CROP RESPONSE TO RESIDUAL EFFECTS OF BASIC SLAG, AGGREGATE SIZE AND GROUNDWATER LEVEL TREATED ACID SULFATE SOILS

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Abstract

A pot experiment with two acid sulfate soils of Badarkhali and Cheringa series were performed. After 18 years of fallow period in 2016, a crop trial was done in order to evaluate the response of rice plant without giving additional treatments. The average maximum temperature during the experimental period was 33.2°C and average rainfall was 57 mm. Two cultivars of rice BRRI 48 and BRRI hybrid dhan 06 showed the tallest plant height of 115 cm and tillers 6.31 in numbers/plant on an average in both the soils. Panicle length was 16.5 cm, 1000-grain weight 22 g, grain yield 4.72 g/m^2 and harvest index was 0.01 on average in both the soils. The experiment indicates that soil condition for crop growth possesses good quality after a long time and growth and yield parameters found satisfactory and significant (p ≤ 0.05).

Introduction

Acid sulfate soils (ASSs) impose two faced problems - acidity and salinity, in terms of crop production. Given the mounting pressure on global ecosystems, the food production increase must be achieved in a sustainable and environmentally sound way[1]. Acid sulfate soils 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[2]. In Bangladesh, acid sulfate soils were first recognized in the coastal areas. In Chittagong coastal belt it is locally known as "Kosh" soil. Fertility level of these soils, specially N and P content is very low to low[3].

The rapid increase of population, development of economic infrastructures and urbanization are snatching agricultural lands. Using marginal and problem soils through proper reclamation can alleviate this problem. Successful reclamation of the ASSs may result in the development of productive fields for crop growth[4]. It also contributes to the net agricultural productivity, economy of the country, employment opportunity to the local community and ensures climate and environmental safety. Deficiency in plant base minerals is an important factor when the reclamation and management practices are performed in acid sulfate soils[5]. The reclamation of these soils may be difficult but

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essential. In order to alleviate the two-folds problem, application of basic slag had made the reclamation processes cost-effective to the farmers.

Basic slag is an excellent soil conditioner, liming agent, provider of trace minerals plus phosphate, calcium, magnesium, manganese and boron, etc. The Si contained in basic slag decreases Mn toxicity, enhances insect and disease resistance, and increases the water-use efficiency, oxidation power of rice roots and the efficiency of phosphorus utilization[6]. Despite of some changes in soil properties after a fallow period of 18 years, it is mandatory to check the crop response of the residual soil to recommend this a sustainable technique. The main objective of this study is to assess the long term effectiveness of basic slag application on crop growth.

Materials and Methods

The potentiality of the acid reclamation measures after 18 years fallow under net house condition was the prime consideration of this present study. Previously, for the simulation studies using concrete tanks, bulk soils from the 1st layer (0 - 20 cm), 2nd layer (20 - 40 cm) and 3rd layer (40 - 60 cm) of Badarkhali (B) and Cheringa (C) series were collected from Purbapukuria of Badarkhali Upazilla and Sarisabari of Chakaria Upazilla under Cox's Bazar district (Latitude 21o3′ N, Longitude 91o6′ E) in Bangladesh during March 1999[4]. About 10 kg of air-dried coarse sand, which was previously treated with tap water followed by 1M HCl, and distilled water was put at the bottom of each of the concrete tanks. Thereafter, the soil layers were placed in the concrete tanks (0.6 × 0.6 × 0.6 m) according to the following 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 1st , 2nd and 3rd layers, respectively, i.e., 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 analyzing 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[6]. The experiments were set up in a completely randomized design (Table 1).

Some chemical properties of soil that changed due to rice production after 18 years of fallow period were analyzed following the methods of Jackson[7] (Table 2) in the Department of Soil, Water and Environment, University of Dhaka. Evaluating the soil condition, the basal dose of NPK fertilizers was applied. No other treatments or amendments were applied. The average maximum temperature during the experimental period was 33.2°C and average rainfall was 57 mm[8] in conjuction to the water level maintenance. The soils from the concrete tanks were prepared for the production of rice. The compact top soil was broken with wooden hammer and leached over a period of week using tap water and a suitable soil bed was prepared by puddling for the cultivation of rice. The top soils (0 - 20 c m depth) in each tank, fertilizer containing

Table 1. Treatments and their combinations for the pot experiments done in 1999[4].

