) with rain and pond waters. Thereafter, the top soil of the ridge was subjected to the different rates of basic slag application as per treatments designed for the experiment. **Technique 2:** The preparation and processing of land such as aggregate size, duration of oxidation through air drying and experimental treatments were similar as those stated for Tech 1, except for the arrangement of soil layers. In the Tech 2, within the ridge (raised bed of 60 cm), the arrangement of soil layers was like as jarosite layer was placed at the bottom (3rd layer: 40-60 cm), then pyrite layer in the middle (2nd layer: 20-40 cm) followed by the surface soil on the top (0-20 cm) of the ridge.

Ditch: Adjacent to each ridge, there was a ditch of about 10 x 5 m² having a depth of about 0.6 m attributed to the excavation of soil for the preparation of ridges. These ditches were constructed as reservoir of acid drainage waters, where these acidic waters were neutralized by the use of basic slag during dry season. But during rainy season, these acidic wastes were automatically diluted by rain and/or controlled runoff waters. The pH level of the drainage waters was maintained to about pH 5.5 by the application of basic slag as per requirement.

Two varieties of rice (high yielding variety – HYV BR 14 and local Pizam) were planted in the Cheringa ASS in August 2004. The top soil (0-20 cm) in each plot (plain and ridge) was fertilized with N, P and K at the rates of 100, 80 and 60 kg ha⁻¹ as urea, triple super phosphate (TSP) and MP, respectively as a basal dose. All the TSP and MP and one-third urea were applied just one day prior to transplantation where as the rest two-third of urea were applied as top dressing at two times after 30 and 60 days of transplantation. The plots were allowed to receive natural rain and pond waters whenever necessary to maintain favorable conditions (maximum saturated to field moist condition) for rice. Each plot of plain and ridge was divided into two equal parts for the transplantation of the two varieties of rice. Thirty day-old healthy and uniform seedlings were transplanted at the rate of four plants per hill. The distances between the hills were 15 cm. Pests were controlled by the use of insecticide, ‘Nogos’ whenever it required.

Soil analysis: The bulk 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 airtied box) just prior to laboratory analyses, when the sub-samples were air-dried and crushed to 2 mm before analyses. Particle size distribution (Day 1965), Soil pH (Jackson 1973), for saturation extract of soil, the electrical conductivity (Richards 1954), water

soluble Na⁺ and K⁺ (flame photometry: Black 1965), water soluble SO₄²⁻ and Cl⁻ contents (Jackson 1973); Ca²⁺, Mg²⁺, Fe³⁺ and Al³⁺ (atomic absorption spectrometry - AAS: Hesse 1971), organic matter content (Nelson and Sommers 1982), available N (1.3M KCl extraction, Jackson 1973), available P (0.002N H₂SO₄, pH 3 extraction, Olsen *et al.* 1954), Cation exchange capacity (Chapman 1965), exchangeable cations by flame photometry (Na⁺, K⁺) and AAS (Ca²⁺, Mg²⁺), Exchangeable Al³⁺ (1M KCl, Thomas 1982) and Fe³⁺ (1M CH₃COONH₄: pH 4.8, Black 1965) were followed for relevant analyses.

Results and Discussion

Pre- and post harvested soils: The Cheringa ASS (depth: 0-20 cm) showed a silty clay loam texture, initially low pH of 3.4, pyrite content of 76 g kg⁻¹, low base saturation (34%), high ECe (1.6 S m⁻¹), high exchangeable Fe³⁺ and Al³⁺ contents of 1.83 and 7.91 c mol kg⁻¹, respectively (Table 1). The contents of basic cations (Na⁺, K⁺, Ca²⁺ and Mg²⁺)

Table 1. Some selected properties of the initial Cheringa acid sulfate soil (depth: 0-20 cm) and the average soil (0-20 cm) data of all the treatments at post harvesting of the rice grown under field condition.

