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Response of Eggplant to Integrated Approaches for Sustainable Reclamation and Improvement of a Cheringa Hot Spot of Acid Sulfate Soil

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The application of basic slag (BS_{20} and BS_{30}: basic slag 20 and 30 t ha^{-1}) and aggregate size (A_{20} and A_{30}: aggregate sizes of soil less than 20 and 20-30 mm) and different techniques (Tech 1: pyrite at top, jarosite 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) exerted significant ($p \leq 0.05$) positive effects on the growth and yield of eggplants cultivated under field condition and the effects varied not only with the kinds and amounts of amending materials but also with the techniques applied. The soil showed a silty clay loam texture, initial pH value of 4.1, pyrite content of 55 g kg^{-1}, base saturation of 47%, ECe value of 3.6 dS m^{-1}, high exchangeable Fe^{3+} and Al^{3+} contents of 1.47 and 5.29 $cmol_c$ kg^{-1}, respectively. The pH value of the average soil data obtained from all the treatments during fruit set (95 days after transplantation) of eggplants was found to be increased in pH by 1.2 units higher compared with the control (i.e. initial pH value). The contents of P, K, Ca and Mg in the average soil data during fruit set were found to be increased (IOC = increased over control) by 41 to 127% IOC, while the contents of Al^{3+}, Fe^{3+}, Na^{+}, Cl^{-} and SO_4^{2-} in the soil were found to be decreased by 28 to 92% IOC.

The different treatments on eggplants grown under the modified-plain-ridge-ditch techniques in the Cheringa acid sulfate soil significantly ($0 \leq 0.05$) increased the fresh yield of eggplants, and the increment was more pronounced with Tech 2. The maximum yield of 17.8 t ha^{-1} of eggplant for Tech 1 and 20.1 t ha^{-1} for Tech 2 were recorded by the application of BS_{30} in the soils of smaller aggregates (A_{20}) at the ridges of Tech 2, followed by the $A_{30}BS_{30}$ treatments in both the techniques. The lowest quantity of 1.7 t ha^{-1} yield was recorded by the control treatment. The eggplants grown in the ridges of both the techniques exhibited the best responses on N, P, K, Ca and Mg contents in eggplant tissues during fruit set. As expected, the lowest contents of these nutrients in the eggplants were recorded in the control treatment. Sulfur content of the eggplants grown in the control plots was 3.6 g kg^{-1} and was in the range of adequate S content (4 g kg^{-1}). However, the S contents in the eggplants grown in different treatments were significantly ($p \leq 0.01$) lower compared with the adequate level. The effectiveness of the treatments for the reclamation of the soil in relation to the growth of eggplants was: Tech 2 > Tech 1, $BS_{30} > BS_{20}$, and $A_{20} > A_{30}$. The results suggest that the physico-chemical properties of the soil, and the growth, yield and nutrition of eggplants were strikingly improved by the application of flash leaching followed by BS_{30} and A_{20} treatments in the ridges of Tech 2, and are regarded as the best reclamation measures for this acid sulfate soil.

Key words: *aggregate size, basic slag, growth-yield of eggplant, modified-plain-ridge-ditch techniques, reclamation and improvement of acid sulfate soil*

1 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 for about 24 M ha of ASSs of which about 0.7 M ha are located in different pockets of inundated coastal areas in Bangladesh where crop production is very low; some where the lands are unproductive though the soils have high agricultural potential (Khan, 2000). The nature and characteristics of these pockets of ASSs varied from place to place and within pockets owing to the difference in mangrove vegetations and accumulation of sediments (Khan, et al. 2007a). Since the ASSs can exert severe effects on surrounding ecosystems, immediate steps should be taken to consider these soils further (Khan, et al. 2002). Delayed effects of potential chemicals stored in the ASSs resulted in harmful effects, like a "chemical time bomb" on the associated environments (Khan and Adachi, 1999). Potential ASSs may have high pH like 6 to 7 does not mean that the soils are safe because at that situation it may create H_2S, Fe, some organic acids and CO_2 problems. The weathering of sulfidic overburdens and mine spoils present the same problems (Orndorff and Daniels, 2002). The reclamation of these soils may be difficult, but essential (Khan, et al. 2006). Successful reclamation of the ASSs may result in the development

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of productive fields for crop growth. While poor soil reclamation may lead to creation of unfavorable soil conditions for crop growth and formation of ASSs, the real problem lies in the coastal tidal flat plain areas (Khan, et al. 2007b).

Leaching treatment alleviated acidity and salinity problems relating to crop production in the ASSs. However, simultaneous leaching practices lead to the deterioration of the fertility status of soils and/or related ecosystems and to permanent soil acidification through exchange reactions between acidic-basic cations (Khan and Adachi, 1999). It was also demonstrated that leaching couldn't be an effective and sustainable method of crop production in the ASSs, unless this practice followed by the addition of materials rich in basic cations like basic slag (Khan, et al. 1994; 1996). 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. Basic slag as a byproduct from the steel industry in Bangladesh can be collected almost free of charge. Moreover, the basic slag had a very high pH of 9.6 and contained 208 g kg^{-1} Ca, 98 g kg^{-1} Mg, and 12.8 g kg^{-1} SiO_2 (Khan, et al. 2006). They also stated that the use of basic slag was found to be harmless in Bangladesh since 1985. To achieve the highest rate of oxidation and effective drainage of sulfidic materials in heavy-textured ASSs, the aggregate sizes of the soils should be reasonably smaller for the higher rate of release of acidity-salinity and toxic elements from the soils, which may enhance crop production.