Soils	Treatment		Aggregate size (A: mm)	Groundwater level (Gw: cm)	Basic slag rate (BS : t/ha)
	Number	Denotation			
Badarkhali series (B)	T_1	$BA_{20}Gw_0BS_{10}$	<20	0	10
	T_2	$BA_{20}Gw_0BS_{20}$			20
	T_3	$BA_{20}Gw_{50}BS_{10}$		50	10
	T_4	$BA_{20}Gw_{50}BS_{20}$			20
	T_5	$BA_{30}Gw_0BS_{10}$	20-30	0	10
	T_6	$BA_{30}Gw_0BS_{20}$			20
	T_7	$BA_{30}Gw_{50}BS_{10}$		50	10
	T_8	$BA_{30}Gw_{50}BS_{20}$			20
Cheringa series (C)	T_9	$CA_{20}Gw_0BS_{10}$	<20	0	10
	T_{10}	$CA_{20}Gw_0BS_{20}$			20
	T_{11}	$CA_{20}Gw_{50}BS_{10}$		50	10
	T_{12}	$CA_{20}Gw_{50}BS_{20}$			20
	T_{13}	$CA_{30}Gw_0BS_{10}$	20-30	0	10
	T_{14}	$CA_{30}Gw_0BS_{20}$			20
	T_{15}	$CA_{30}Gw_{50}BS_{10}$		50	10
	T_{16}	$CA_{30}Gw_{50}BS_{20}$			20

Composition of basic slag (%): SiO_2 12.8, Ca 20.8, Mg 9.8, Fe 11.3, Mn 0.04, PO_4 0.3 and others 44.96, pH 9.6 (Laboratory of Soil Science, Inst. For Plant Nutrition and Soil Science, University of Keil, D-24109 Kiel, Germany 1999).

Table 2. Initial properties of Badarkhali and Cheringa acid sulfate soil before and after the applied treatments (aggregate size, groundwater level and basic slag).

Soil properties	Badarkhali series		Cheringa series	
	Initial 1998[6]	Fallow 2016 (avg. of T_1-T_8)	Initial 1998[6]	Fallow 2016 (av. of T_9-T_{16})
Soil pH (dry, 1 : 2.5)	3.9	6.1	3.6	5.7
EC (mS cm^{-1})	23	4.0	10.5	2.7
Organic carbon (%)	1.8	1.08	2.3	1.0
Total N (%)	0.01	0.02	0.01	0.05
C/N ratio	15.0	20.7	16	20.1
Available N (1.3 M KCl : m mol/kg)	3.2	14.7	3.6	15.2
Available P (0.001 M H_2SO_4, pH 3: m mol/kg)	0.1	3.1	0.1	0.1
Sulfate ($BaCl_2$: c mol/kg)	4.12	0.1	4.96	0.1
CEC (1 M CH_3COONH_4 pH 7.0 : c mol/kg)	20.2	22.0	33.5	15.8

N, P and K at the rate of 120, 60 and 80 kg/ha 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 was applied before transplantation. The remaining half of the urea was

applied in two equal splits, one at the maximum tillering stage of rice and other at the panicle initiation stage.

Twenty five days old seedlings of BRRI 48 and BRRI hybrid dhan 06 were collected from Bangladesh Rice Research Institute, Gazipur. Seedlings were transplanted on 7th May, 2016 at the rate of 3 plants per hill, 3 hills in a row and two rows for each variety in the tank (i.e. 3 × 2 × 2 = 12 hills per unit of 0.4 m^2 tank). These two rows of each variety were considered as replications. The distances between the hills were 15 cm. The varieties were chosen due to their high yielding capacity, popularity and seasonal availability. The soils in the tanks were irrigated by natural rain and tap water. After 10 - 12 days of seedlings transplantation soil was kept at submerged condition. At the rest of the stages water content was maintained near field capacity. Weeds were removed manually. Adequate plant protection measures like pest control, shading were taken during the growing period. Hilthion 57EC were applied to protect plants from the pest named Long-horned cricket.

