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MAGNITUDES OF BASIC SLAG ON IRON DYNAMICS IN TWO ACID SULFATE SOILS DURING 30-MONTHS OF INCUBATION UNDER VARIOUS MOISTURE REGIMES

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Keywords: Acid sulfate soils, Basic slags, Incubation times, Moisture regimes, Soil pH and Fe dynamics.

Abstract

The magnitudes of basic slag (BS) at 0, 10, 20 and 30 t ha^{-1} on iron dynamics in two acid sulfate soils (ASSs) under moisture at field capacity, saturated condition and wetting-drying cycle were studied during 30 months of incubation (25-30 ^{0}C). The impacts of BS in Sarisabari ASS were almost similar as those obtained in Purbapukuria ASS under various treatments, but the increments of pHs in Sarisabari ASS were not as pronounced as those observed in Purbapukuria ASS. The pH values were increased by about 1.0, 1.5 and 1.2 units in Sarisabari and 2.0, 1.7 and 1.5 in Purbapukuria ASSs, those received BS_{30} at field capacity, saturated condition and wetting-drying cycle, respectively and followed by BS_{20} > BS_{10} treatments. The contents of basic cations in the studied ASSs were low to medium, while acidic cations were very high in relation to the amounts found in the ASSs elsewhere. Magnesium contents were about 2 to 3 -folds than those of Ca but Fe contents were very high. The application of basic slag in the ASSs was found to reduce the acidity problems noticeably and decreased the Fe contents remarkably. Neutralization of acidity by BS_{30} at saturation moisture level was determined to be the best for both the ASSs followed by moisture at field capacity and wetting-drying cycle. The soil pH was found to have strong positive relationship with time, while the Fe contents showed strong negative relationship with the corresponding pHs of the ASSs. These indicate that the amelioration of ASSs by the application of BS is a sustainable reclamation and improvement measures regarding Fe toxicity of the soils.

Introduction

Acid sulfate soils (ASSs) worldwide occupy an area of at least 17 million ha(1). They are mostly located in tropical coastlands but they are also found in higher latitudes, as in several countries in Central and North Europe(2). While they are generally associated with coastal areas, inland ASSs are also profusely reported, mainly in Australia, in Fe-rich areas subjected to waterlogging(2,3). Acid sulfate soils are hazardous to natural and managed ecosystems(4). In particular, potential ASSs, when drained, can be responsible for fresh water acidification, which in mountain environments such as the Pyrenees could severely affect aquatic and soil ecosystems. Management techniques to minimize these hazards rely on the correct identification and classification of ASS materials(5).

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Acid sulfate soils release huge amounts of acid and toxically high concentrations of metals, affecting biological activity in the soils as well as in the surrounding water environments(6). For proper correction, planning and utilization of vast areas of ASSs, it is essential to have information on the influence of some main natural factors relating to ASSs. Basic research should be conducted for determining the main factors responsible for the rate of reduction associated with climatic elements, and the rate of pH rise to levels at which toxicity of element does not occur. These undertakings will help to find out the suitable reclamation and/or management measures. The Fe and Al deserve attention as some ASSs release significant amounts of Fe and Al, which can be toxic to fish and rice production(7). Researchers also emphasized on the severity and reserve of soil acidity. These cannot be quantitatively determined from morphology and field relationships, but rapid and simple methods are being developed to estimate the amount of acid present and the amount to be generated upon drainage.

Effective 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 arises in the coastal tidal flat plain areas(6). Cook *et al.*(8) reported that the progressive oxidation of organic matters, sulfides and increasing acidity in the profiles of ASSs do not only decrease bases in the soil solution but also strongly affect the fate/mobility of metals and metalloids in groundwater, posing threat to groundwater resources and health of both terrestrial and aquatic ecosystems. In ASSs, water management is the key to soil management and proper water management can limit acidification(10). However, the potentiality of BS for the reduction of ASSs and associated ion dynamics under variable soil moisture regimes is likely to provide insights into reclamation and improvement of ASSs. Considering the above background, the present study was conducted in order to assess the remediation capacity of BS under various moisture conditions, incubation times and its effects on the reduction of Fe toxicities in the ASSs.