The eggplant or brinjal (*Solanum melongena* L.) is a solanaceous plant bearing a fruit of the same name, commonly used as a vegetable in cooking. The scientific name *Solanum melongena* is derived from a 16^{th} century Arabic term for one kind of eggplant (*http://en.wikipedia. org/wiki/Eggplant*). The name eggplant in the United States, Australia, and Canada development from the fact that the fruits of some 18^{th} century European cultivars were yellow or white and resembled goose or hen's eggs. It is closely related to the tomato and potato and is native to southern India and Sri Lanka. It is a short-lived perennial plant often cultivated as an annual crop. The eggplant is an important food crop grown for its large, pendulous, purple or white fruit. It has been cultivated in southern and eastern Asian countries since prehistory but appears to have become known to the Western world no earlier than ca. 1500 CE. Eggplant fruit is said to be very nutritious and is a good source of vitamin C and potassium. The fruit is used as an antidote to poisonous mushrooms. Eggplant has also medicinal value. It can be pounded with vinegar to create a poultice for cracked nipples, abscesses, and hemorrhoids. This fruit is hypotensive and helps to lower blood cholesterol levels and is suitable as part of diet to help regulate high blood pressure (www.*plant.usda.gov*.).

Eggplant is one of the major popular fruit crops of many countries for it nutritional and medicinal values. The current high prices and consumption of eggplant increased its planting. The consumption of eggplant in the USA has doubled since 1990; it is still less than 1 pound per person per year (*www.uky.edu/Ag/newcrops/ introsheets/eggplant.pdf*). Year round cultivation of this crop and easy maintenance make the crop popular to the farmers. Eggplants can be a profitable first crop in Bangladesh. The vegetable crops are in short supply in Bangladesh and eggplants can contribute substantially to overcome this shortage. Eggplant needs to be in moist soil at all times and it is a heavy feeder and therefore may need extra fertilizer. Accordingly, the nutrient-enriched ASSs deserve attention to use these soils for eggplants production after proper reclamation. Against this background, the objectives of the present study were to evaluate the effects of basic slag, aggregate size and modified-plain-ridge-ditch techniques as physico-chemical amendments of pre-leached Cheringa acid sulfate soil and its response to eggplants.

2 MATERIALS AND METHODS

2.1 Site condition

The experiment was conducted in a fallow land at Cheringa hot spot of ASS in the coastal old mangrove floodplain area in the Cox' Bazar district of Bangladesh (**Fig. 1**). The site enjoy "tropical monsoon climate", has three main seasons, namely, the monsoon or rainy season, the dry or winter season and the pre-monsoon or summer season. The monsoon season extends from June to October and is warm and humid. During this period, this locality receives above 85% of total annual rainfall. The dry season extends from November to February and has the lowest temperature and humidity of the year. The pre-monsoon season extends from March to May and has the highest temperature and evaporation of the year. This area in Bangladesh 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 on the basis of land type, land use, hydrological conditions and depths of acid forming layers. Among these, the Cheringa ASS at Sarisabari was selected for further studies in relation to crop production.

2.2 Experimental design and field preparation

Completely randomized block design having three replications were considered to set up the experiment. 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 (4 for plan, 4 for ridge and 4 for ditch) each having 10 X 5 m^2 sizes. In each main plot of plain or ridge, there were a total of 24 sub-subplots (treatments: BS = 2, A = 2, Tech = 2 and replications = 3, i.e., 2X2X2X3 = 24) and each sub-subplot had an area of 1 X 1 m^2. The ditches were not considered for crop cultivation due to their new