The rice plants were allowed to grow for 110 days. The height of the collected plants was recorded using meter scale. Then plant sampling was done by uprooting carefully from the experimental blocks. The plants were put into the plastic bags with proper labeling and brought into the laboratory. Fresh weight was measured using electric balance. Then the samples were first air dried and then oven dried at 70 ± 5° for 48 hrs. The oven dried weight of the plants was taken using an electric balance. Plant agronomic parameters - panicle length, number of panicle, number of grain per pot, per cent filled grain, weight of filled grains, 1000-grain weight and harvest index were studied in the laboratory. The results of the experiments were calculated and graphically evaluated using Microsoft Excel 2010. All statistical analyses were performed with Minitab version 15.

Results and Discussion

Plant height and tiller production: Plant height and tiller numbers were found significant on the long term effects of selected treatments ($p \leq 0.05$) in least significant difference (LSD) and Tukey test. The notations followed by the same letter in Tukey test are not significantly different at 5% level.

The tallest plant height for BRRI 48 variety in Badarkhali series was 112 cm and the shortest was 87 cm and for Cheringa series tallest plant height was 114 cm and the shortest was 97 cm (Fig. 1). In panicle initiation stage, the maximum number of tillers were 8.3 in numbers/plant for Badarkhali and the minimum is 5.8 in numbers/plant and maximum 7.5 in numbers/plant for Cheringa soils and minimum 3.8 in numbers/plant (Fig. 1).

For BRRI hybrid dhan 06 the maximum plant height was recorded 118 cm both in Badarkhali and Cheringa series and lowest plant height was 96 cm on average for both

the series. In panicle initiation stage, the maximum number of tillers were 9.1 numbers/ plant and minimum was 4.1 numbers/plant for Badarkhali and maximum 7 numbers/ plant and minimum 2.6 numbers/plant for Cheringa series (Fig. 2).
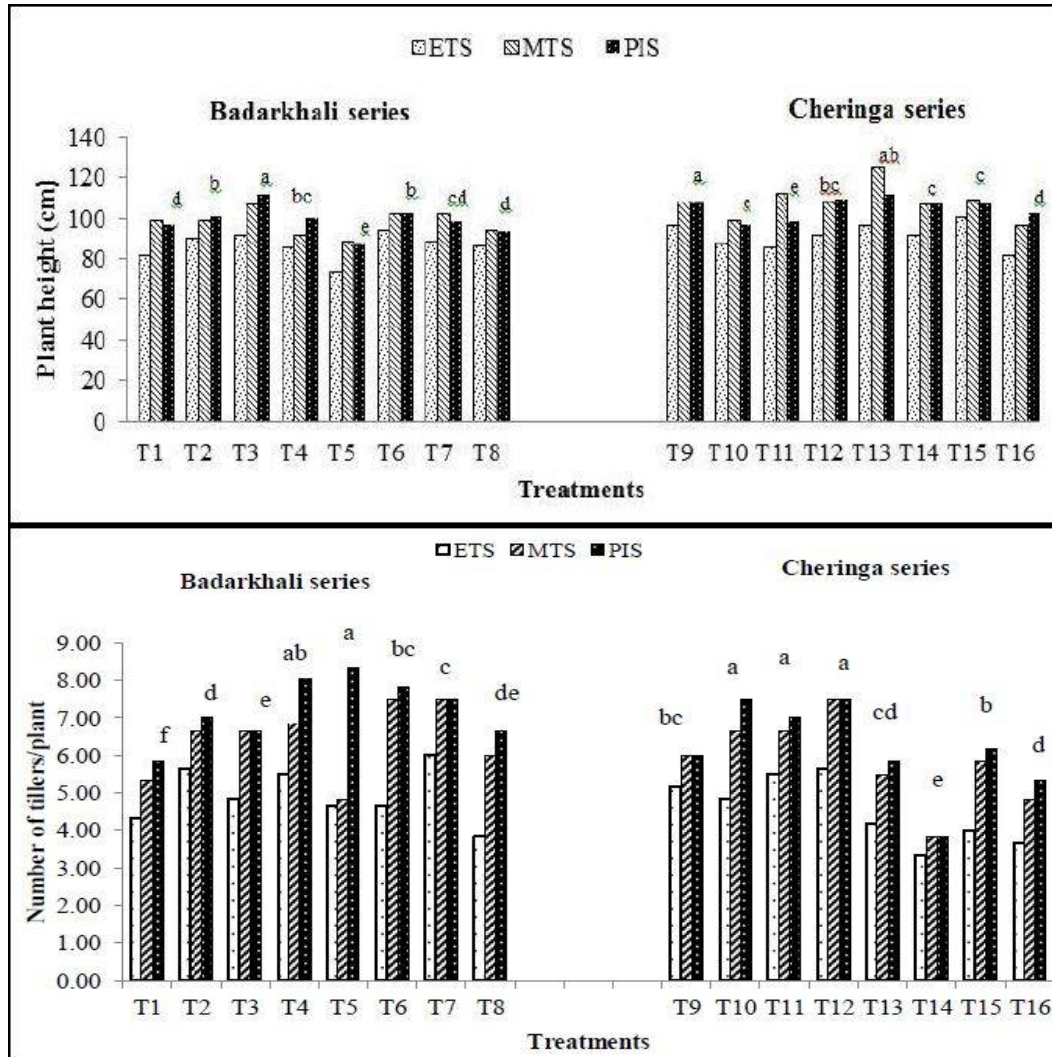