Materials and Methods

In order to understand the performance of basic slag at different moisture conditions in variable acidity levels of acid sulfate soils were studied in a laboratory of the Department of Soil, Water and Environment, University of Dhaka, Bangladesh. Surface layers (0-20 cm) of the two different acid sulfate soils were collected from Sarisabari and Purbapukuria of Chakaria upazila. The soils belong to Cheringa series and Badarkhali series, respectively. These soils were air dried and ground uniformly into <2 mm sizes. Fifty grams of each soil with respective treatments were taken in a plastic bottle (10 cm height and 4 cm diameter). The four different doses of 0, 10, 20 and 30 t ha^{-1} of basic slag (BS) were selected for this incubation study. Three moisture regimes were assessed such as (a) Moisture at field capacity; (b) Moisture at saturated condition; and (c) Wetting-drying cycle (from saturation towards field capacity). In wetting-drying cycle, the soil samples were kept open under saturated condition for the first 15 days and then, the saturated soils were kept at room temperature for natural air drying towards field capacity for the next 30 days. This cycle of wetting-drying was continuously repeated within every one and half months and maintained up to the end of the incubation period of 30 months.

The experiment was conducted under room temperatures of 25 to 30^{0}C). The bottles having the treated soils were kept in aerated condition and the desired level of moisture was maintained by the addition of distilled water when required. The soils were sampled in order to analyses the element dynamics at 0, ½, 1$^1/_2$, 2, 3, 3$^1/_2$, 4$^1/_2$, 5, 6, 9, 12, 15, 21, 27 and 30 months after incubation. And for this, there were 15 sets of bottles and each set contained 24 bottles, i.e. the numbers of total bottles were 360 for this experiment.

The soils were analyzed (Table 1) for textural class (pipette method)[9]; pH (field, 1:2.5 water and 0.02 M $CaCl_2$)[10], ECe[11], organic carbon (wet combustion with $K_2Cr_2O_7$)[12], available nitrogen (micro-Kjeldhal method)[10], available phosphorus (0.02 N H_2SO_4, .

Table 1 Selected properties of the soils (0-20 cm depth) used for the study.

Soil properties	Sarisabari soil	Purbapukuria soil
Texture	Silty clay loam	Silty clay loam
Moisture at field condition (vol. %)	48	49
Soil pH (Field)	3.8	4
Soil pH (Soil:Water = 1: 2.5)	3.6	3.9
Soil pH (Soil:0.02 M $CaCl_2$ = 1.2.5)	3.3	3.4
Pyrite content (%)	7.3	6.6
Electrical Conductivity (1: 5 dS m^{-1})	18.5	19
Organic matter (Wet oxidation, g kg^{-1})	39.1	30.7
Available nitrogen (1.3 M KCl, mM kg^{-1})	3.6	3.3
Available phosphorus (0.02N H_2SO_4, mM kg^{-1})	0.1	0.11
CEC (1 M NH_4Cl: $cmol_c$ kg^{-1}, at pH 7.0)	17.2	18.5
Aluminium-saturation (1M NH_4Cl: %)	40.3	41.2
Iron-saturation (1M NH_4Cl: %)	8.3	7.1
Sodium-saturation (1M NH_4Cl: %)	12.4	13
Potassium-saturation (1M NH_4Cl: %)	1.4	1.6
Calcium-saturation (1M NH_4Cl: %)	1.8	1.9
Magnesium-saturation (1M NH_4Cl: %)	5.5	6.2
Water-soluble ions		
Sodium (Flame photometry: $cmol_c$ kg^{-1})	3.01	3.2
Potassium (Flame photometry: $cmol_c$ kg^{-1})	0.3	0.25
Calcium (*AAS: cmol kg^{-1})	0.3	0.37
Magnesium (AAS: $cmol_c$ kg^{-1})	3.34	3.43
Iron (AAS: $cmol_c$ kg^{-1})	0.35	0.31
Aluminium (AAS: $cmol_c$ kg^{-1})	2.1	1.9
Sulfate ($BaCl_2$, : $cmol_c$ kg^{-1})	4.86	4.2

*Atomic Absorption Spectrophotometer

spectrophotometry at 880 nm wave length)[13], exchangeable cations[10] such as Na^+, K^+ (flame photometry), Ca^{2+} and Mg^{2+}, Fe^{2+}, Mn^{2+}, Al^{2+} (atomic absorption spectrophotometry) [14], CEC[15]. Pyrite content was determined from the total Fe content {(Fe content/46.7) x 100, i.e., FeS_2 was considered to contain 46.7% Fe} in the ASSs.

Results and Discussion

Changes in soil pH: A wide-ranging and significant ($p \leq 0.05$) changes in soil pHs of both the soils at Sarisabari and Purbapukuria were recorded by the treatments of basic slag and moisture levels (Fig. 1). Both the soils were found to reach the lowest pH values under the condition of moisture at field capacity as compared with those obtained from the conditions of saturated and wetting-drying cycles.