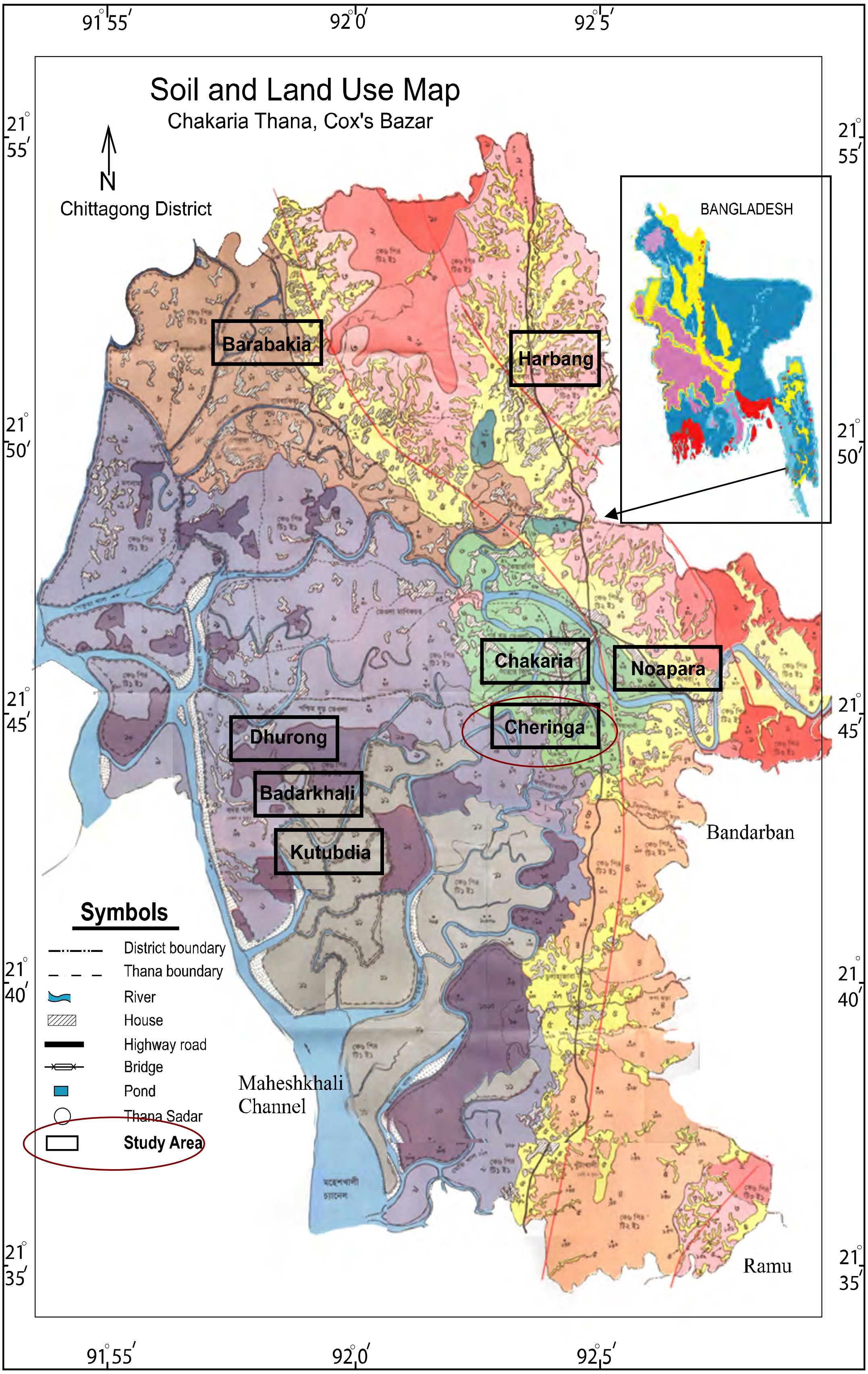
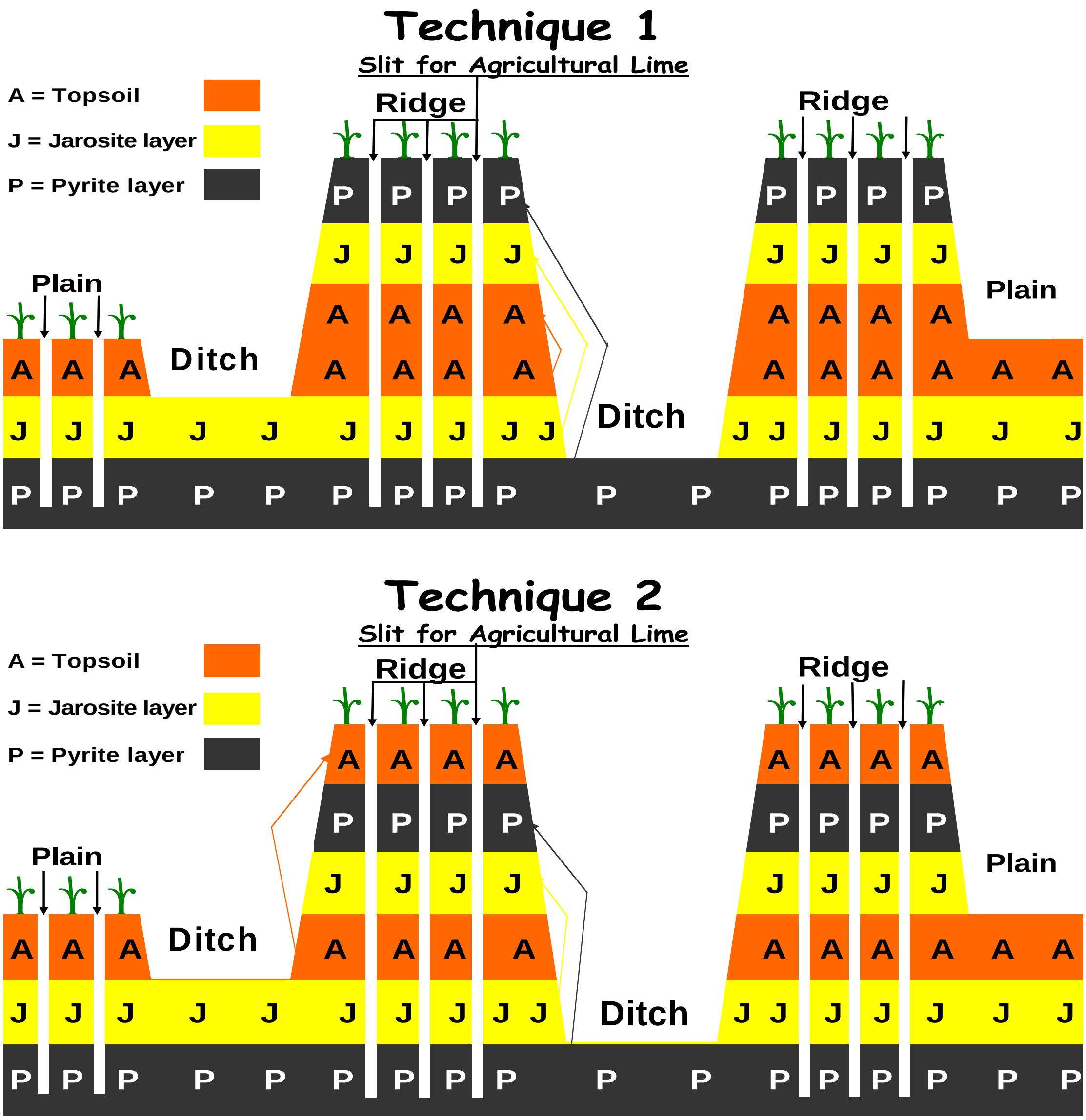


Fig. 1 Site map of the study area (oval shaped) in Cox' Bazar Bangladesh

excavation and also did not count as cropped area. The size of ditch was about 10 X 5 m^2 wide and 0.4 to 0.6 m deep. There were 3 (replications) separate subplots in plain land for control or check plots, where there was no exercise of A, BS and techniques. But these control plots were used to compare with the treatments and techniques. Each main plot was about 10 X 5 m^2 and the size of subplot for the individual treatment was 1 X 1 m^2. These plots were then subjected to flash leaching (5-7 times washing within a week: till the soil pH becomes >4) by using rainwater (yearly rainfall >4000 mm) reserved in the nearby pond. 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 BS_{10} and BS_{20} 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. 2**), the same doses of BS were incorporated into the subsoil (20-40 cm) by using a soil Slitter (5 cm diameter) at every 20 cm distances.