Fig. 1. Long term effects of basic slag application rate, aggregate size and groundwater level treatments on plant height and tiller production at different growth stages of the BRRI 48 rice variety cultivated in two acid sulfate soils. [ETS = Early tillering stage (20-40 days); MTS = Maximum tillering stage (41-70 days); PIS = Panicle initiation stage (71-100 days)].

In both varieties, the plant height was more than the average plant height which was 105 cm[9]. In case of tiller number, the stands might be very dense and tillers were undeveloped. Some tillers died before producing a panicle due to uneven distribution of

sunlight. Consequently only the main culm produced a panicle. The reasons behind reduced tillering could be nitrogen deficiency, weed competition and application of fungicides[10].
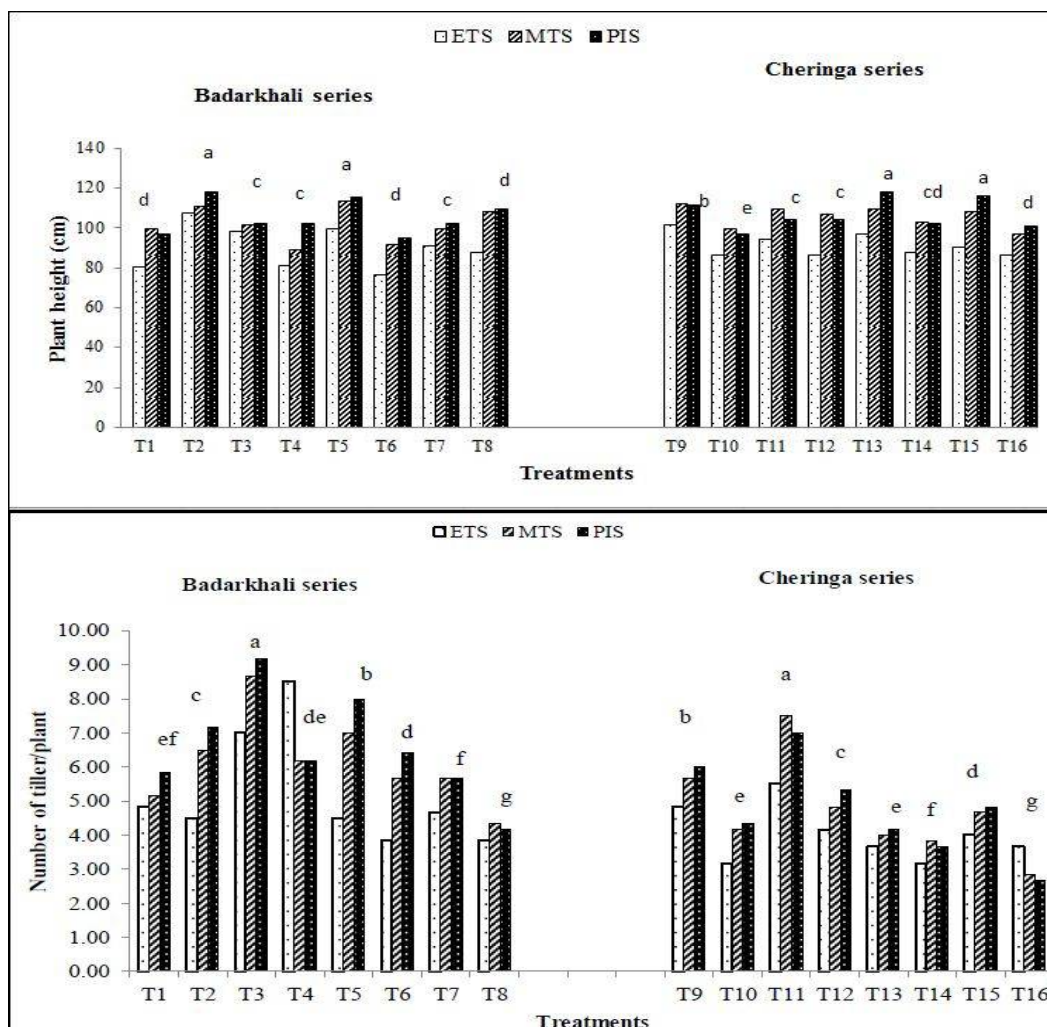

Fig. 2. Long term effects of basic slag application rate, aggregate size and groundwater level treatments on plant height and tiller production at different growth stages of the BRRI hybrid 06 rice variety cultivated in two acid sulfate soils. [ETS = Early tillering stage (20-40 days); MTS = Maximum tillering stage (41-70 days); PIS = Panicle initiation stage (71-100 days).]

Yield and yield components of rice: The analyses of the data on straw and grain yields (Tables 3 and 4) revealed that the average grain and straw yields were more in Badarkhali soil than that of Cheringa soil. The maximum yields for BRRI 48 (grain: 20.05

g m^{-2} and straw: 277.65 g m^{-2} for Badarkhali soil and grain: 10.45 g m^{-2} and straw: 374.75 g m^{-2} for Cheringa soil) were recorded (Table 3).

The maximum yields for BRRI hybrid dhan 06 (grain: 5.88 g m^{-2} and straw: 209.70 g m^{-2} for Badarkhali soil and grain: 5.35 g m^{-2} and straw: 337.23 g m^{-2} for Cheringa soil) were recorded (Table 4). The effects of the treatments were not found prominent in grain and straw yields in both the series.

The treatment T_1 for Badarkhali and T_9 for Cheringa series were considered as control in calculating % IOEC (Increased over experimental control) because of aggregate size following the previous reports[4]. The grain and straw dry matter production was higher in the Badarkhali soil as compared to Cheringa soil, which might be attributed to the high organic matter content of Badarkhali soil for both the variety BRRI 48 and BRRI hybrid dhan 06.