Soil properties	Initial soil	Post harvested soil	% IOC [†]
Textural class		Silty clay loam	
Bulk density (Mg m ⁻³)	1.12	1.21	8
Moisture at Field Capacity (%)	49	51	4
Soil pH (Field, 1:2.5)	4.2	5.7	36
Soil pH (Dry, 1:2.5)	3.4	4.9	44
Soil pH (0.02 M CaCl ₂ , 1:2.5)	3.2	4.5	41
[‡] Pyrite content (g kg ⁻¹)	76	35	-54
ECe (S m ⁻¹)	1.6	0.38	-76
Organic Carbon (g kg ⁻¹)	21.3	21.8	2
Available N (1.3 M KCl: mM kg ⁻¹)	6.44	7.21	12
Avail. P (0.002N H ₂ SO ₄ , pH 3: mM kg ⁻¹)	0.11	0.25	127
CEC (1 M NH ₄ Cl: c mol kg ⁻¹)	19.1	19.8	4
Base saturation at pH 7.0 (%)	34.2	77.8	127
Exchangeable cations (1 M KCl)			
Sodium (flame photometer: c mol kg ⁻¹)	3.43	2.41	-30
Potassium (flame photomet.: c mol kg ⁻¹)	0.36	0.76	111
Calcium (AAS*: c mol kg ⁻¹)	0.95	5.35	463
Magnesium (AAS: c mol kg ⁻¹)	1.79	6.53	265
Aluminum (AAS: c mol kg ⁻¹)	7.91	0.53	-93
Iron (AAS: c mol kg ⁻¹)	1.83	0.91	-50
Water-soluble ions:			
Sodium (flame photometer: c mol kg ⁻¹)	3.11	2.21	-29
Potassium (flame photomet.: c mol kg ⁻¹)	0.26	0.44	69
Calcium (AAS [†] : c mol kg ⁻¹)	0.76	3.22	324
Magnesium (AAS: c mol kg ⁻¹)	3.59	4.87	36
Aluminum (AAS: c mol kg ⁻¹)	1.31	0.26	-80
Iron (AAS: c mol kg ⁻¹)	0.43	0.57	33
Chloride (0.05N AgNO ₃ : c mol kg ⁻¹)	3.31	2.40	-27
Sulfate (BaCl ₂ : c mol kg ⁻¹)	4.06	2.63	-35

[†]IOC = Increased over control (initial value), [‡]Pyrite (FeS₂) content was calculated from the total content of Fe {(Fe content/46.7) x 100, i.e. FeS₂ was considered to contain 46.7% Fe} in the acid sulfate soils. [†]AAS=Atomic Absorption Spectrophotometer.

in the initial soil were low to medium, while acidic cations (Al^{3+} and Fe^{3+}) were very high in relation to the amounts found elsewhere (Khan 2015). The pH value of the average soil data of all the treatments at post harvesting of rice was found to increase from 3.4 to 4.9, i.e. by 1.5 units higher compared with the control (i.e. initial value), while the ECe value of the soil was found to decrease to 0.38 S m^{-1} (76% decreased over control: Table 1). The contents of N, P, Ca and Mg in the average soil data at post harvesting were found to increase by 12 to 463% over control. The contents of exchangeable Al^{3+} , Fe^{3+} , Na^+ , Cl^- and SO_4^{2-} in the soil were found to decrease by 27 to 93% over control (Table 1). The results also indicate that the physico-chemical properties of the ASS were strongly influenced by the application of leaching followed by basic slag and aggregate size treatments in different reclamation and management techniques.