Area of individual Plain = Ridge = Ditch = about 10 X 5 m^2, height of the ridge onto the plain = 0.6 m and depth of the ditch = 0.4 to 0.6 m.

Fig. 2 Modified-Plain-Ridge-Ditch techniques used in the field experiment for the reclamation and improvement of acid sulfate soil in relation to crop production

2.3 Modified-Plain-Ridge-Ditch Techniques

2.3.1 Plain: The area of each main plain (flood plain land) plot was 10 X 5 m^2 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. 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 followed by the application of BS treatments (BS_{20} and BS_{30} as suggested by Khan, 2002). 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 within a week.

2.3.2 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. 2** (Tech 1 and Tech 2). These 60 cm high beds were constructed to facilitate leaching of acidity and salinity of the soil. The area of the top of each ridge was 10×5 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 was 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 as explained in the following techniques 1 and 2.

Technique 1: Top layer (surface soil) was extended to about 20 cm thick (1^{st} layer: 0-20 cm) first onto the adjacent plots and was grounded into different aggregate sizes (A_{20} and A_{30}) as per treatment requirement and was kept open to air for oxidation within 2 days. Then second layer (20-40 cm: sub-surface soil with jarosite material) was extended to about 20 cm thick onto that processed first layer. The soils of the second layer was also grounded to the desired sizes of aggregates and kept for oxidation within 2 days. Finally, the third layer (40-60 cm: 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 rainwater reserved in the nearby pond. 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 (3^{rd} layer: 40-60 cm), then pyrite layer in the middle (2^{nd} layer: 20-40 cm) followed by the surface soil on the top (0-20 cm) of the ridge.

2.3.3 Ditch: Adjacent to each ridge, there was a ditch of about 10 X 5 m^2 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 be 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.

Prior to the transplantation of eggplants, the top soil (0-20 cm) in each plot (plain and ridge) was fertilized with N, P and K at the rates of 100, 60 and 60 kg ha^{-1} as urea, triple super phosphate (TSP) and muriate of potash (MP), respectively as a basal dose. All the TSP and one-third of urea and MP were applied two days before transplantation. The rest two-third of urea and MP were applied at 40 and 70 days after transplantation (DAT). The BS was also applied before two days of transplantation. The seedlings of eggplant were collected from the Bangladesh agriculture research institute and were planted in the Cheringa ASS on 11^{th} of December'03. Forty day-old healthy and uniform seedlings were transplanted at the distances 60 cm between the plants. The soils in the plots were allowed to receive natural rain and pond waters whenever necessary to maintain favorable condition (field moist condition) for eggplants. Insects were controlled by the use of insecticide, "Endosulfan 3EC" whenever it required.

2.4 Soil analysis

The bulk samples obtained from the initial and during fruit set (95 DAT) of eggplants grown in the ASS were stored for a couple of days under field-moist conditions (by putting the soil samples into polyethylene bags in an air-tight 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 300 g L^{-1} 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 1M CH_3COONH_4 (pH 7.0), ethanol washing, NH_4^+ displacement with acidified 100 g L^{-1} 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.

2.5 Plant analysis

Plant height and leaf area of eggplants were recorded at 30 and 90 DAT. The fresh weight of brinjal (eggplant) was determined at 140 DAT. The composite samples of shoot dry matter during fruit set (95 DAT) were analyzed for N content by the micro-Kjeldahl method (Jackson, 1973); P content by spectrometry (Jackson, 1973); K content by flame photometry (Black, 1965); S content by turbidometry (Jackson, 1973); Ca and Mg contents by AAS (Hesse, 1971) in HNO_3-$HClO_4$ acid (2:1) digest. The level of significance of the different treatments was determined using Duncan's New Multiple Range Test (DMRT) and least significant difference (LSD: Zaman, et al. 1982).

3 RESULTS AND DISCUSSION

3.1 Soils at initial and fruit set stage of eggplant

The Cheringa ASS (depth: 0-20 cm) showed a silty clay loam texture, initial pH value of 4.1, pyrite content of 55 g kg^{-1}, base saturation of 47%, ECe value of 3.6 dS m^{-1}), high exchangeable Fe^{3+} and Al^{3+} contents of 1.47 and 5.29 $cmol_c$ kg^{-1}, respectively (**Table 1**). The contents of basic cations in the initial soil were low to medium, while acidic cations were very high in relation to the amounts found elsewhere. The pH value of the average soil data of all the treatments at post harvesting of eggplant was found to be increased in pH from 4.1 to 5.3, i.e., by 1.2 units higher compared with the control (i.e. initial value), while the ECe value of the soil was decreased to 2.8 dS m^{-1} (13% decreased over control: **Table 1**). The contents of P, K, Ca and Mg in the average soil data at post harvesting were found to be increased (IOC = increased over control) by 41 to 127% IOC. The contents of exchangeable Al^{3+}, Fe^{3+}, Na^+, Cl^- and SO_4^{2-} in the soil were found to be decreased by 28 to 92% IOC (**Table 1**). The results also indicated 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. 3**) 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 $A_{20}BS_{30}$ attained the highest value of soil pH of 6.0 in the ridge of Tech 1 and 6.4 in the ridge of Tech 2 during post harvesting followed by the $A_{20}BS_{20}$ (pH 5.5 in Tech 1 and 5.9 in Tech 2: **Fig. 3**) treatment in the ridges. The lowest soil pH of 4.1 was recorded by the control treatment (where there was no application of A, BS and techniques). 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. 3**). The highest amount of exchangeable Al^{3+} of 5.29 $cmol_c$ kg^{-1} was recorded for the control plots, while this value was decreased to 0.15 for Tech 1 and 0.11 for Tech 2 by the $A_{20}BS_{30}$, preceded by the $A_{30}BS_{30}$ and $A_{20}BS_{20}$ treatments in the ridges. The decrements of Al^{3+} by all the treatments were more pronounced with Tech 2. Among the treatments, the application of BS ranked first for the increments of soil pH and nutrient status of the soil, followed by the aggregate size treatments and techniques, which might be owing to basic nature of BS (pH 9.6: Khan, et al. 2006) as well as its release of some elements mainly Ca, Mg, etc. into the soils. The results agreed with the findings of some researchers. Of them, Khan (2002) reported that the ASSs released a very large amount of Al, e.g., 10 mM L^{-1}. But a very low concentration of Al can be hazardous. Concentrations of 1 to 2 mM Al L^{-1} is toxic to most crops. Fishes are most susceptible; fish deaths occur at 0.5 mM Al L^{-1}. Standards and potable water mostly range from 5 to 1450 µg 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 with an associated decrease in Na, Fe and Al concentrations over time. However, it was reported that the increase in pH by the application of slag fertilizer caused the decrease in Eh (Ponnamperuma, et al. 1967; Nozoe, et al. 1999). But the studied site is in a coastal belt, which receives daily tides (0.2 to 0.6 m high) more than 180 times a year. Therefore, the chance of decrease in Eh and its associated problems might be less for this study area.