From the analyses, the per cent filled grain, grain yield and straw yield showed unusual results. In Bangladesh, a high percentage of spikelet sterility usually occurs in Transplanted Aus season (March-June) when the temperature exceeds 35°C at anthesis and lasts for more than 1 hour[11]. On July, 2016, the average maximum temperature was 33.6°C which was above the critical temperature (between 20 and 30°C) and the average maximum humidity was 91%[12]. Moreover, as the temperature rises, accompanied by rainfall or high humidity, possibility of pest and disease attack increases. Empty grains or blanks, can be the result of hot temperature during pollen formation. After flowering, temperatures above 35°C can adversely affect pollination[13]. Other factors could be stand density, panicle blast, sulfur deficiency and armyworms feeding on developing grains. Grain weight was negatively affected because of drying the field too early before harvesting.

Seedling age is an important element affecting the number of filled grains per panicle, the panicle length, the 1000-grain weight and the grain yield in rice, as reported by Ginigaddara[14]. Li[15] reported that, when rice plants were mechanically transplanted at a 20 days seedling age, the grain yield markedly decreased by 4.66% compared to that under artificial transplantation.

Based on the values of the harvest index the treatments can be arranged in the following sequence on the growth of BRRI 48:

Badarkhali soil: T_2 ($BA_{20}GW_0BS_{20}$) > T_8 ($BA_{30}GW_{50}BS_{20}$) = T_7 ($BA_{30}GW_{50}BS_{10}$) > T_3 ($BA_{20}GW_{50}BS_{10}$) > T_6 ($BA_{30}GW_0BS_{20}$) = T_1 ($BA_{20}GW_0BS_{10}$) > T_4 ($BA_{20}GW_{50}BS_{20}$) = T_5 ($BA_{30}GW_0BS_{10}$).

Cheringa soil: T_{13} ($CA_{30}GW_0BS_{10}$) > T_{16} ($CA_{30}GW_{50}BS_{20}$) = T_{11} ($CA_{20}GW_{50}BS_{10}$) > T_9 ($CA_{20}GW_0BS_{10}$) = T_{12} ($CA_{20}GW_{50}BS_{20}$) = T_{14} ($CA_{30}GW_0BS_{20}$) = T_{15} ($CA_{30}GW_{50}BS_{10}$) > T_{10} ($CA_{20}GW_0BS_{20}$).

Table 3. Long term effects of basic slag application rate, aggregate size and groundwater level treatments on the growth, yield and yield components of BRRI 48 rice variety cultivated in two acid sulfate soils.

Treatment Number	Denotation	No. of panicles	Panicle length (cm)	Filled grains (%)	1000-grain wt. (g)	Grain yield Dry wt. (g m^{-2})	Grain yield IOEC (%)[a]	Straw yield Dry wt. (g m^{-2})	Straw yield IOEC (%)[a]	Harvest index[b]	1000-grain wt./panicle (g)	Grain wt./ panicle (g)
T_1	$BA_{20}Gw_0BS_{10}$	9	14.5	5.60	87.8	4.18	-	145.90	-	0.03	0.79	0.19
T_2	$BA_{20}Gw_0BS_{20}$	18	15	37.6	21.3	20.05	379.67	277.65	90.30	0.07	0.17	0.36
T_3	$BA_{20}Gw_{50}BS_{10}$	18	16	38.4	21.0	7.25	73.44	190.00	30.23	0.04	0.38	0.45
T_4	$BA_{20}Gw_{50}BS_{20}$	12	18	20.0	21.9	5.60	33.97	232.25	59.18	0.02	0.26	0.19
T_5	$BA_{30}Gw_0BS_{10}$	7	17	13.2	17.2	2.38	-43.18	125.78	-13.79	0.02	0.12	0.14
T_6	$BA_{30}Gw_0BS_{20}$	15	18	34.0	21.0	4.05	-3.11	126.28	-13.45	0.03	0.27	0.33
T_7	$BA_{30}Gw_{50}BS_{10}$	13	19	13.8	20.5	10.73	156.58	200.30	37.29	0.05	0.31	0.11
T_8	$BA_{30}Gw_{50}BS_{20}$	13	22	37.0	23.1	10.53	151.79	191.18	31.03	0.05	0.30	0.32
LSD at 5% level		1.4	1.41	0.93	0.76	0.09		0.5		0.01		