The post harvested soil data (Fig. 2) of pH, exchangeable K^+ , Ca^{2+} , Mg^{2+} , Fe^{3+} and Al^{3+} contents were found to be affected significantly ($p \leq 0.05$) by the application of basic slag and aggregate size treatments in different techniques. The application of $\text{A}_{20}\text{BS}_{30}$ attained the highest value of soil pH of 5.6 in the Tech 1 and 5.8 in the Tech 2 during post harvesting followed by the $\text{A}_{20}\text{BS}_{20}$ (pH 5.2 in Tech 1 and 5.3 in Tech 2: Fig. 2) treatment. The contents of exchangeable Al^{3+} and Fe^{3+} during post harvesting were found to decrease sharply by the treatments and the decrements were more pronounced in the soil of the ridges of the techniques (Fig. 2). The highest amount of exchangeable Al^{3+} of $7.91 \text{ c mol kg}^{-1}$ was recorded for the control plots, while this value decreased to 0.18 for Tech 1 and 0.11 for Tech 2 by the $\text{A}_{20}\text{BS}_{30}$ preceded by the $\text{A}_{30}\text{BS}_{30}$ and $\text{A}_{20}\text{BS}_{20}$ treatments. The decrease was more pronounced with the Tech 2. Among the treatments, the application of BS ranked first followed by the aggregate size treatments and techniques for the increments of soil pH and nutrient status of the soil which might be due to basic nature of BS (pH 9.6) as well as its release of some elements mainly Ca, Mg, etc. into the soils. The results agreed well with the findings of some researches. Of them, Khan (2002) reported that the acid sulfate soils released a very large amount of Al, e.g. 10 mM L^{-1} , while a very low concentration of Al can be hazardous. Concentrations of 1 to 2 mM Al L^{-1} are toxic to most crops and about 2 mM Al L^{-1} is toxic for rice. Fishes are most susceptible and fish death occur at 0.5 mM Al L^{-1} . Standard and potable water mostly range between 0.05 and 1.5 mM Al L^{-1} (Sittig 1994). Khan *et al.* (2006) reported that the application of basic slag in ASSs significantly increased soil pH, Ca and Mg and decreased Na, Fe and Al concentrations over time.

Tiller production: The maximum numbers of tillers/hill of 19 and 17 for BR 14 and 20 and 18 for Pizam were recorded by the application of $\text{A}_{20}\text{BS}_{30}$ in the Tech 1 and Tech 2, respectively and followed by the treatments of $\text{A}_{20}\text{BS}_{20}$ (Fig. 3). The effects of the treatments in the soil in relation to the production of tillers were: Tech 2 > Tech 1; BS_{30} > BS_{20} and A_{20} > A_{30} (Fig. 3). In most cases, the productions of tillers by the two rice cultivars were found to be significant ($p \leq 0.05$) by the application of basic slag and aggregate size treatments and techniques. Most of the treatments were found to exert

more positive effects in increasing the tiller production on the soil at the ridges of both the techniques and the effect was more pronounced under Tech 2 (Fig. 3). Khan *et al.* (1996) also observed almost similar effects by the application of basic slag for the vegetative growth of rice cultivated in two saline-acid sulfate soils.