3.2 Plant height and leaf area of eggplant

The application of basic slag, aggregate size and different techniques exerted significant ($p \leq 0.05$) positive effects on the vegetative growth of eggplant and their effects varied not only with the kinds and amounts of amending materials but also with the techniques applied (**Fig. 3**). The highest value of plant height and maximum leaf area/leaf of 87 cm and 187 cm^2 in the ridges of Tech 1, and 99 cm and 197 cm^2 in the ridges of Tech 2 were recorded during 90 DAT by the $A_{20}BS_{30}$ treatment, followed by the $A_{20}BS_{20}$ treatment in the ridges (**Fig. 4**). The effects of the treatments in the soil in relation to the biomass production of eggplant were: Tech 2 > Tech 1; BS_{30} > BS_{20} and A_{20} > A_{30} (**Fig. 4**). In most cases, the biomass production of eggplants was found to be significant ($p \leq 0.05$) by the application of basic slag, aggregate size treatments and techniques applied. Most of the treatments were found to be exerted highly positive effects in increasing the biomass production of eggplants grown on the soil at the ridges of both the techniques and the effect was more pronounced under the Tech 2 (**Fig. 4**). **.** The present results agreed with the findings available in the site: *http://en.wikipedia.org/ wiki/eggplants*. 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.

3.3 Yield performance of eggplant

The different treatments on eggplants grown under modified-plain-ridge-ditch techniques in the Cheringa ASS significantly ($0 \leq 0.05$) increased the fresh yield, and the increment was more pronounced with Tech 2 (**Fig. 4**). This might be because of a smaller requirement of the basic slag regarding neutralizing of the acidity in the soil under Tech 2. In Tech 1, the oxidized layer required more basic slag in increasing pH level (~6) for optimum crop

Table 1 Some selected properties of the initial Cheringa acid sulfate soil (depth: 0-20 cm) and the average soil (0-20 cm) data obtained from all the treatments during fruit set (95 days after transplantation) of the eggplants grown under field condition.

Soil properties	Initial soil	Post harvested soil	% IOC†
Textural class		Silty clay loam	
Moisture at Field Capacity (%)	43	44	**2**
Soil pH (water, 1:2.5)	4.1	5.3	**29**
Pyrite content (g kg^{-1})	55	33	**-40**
ECe (dS m^{-1})	3.2	2.8	**-13**
Organic Carbon (g kg^{-1})	21.6	21.8	**1**
Available N (1.3 M KCl: mM kg^{-1})	7.83	8.44	**8**
Avail. P (0.002N H_2SO_4, pH 3: mM kg^{-1})	0.16	0.28	**75**
CEC (1M CH_3COONH_4 pH 7.0: $cmol_c$ kg^{-1})	19.1	19.4	**2**
Base saturation at pH 7.0 (%)	47	76	**61**
Exchangeable cations:			
Sodium (flame photometer: $cmol_c$ kg^{-1})	2.11	1.53	**-27**
Potassium (flame photometer: $cmol_c$ kg^{-1})	0.81	1.38	**70**
Calcium (AAS*: $cmol_c$ kg^{-1})	2.54	5.76	**127**
Magnesium (AAS: $cmol_c$ kg^{-1})	3.43	6.00	**75**
Aluminum (AAS: $cmol_c$ kg^{-1})	5.29	0.39	**-93**
Iron (AAS: $cmol_c$ kg^{-1})	1.47	0.75	**-49**
Water-soluble ions:			
Sodium (flame photometer: $cmol_c$ kg^{-1})	1.89	1.36	**-28**
Potassium (flame photometer: $cmol_c$ kg^{-1})	0.36	0.58	**61**
Calcium (AAS¶: $cmol_c$ kg^{-1})	2.31	4.26	**84**
Magnesium (AAS: $cmol_c$ kg^{-1})	3.17	4.48	**41**
Aluminum (AAS: $cmol_c$ kg^{-1})	0.79	0.15	**-81**
Iron (AAS: $cmol_c$ kg^{-1})	0.56	0.61	**9**
Chloride (0.05N $AgNO_3$: $cmol_c$ kg^{-1})	3.06	2.19	**-28**
Sulfate ($BaCl_2$: $cmol_c$ kg^{-1})	3.81	2.29	**-40**

†IOC = Increased over control (initial value), ¶AAS=Atomic Absorption Spectrophotometer.

growth. The effectiveness of basic slag application, aggregate size treatments and techniques on the yield of eggplant (**Table 2**) was almost similar to and significant ($p \leq 0.05$) as that of the effects observed on the biomass production of eggplants. The maximum yield of 17.8 t ha^{-1} for Tech 1 and 20.1 t ha^{-1} for Tech 2 (**Table 2**) were recorded by the application of BS_{30} in the soils of smaller aggregates (<20 mm: A_{20}) at the ridges of Tech 2, followed by the $A_{30}BS_{30}$ treatments in both the techniques.