Treatment Number	Denotation	No. of panicles	Panicle length (cm)	Filled grains (%)	1000-grain wt. (g)	Grain yield Dry wt. (g m^{-2})	Grain yield IOEC (%)[a]	Straw yield Dry wt. (g m^{-2})	Straw yield IOEC (%)[a]	Harvest index[b]	1000-grain wt./panicle (g)	Wt. Grain wt./ panicle (g)
T_9	$CA_{20}Gw_0BS_{10}$	30	16	18.0	19.3	5.13	-	212.53	-	0.02	0.58	0.07
T_{10}	$CA_{20}Gw_0BS_{20}$	6	17.5	24.2	22.5	0.68	-86.84	144.55	-31.99	0.005	0.14	0.69
T_{11}	$CA_{20}Gw_{50}BS_{10}$	10	23.5	7.3	19.6	10.33	101.27	374.75	76.33	0.03	0.20	0.03
T_{12}	$CA_{20}Gw_{50}BS_{20}$	11	24	12.0	18.4	3.38	-34.21	219.40	3.23	0.02	0.20	0.12
T_{13}	$CA_{30}Gw_0BS_{10}$	18	15	41.7	23.6	10.45	103.70	241.38	13.57	0.04	0.42	0.23
T_{14}	$CA_{30}Gw_0BS_{20}$	12	15	19.2	25.7	1.68	-67.35	69.00	-67.53	0.02	0.31	0.23
T_{15}	$CA_{30}Gw_{50}BS_{10}$	12	18	18.3	21.0	6.83	33.04	297.30	39.89	0.02	0.25	0.06
T_{16}	$CA_{30}Gw_{50}BS_{20}$	10	18	14.3	19.6	4.58	-10.82	150.20	-29.33	0.03	0.20	0.18
LSD at 5% level		1.5	1.30	0.76	0.55	0.07	0.05	0.01		0.01		

[a]IOEC = Increase over experimental control; [b]Harvest index = Grain yield/(Grain + straw yield)[6].

Table 4. Long term effects of basic slag application rate, aggregate size and groundwater level treatments on the growth, yield and yield components of BRRI hybrid dhan 06 rice variety cultivated in two acid sulfate soils.

Number	Denotation	No. of panicles	Panicle length (cm)	Filled grains (%)	1000-grain wt. (g)	Grain yield Dry wt. (g m⁻²)	Grain yield IOEC (%)[a]	Straw yield Dry wt. (g m⁻²)	Straw yield IOEC (%)[a]	Harvest index[b]	1000-grain wt./ panicle (g)	Grain wt./ panicle (g)
T_1	$BA_{20}Gw_0BS_{10}$	10	22	25.7	22.7	3.48	-	120.98	-	0.03	2.28	0.14
T_2	$BA_{20}Gw_0BS_{20}$	8	19	20.3	16.1	3.35	−3.46	192.30	58.95	0.02	2.02	0.17
T_3	$BA_{20}Gw_{50}BS_{10}$	13	17	36.4	18.0	1.58	−54.61	209.70	73.33	0.01	1.38	0.05
T_4	$BA_{20}Gw_{50}BS_{20}$	12	17	23.1	18.7	3.85	10.95	118.38	−2.15	0.03	1.57	0.13
T_5	$BA_{30}Gw_0BS_{10}$	6	19	21.0	17.5	2.55	−26.51	192.43	59.06	0.01	2.93	0.17
T_6	$BA_{30}Gw_0BS_{20}$	6	16	22.3	17.1	5.88	69.31	143.60	18.70	0.04	2.86	0.39
T_7	$BA_{30}Gw_{50}BS_{10}$	5	16	14.4	11.5	1.50	−56.77	189.18	56.37	0.01	2.31	0.12
T_8	$BA_{30}Gw_{50}BS_{20}$	12	15	25.7	14.6	4.58	31.84	144.75	19.65	0.03	1.22	0.15
LSD at 5% level=		1.5	1.5	0.55	0.55	0.02		0.05		0.01		