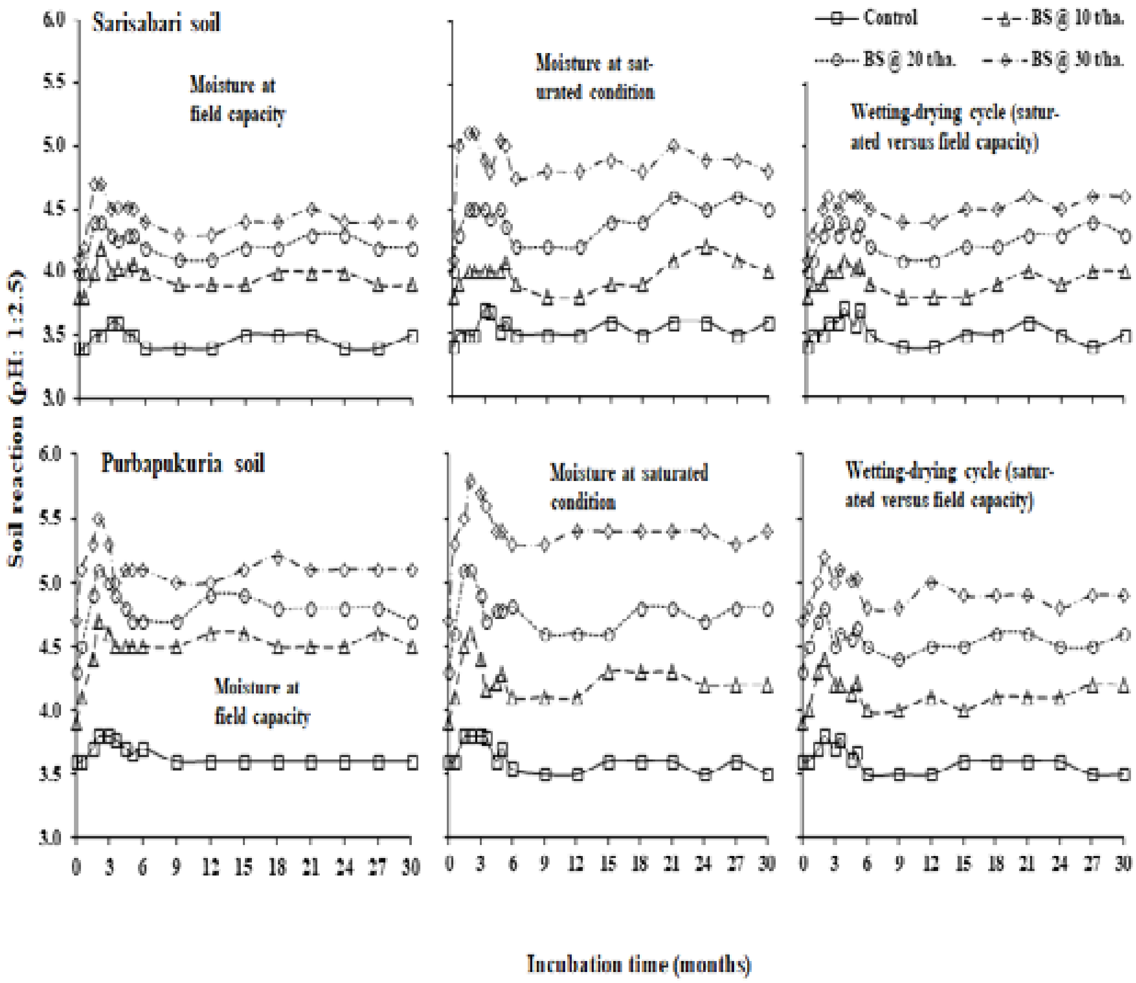

Fig. 1. Consequences of basic slag (BS) on soil reaction (pH) in two acid sulfate soils under various moisture conditions during 30 months of incubation time[16].

This phenomenon could be attributed to more oxidized conditions in field capacity than those of the other soil conditions and the results are quite similar with the findings of Sullivan *et al.*[17], and Isbell and National Committee on Soils and Terrain[18]. As the release of acidic materials occurred from the breakdown of pyrite in more oxidized acid sulfate soil, more liming materials were needed to neutralize more acidity in both the soils. Basic slag at the rate of 30 t ha^{-1} was recorded to be the best dose with respect to increment in soil pHs than those of the other lower doses of 20 and 10 t ha^{-1}. In case of control (0 t ha^{-1} of basic slag), except for several initial increasing trends within the first five months (0.1 to 0.2 units raise of pH), the almost unchanged values of soil pHs were found in both the soils throughout the 30 months of incubation. But the application of BS was found to increase the soil pH linearly with their increased doses regardless of moisture contents and soil conditions. Khan *et al.*[19] reported that the application of basic slag at the rate of 12 t ha^{-1} in acid sulfate soils increased the soil pH from 5.3 to 7.4. The rise of soil pH in the present study also remained almost in similar range, which might be due to the formation of insoluble sulfate compounds such as gypsum, akaganeite[20].