The lowest quantity of 1.7 t ha^{-1} yield was recorded by the control treatment. The present attainment of fresh yield of eggplants from the different treatments in the Cheringa ASS is even the lower level of the normal range (14 - 28 t ha^{-1}) of yield eggplant (BBS, 1998), which reflecting that the present treatments were effective for the amendment of the ASS in relation to eggplant production. The sizes of soil aggregates also influenced the growth of eggplants in presence of basic slag treatments. The A_{20} aggregated soils produced the highest yield of eggplants, which might be because of the maximum oxidation of pyrite, release of Al and acidity from the soil, which in turn helped to increase the pH levels (**Fig. 3**) resulting in better availability of nutrients in the soil. Westerhof (1998) revealed that exchangeable bases and CEC had a positive relationship, while exchangeable Al was negatively correlated with the amount of soil in the micro-aggregate and primary particle fractions as studied in the field experiments. The plain lands in the present study have the similar sizes of aggregate and treatments but failed to obtain the expected production of eggplants. Though the general trends of the treatments on the yield of eggplants were observed almost similar to $A_{20}BS_{30} > A_{30}BS_{30} > A_{20}BS_{20}$ in the ridges of both the techniques.

3.4 Mineral nutrition of eggplants

Nitrogen, phosphorus, and potassium

The eggplants grown in the ridges of both the techniques exhibited the best responses on N, P, K, Ca and Mg contents in eggplant tissues during fruit set (95 DAT).

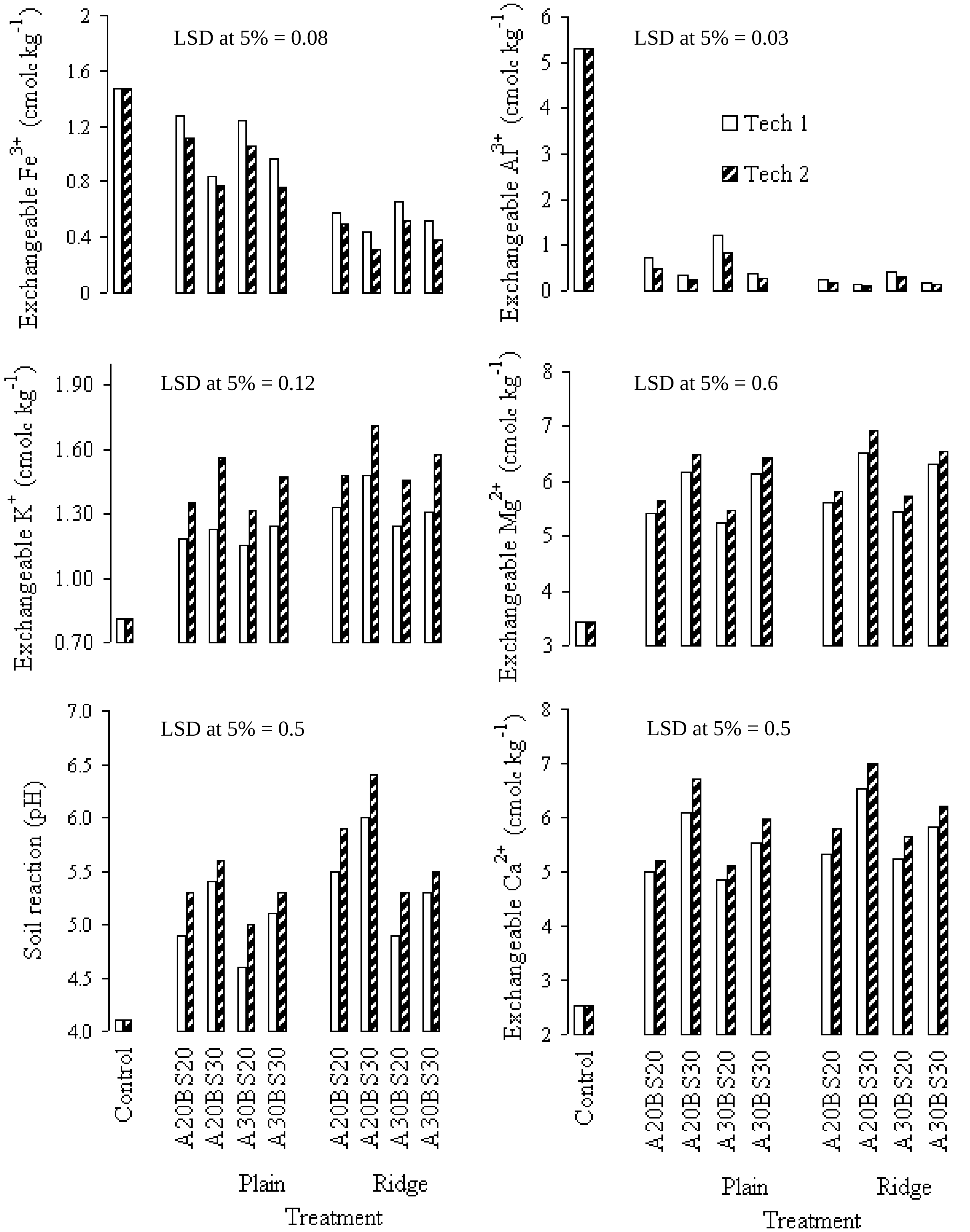


Fig. 3 Influence of different techniques, basic slag and aggregate size treatments on the status of elements in the soils during fruit set (95 days after transplantation) of eggplant grown in the Cheringa acid sulfate soil