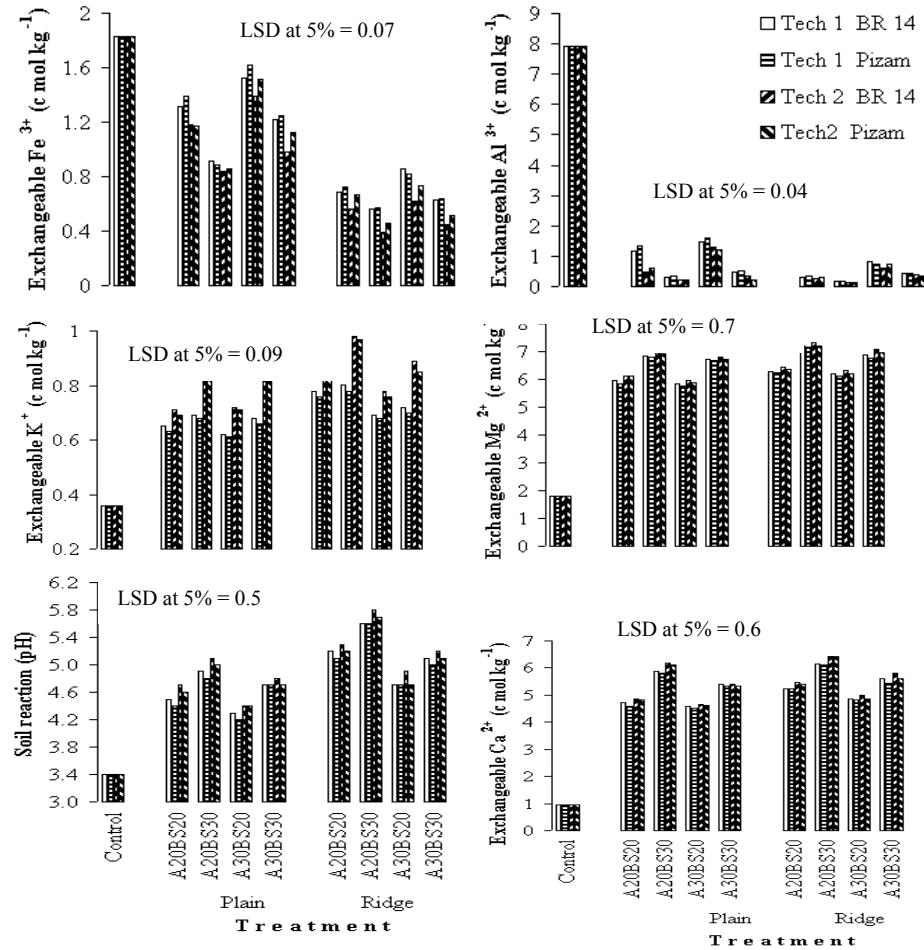


Fig. 2. Influence of different techniques, basic slag (BS) and aggregate size (A) treatments on the selected properties of soil studied under field condition.

Yield performance of rice: The straw and grain yields of the rice cultivars grown under the modified plain-ridge-ditch techniques in the Cheringa ASS were found to increase significantly ($0 \leq 0.05$) by the different treatments and the improvement was more pronounced with the Tech 2 (Fig. 3). This might be due to the less requirement of the basic slag regarding neutralizing the acidity in the soil under Tech 2. In the Tech 1, the oxidized layer required more amount of basic slag in increasing pH level (5 to 6) for optimum crop growth. The lowest quantities of straw and grain yields were recorded by

the control treatment. Fageria and Baligar (1999) reported that rice was the most tolerant among the tested crops and produced the maximum dry matter at the pH of 4.9. The present data show that on average pH value ranged from 3.4 to 5.8 (Fig. 2), where the higher rate of BS₃₀ was found to increase the soil pH at the highest level that resulted the maximum yield of rice under both the techniques. The highest yields of grain and straw were recorded for the local Pizam (grain: 5.4; straw: 5.5 t ha⁻¹) followed by the HYV BR 14 (grain: 5.1; straw: 5.0 t ha⁻¹) by the treatment of A₂₀BS₃₀ in Tech 2 > Tech 1 (Fig. 3).