The saturated conditions in both the soils might protect the pyrite from more oxidation, which will result in less acidity; the soils will require less amount of basic slag to be neutralized as well as induce more increment of soil pH than those of the low moisture content of the soils. The maximum values of soil pHs were determined in Sarisabari soils where the soil pHs ranged from 4.2 to 4.7, 4.8 to 5.1 and 4.3 to 4.6 by the basic slag treatment of 30 t ha^{-1} under the moisture at field capacity, saturated condition and wetting-drying cycle, respectively (Fig. 1). In Purbapukuria soil, the values of soil pHs ranged from 5.1 to 5.8, 5.1 to 5.5 and 4.8 to 5.2 by the same doses of BS treatments under the same moisture conditions as in Sarisabari soils. In wetting-drying cycle, the soil pH was found to be increased during wetting, while decreased during drying period of incubation in both the soils. The higher values of soil pHs were found in Purbapukuria soil than those of Sarisabari soil, which might be due to the initial contents of the lower amounts of potential acidity as compared with Sarisabari soils (Table 1). The neutralizing capacity of BS by releasing basic elements in the acid soil solution was found to be best after 2 months of incubation in each of the moisture conditions and treatments under both the soils. And then the pH values were noted to be decreased again up to 6 months of incubation and later on those values of soil pHs were recorded to remain almost the same with the passage of time. The initial increments of soil pHs might be due to the quick release of soluble basic ions which reacted with the amount of acids formed from the acid sulfate soils that resulted the increment of the soil pH after neutralization. With the passage of time, the productions of acids were occurred and the acids reacted with the slow released basic ions from the BS and holds the steady increments of soil pHs. In Sarisabari soils, the highest values of soil pH was recorded as 4.7, 5.1 and 4.6 by the treatments of 30 t ha^{-1} under the moisture conditions of field capacity, saturated and wetting-drying cycle, respectively. While in Purbapukuria soil having the same conditions, the pH values were 5.8, 5.5, and 5.2, respectively. In comparison to the control (pH 3.6 for Sarisabari and 3.9 for Purbapukuria soils at 0 month) with the final stage (30 months), the pH values were found to be increased by about 1.0, 1.5 and 1.2 units in Sarisabari soils and 2.0, 1.7 and 1.5 units in Purbapukuria soils, both received BS_{30} under the condition of field capacity, saturated and wetting-drying cycle, respectively and followed by the $BS_{20} > BS_{10}$ (Fig. 1). Throughout the incubation period, it was noticed that the strength of basic slag as a liming material was effective for neutralizing the acidity of acid sulfate soils for long time. To maintain a reasonably good conditioned soil for growing crops, the soils should be amended at saturated soil condition followed by the application of BS_{30}. The basic slag was also reported to be effective in increasing soil pH as well as in maintaining a favorable soil condition[6,21].

Water soluble iron: Iron is mostly a pH dependent element and the amount of water soluble Fe was low throughout the incubation time and the quantity was recorded to be decreased with the increment of pH in both the soils as compared with the control (Fig. 2). The lowest amounts of Fe were determined in the soils of high pH as a result of BS_{30} treatment under saturated condition in both the soils followed by the condition of field capacity and wetting-drying cycle. With the BS_{30} treatment, the amounts of Fe after 2 months of incubation were 0.17, 0.19 and 0.21 for Purbapukuria soil and 0.19, 0.20, and 0.21 $cmol_c\ kg^{-1}$ for Sarisabari soil under the moisture at saturated condition, field capacity, and wetting-drying cycle, respectively. After 2 months, the amounts of water soluble Fe were found to be increased slightly and the amounts were reasonably stable after 5 months of incubation, which ranged from 0.21 to 0.23 for Purbapukuria soil and 0.20 to 0.23 $cmol_c\ kg^{-1}$ for Sarisabari soil both received BS_{30} treatments. The steepest fall in the concentrations of the Fe were observed with the application of lime [7,22]. They also reported that the concentrations of K, Ca and Mg were increased while the concentrations of Fe and Mn decreased with the application of basic slag in the acid sulfate soils.