As expected, the lowest contents of these nutrients in the eggplants were recorded in the control treatment (**Table 3**). The highest N, P, K, Ca and Mg contents in the eggplants were mostly obtained in the $A_{20}BS_{30}$ followed by $A_{20}BS_{20} \geq A_{30}BS_{30}$ treatments in the ridges under Tech 1 and Tech 2 (**Table 3**). It is noted that the air-drying during preparation of ridges might affect on ammonification as well as alkalization might also be associated with the increase in N content. The adequate levels of these nutrients (N: 42-50; P: 3-6; K: 35-50; Ca: 8-15; Mg: 2.5-6.0 g kg^{-1}: Simonne, et al. 2006) were determined in the eggplants grown mostly on the ridges of both the techniques, while the contents of these nutrients in the eggplants grown in the control plots were far below the deficient level, i.e., far below the lowest adequate level. The application of basic slag and aggregate size treatments in different techniques significantly ($p \leq 0.05$) increased the contents of these

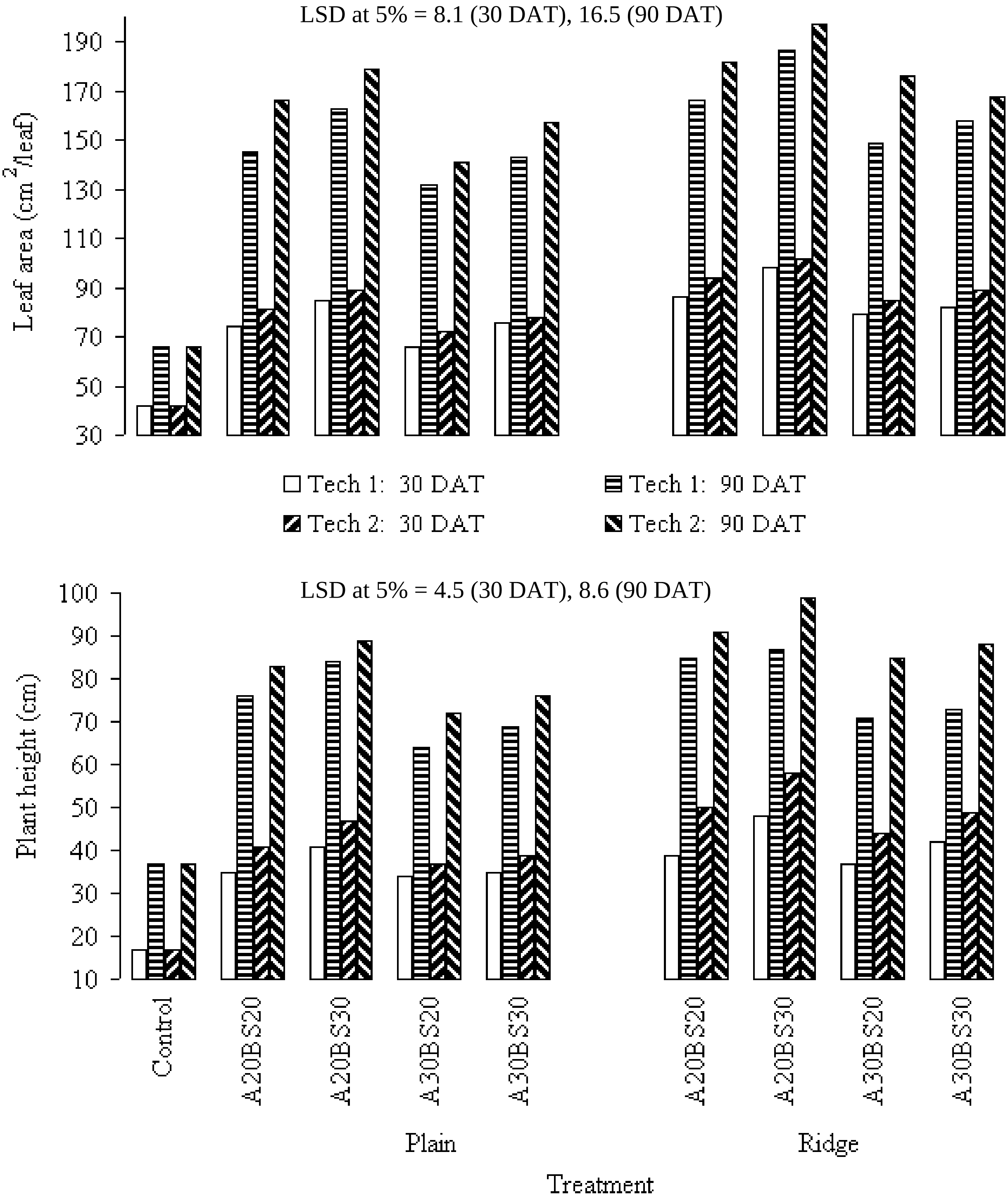


Fig. 4 Influence of different techniques, basic slag and aggregate size treatments on plant height and leaf area at 30 and 90 days after transplantation (DAT) of eggplants grown in the Cheringa acid sulfate soil

Table 2 Influence of different techniques, basic slag and aggregate size treatments on the yield (fresh weight basis) of eggplants at the first harvesting (140 days after transplantation) of eggplants grown in the Cheringa acid sulfate soil.