Number	Denotation	No. of panicles	Panicle length (cm)	Filled grains (%)	1000-grain wt. (g)	Grain yield Dry wt. (g m⁻²)	Grain yield IOEC (%)[a]	Straw yield Dry wt. (g m⁻²)	Straw yield IOEC (%)[a]	Harvest index[b]	1000-grain wt. per panicle (g)	Grain wt./ panicle (g)
T_9	$CA_{20}Gw_0BS_{10}$	8	20	32.0	17.5	5.35	-	172.18	-	0.03	2.19	0.27
T_{10}	$CA_{20}Gw_0BS_{20}$	5	18	3.4	16.6	0.25	−95.33	71.20	−58.65	0.003	2.67	0.02
T_{11}	$CA_{20}Gw_{50}BS_{10}$	7	13.5	20.5	18.7	2.65	−50.47	337.23	95.86	0.01	3.33	0.17
T_{12}	$CA_{20}Gw_{50}BS_{20}$	5	11.5	4.0	8.8	0.20	−96.26	165.93	−3.63	0.00	1.78	0.02
T_{13}	$CA_{30}Gw_0BS_{10}$	7	20	25.5	16.4	1.85	−65.42	135.68	−21.20	0.01	2.35	0.11
T_{14}	$CA_{30}Gw_0BS_{20}$	4	13	11.6	15.5	0.70	−86.92	72.05	−58.15	0.01	1.22	0.07
T_{15}	$CA_{30}Gw_{50}BS_{10}$	11	12	17.9	13.3	2.18	−59.35	98.43	−42.84	0.02	3.89	0.08
T_{16}	$CA_{30}Gw_{50}BS_{20}$	12	18	39.7	16.2	3.63	−32.24	70.60	−59.00	0.05	2.33	0.21
LSD at 5% level=		1.5	1.3	0.76	0.15	0.01		0.01		0.01		

[a]IOEC = Increase over experimental control; [b]Harvest index = Grain yield/(Grain + straw yield)[6].

Based on the values of the harvest index the treatments can be arranged in the following sequence on the growth of BRRI hybrid dhan 06:

Badarkhali soil: T_6 ($BA_{30}GW_0BS_{20}$) > T_1 ($BA_{20}GW_0BS_{10}$) = T_4 ($BA_{20}GW_{50}BS_{20}$) = T_8 ($BA_{30}GW_{50}BS_{20}$) > T_2 ($BA_{20}GW_0BS_{20}$) > T_3 ($BA_{20}GW_{50}BS_{10}$) = T_5 ($BA_{30}GW_0BS_{10}$) = T_7 ($BA_{30}GW_{50}BS_{10}$).

Cheringa soil: T_{16} ($CA_{30}GW_{50}BS_{20}$) > T_9 ($CA_{20}GW_0BS_{10}$) > T_{15} ($CA_{30}GW_{50}BS_{10}$) > T_{11} ($CA_{20}GW_{50}BS_{10}$) = T_{13} ($CA_{30}GW_0BS_{10}$) = T_{14} ($CA_{30}GW_0BS_{20}$) > T_{10} ($CA_{20}GW_0BS_{20}$) > T_{12} ($CA_{20}GW_{50}BS_{20}$).

The above results indicate that the application of treatments is effective for the improvement of soil condition but shows variation in plant growth. The major reasons were late transplantation, climatic condition like humidity and temperature during crop growth.

Conclusion

The major investigation after 18 years of fallow acid sulfate soils revealed that, the soils reclaimed properly for crop growth. But the growth and yield parameters of rice grown were affected by temperature variation, unusual rainfall and excessive humidity. So, basic slag application in acid sulfate soils could be recommended as a sustainable approach for the cultivation of rice. The experiment revealed that not only the improvement of soil but also the environmental factors and proper maintenance should be given equal importance to get maximum crop yield.

Acknowledgement

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