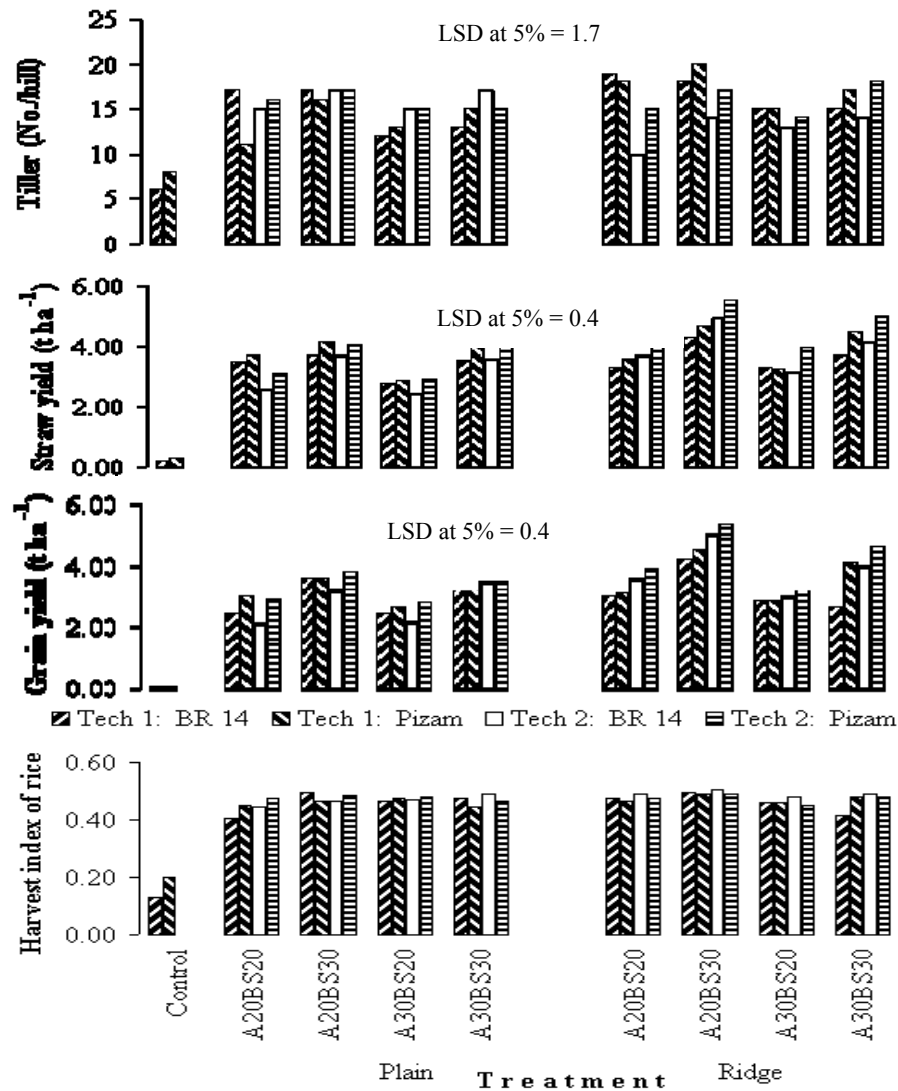


Fig. 3. Influence of different techniques, basic slag (BS) and aggregate size (A) treatments on the growth and yield performance of rice grown in acid sulfate soil under field condition.

The sizes of soil aggregates also influenced the growth of rice in presence of basic slag treatments. The A₂₀ aggregated soils mostly yielded the highest production of rice which might be due to the maximum oxidation of pyrite, release of Al and acid from the soil. This in turn helped to increase the pH levels (Fig. 2) resulting in better availability of plant nutrients in the soil. Westerhof (1998) revealed that exchangeable bases and CEC had positive correlation, while exchangeable Al was negatively correlated with the amount of soil in the micro-aggregate and primary particle fractions. The plain lands which have the similar aggregate sizes and treatments failed to obtain expected production of rice. The general trends of the treatments on the yield of rice were observed almost similar to A₂₀BS₃₀ > A₃₀BS₃₀ > A₃₀BS₂₀ > A₂₀BS₂₀ in the ridges for both the rice cultivars and the techniques.

Apart from the treatments and techniques, the average grain yield increments of rice were about 12% higher for the local Pizam compared with the HYV BR 14 rice. The HYV rice failed to give better yield under present condition of soil salinity and acidity. But the local Pizam cultivar showed better growth and yield performance due to its better tolerance/adaptive capability to the salinity, acidity or other environmental hazards. The harvest indexes of rice grown on the studied soil were also the best in the treatment of A₂₀BS₃₀ followed by A₂₀BS₂₀ under both the Tech 2 and Tech 1, respectively (Fig. 3). Anderson *et al.* (1987) also reported that the long-term use of calcium silicate slag was beneficial for the growth of sugarcane, rice and rice-sugarcane rotation crops grown on Everglades Histosols. 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 amount of Si, which is beneficial to rice growth (Khan *et al.* 1996). The effect of a smaller aggregate size (A₂₀), compared with a larger (A₃₀) size was more effective for rice production, which might be due to the maintenance of relatively more favorable conditions associated with the initial fast waste out of acidity and salinity (Khan *et al.* 2006).

The application of BS₃₀ ranked first, followed by the A₂₀ > A₃₀ for the reclamation and improvement of the soil under Tech 2. The significant ($p \leq 0.05$) positive improvements of growth, yield of rice and soil properties were more pronounced under Tech 2 than that of Tech 1 under the modified-plain-ridge-ditch system. Application of basic slag and aggregate size treatments in different techniques not only increased soil pH, but also improved ionic balance between Ca and Mg and remarkably decreased the Fe and Al contents in the soil.

The use of modified-plain-ridge-ditch techniques and the different sizes of aggregates were found to be contributed for the physico-chemical amendments of the soil as well as improved rice production. The application of basic slag in the ASS was an effective measure, which can be used at a reasonable price and improved the growth and yields of the rice cultivars, but was also beneficial to the surrounding environment. However, for a cost benefit analysis of these treatments in relation to acid neutralizing capacity for a long time

in different fields, further studies on different soils and crops under variable climatic conditions should be carried out.

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