Treatment/ Denotation		Yield (t ha^{-1})		Mean
		Tech 1	Tech 2	Yield
Plain	Control	1.7 f†	1.7 f	12.2 q
	$A_{20}BS_{20}$	11.7 d	13.1 d	
	$A_{20}BS_{30}$	13.2 c	14.9 c	
	$A_{30}BS_{20}$	9.1 e	10.6 e	
	$A_{30}BS_{30}$	11.8 d	12.7 d	
Ridge	$A_{20}BS_{20}$	14.4 c	16.2 b	15.9 p
	$A_{20}BS_{30}$	17.8 a	20.1 a	
	$A_{30}BS_{20}$	12.3 d	14.2 c	
	$A_{30}BS_{30}$	15.6 b	16.6 b	
Tech Mean		**13.2 n**	**14.8 m**	
LSD at 5% =				**1.6**

A_{20} and A_{30} = Aggregate size less than 20 and 20 to 30 mm; BS_{20} and BS_{30} = Basic slag application at the rates of 20 and 30 t ha^{-1}. †In a column and row, means followed by a common letter are not significantly different at 5% level.

nutrients in eggplants presumably because of reduced soil acidity and salinity as well as the release of N, P, etc. by microbial decomposition and associated soil chemistry with the treatments. Nitrogen (r=0.93**, 0.98** for Tech 1 and Tech 2, respectively), phosphorus (r = 0.88**, 0.96**), potassium (r=0.96**, 0.98**), calcium (0.89**, 0.96**), and magnesium (0.95**, 0.97**) contents in the eggplants during fruit setting (95 DAT) stage showed significant positive relationships with the fresh yield of the eggplants. Sulfur content of the eggplants grown in the control plots was 3.6 g kg^{-1} and was in the range of adequate S content (4 g kg^{-1}: Simonne, et al. 2006). However, the S contents in the eggplants grown in different treatments were significantly ($p \leq 0.01$) lower compared with the adequate level. The S content in the eggplant showed a significant ($p \leq 0.01$) negative relationship with the fresh yield of eggplants grown under the different techniques.

4 CONCLUSIONS

The application of BS_{30} ranked first for the reclamation and improvement of productivity of the Cheringa acid sulfate soil, followed by the $A_{20} > A_{30}$ under Technique 2. The significant ($p \leq 0.05$) positive improvements of growth and yield of eggplants and soil properties were more pronounced under Technique 2 than that of Technique 1. Application of basic slag and aggregate size treatments in the modified-plain-ridge-ditch techniques not only increased soil pH, but also improved the ionic balance between Ca and Mg, and remarkably decreased the Fe and Al contents in the soil and plants.

The application of basic slag in the Cheringa acid sulfate soil was an effective measure, also available at a reasonable price, which not only enabled to reclaim the soil and improved the growth and yield of the eggplant, but was also beneficial to the surrounding environment. Moreover, the modified-plain-ridge-ditch techniques and

Table 3 Influence of different techniques, basic slag and aggregate size treatments on the tissue concentrations (g kg^{-1}: dry weight basis) of nutrients at early fruit set (95 days after transplantation) of eggplants grown in the Cheringa acid sulfate soil.

Treatments		Nitrogen		Phosphorus		Potassium		Calcium		Magnesium		Sulfur	
		Tech 1	Tech 2	Tech 1	Tech 2	Tech 1	Tech 2	Tech 1	Tech 2	Tech 1	Tech 2	Tech 1	Tech 2
	Control	25.3 d†	25.3 d	1.5 g	1.5 g	21.7 e	21.7 d	4.7 e	4.7 e	2.1 e	2.1 e	3.6 a	3.6 a
	$A_{20}BS_{20}$	37.3 c	38.7 c	2.5 f	2.8 f	36.1 d	37.2 c	8.8 c	9.1 c	3.2 d	3.7 d	2.7 c	2.7 b
Plain	$A_{20}BS_{30}$	42.7 b	43.1 b	3.8 c	3.9 d	38.0 c	39.6 b	9.3 c	9.5 c	4.3 c	4.6 c	2.7 c	2.6 c
	$A_{30}BS_{20}$	36.8 c	38.4 d	2.9 e	3.2 e	36.6 c	37.8 b	8.3 d	8.5 d	3.3 d	3.5 d	3.0 b	2.8 b
	$A_{30}BS_{30}$	38.1 c	39.3 c	3.4 d	3.6 d	37.5 c	38.2 b	8.9 c	9.2 c	4.2 c	4.6 c	2.7 c	2.8 b
	$A_{20}BS_{20}$	44.1 b	45.9 b	4.1 b	4.5 b	39.1 c	40.9 b	10.1 b	10.5 b	4.5 b	4.9 b	2.6 c	2.6 c
Ridge	$A_{20}BS_{30}$	49.2 a	51.3 a	4.9 a	5.2 a	43.6 a	44.9 a	11.4 a	11.7 a	5.2 a	5.6 a	2.4 d	2.3 d
	$A_{30}BS_{20}$	38.9 c	39.9 c	3.7 c	4.0 c	37.7 c	38.0 b	9.1 c	9.4 c	3.5 d	3.7 d	2.9 c	2.9 b
	$A_{30}BS_{30}$	43.1 b	44.7 b	3.8 c	4.2 c	39.9 b	41.1 b	10.2 b	10.3 b	4.3 c	4.6 c	2.6 c	2.6 c
LSD at 5% =		**4.7**	**4.9**	**0.5**	**0.5**	**3.7**	**3.8**	**0.9**	**1.0**	**0.4**	**0.5**	**0.3**	**0.3**
r-value		**0.93****	**0.98****	**0.88****	**0.96****	**0.96****	**0.98****	**0.89****	**0.96****	**0.95****	**0.97****	**-0.85****	**-0.89****

A_{20} and A_{30} = Aggregate size less than 20 and 20 to 30 mm; BS_{20} and BS_{30} = Basic slag application at the rates of 20 and 30 t ha^{-1}.
†In a column and row, means followed by a common letter are not significantly different at 5% level.

the use of different sizes of aggregates contributed for the physico-chemical amendments of the soil as well as improved the production of eggplants. 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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