Exchangeable iron: During 30 months of incubation, the content of exchangeable Fe^{+2} ranged from 0.68 to 0.84, 0.68 to 0.84 and 0.71 to 0.84 $cmol_c\ kg^{-1}$ by the BS_{30} treatment and 0.78 to 0.88, 0.75 to 0.88 and 0.76 to 0.88 $cmol_c\ kg^{-1}$ by the BS_{20} treatment in Purbapukuria soil under moisture conditions at field capacity, saturated and wetting-drying cycle, respectively (Fig. 3). At Sarisabari soils, it was ranged from 1.05 to 1.35, 0.98 to 1.35 and 1.03 to 1.35 $cmol_c\ kg^{-1}$ by the BS_{30} treatment followed by 1.06 to 1.38, 1.07 to 1.38 and 1.09 to 1.38 $cmol_c\ kg^{-1}$ by the BS_{20} treatment under moisture conditions at field capacity, saturated and wetting-drying cycle, respectively.

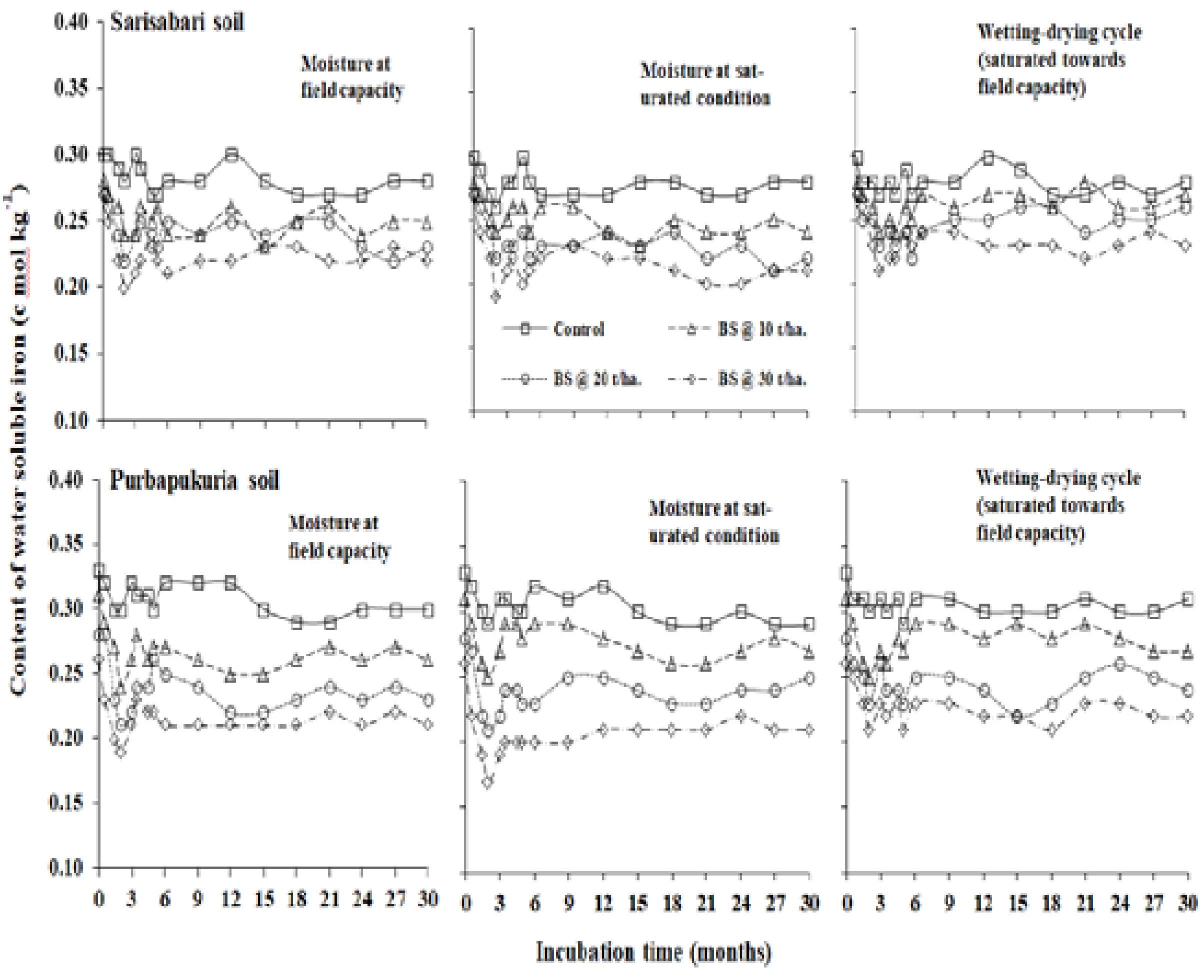

Fig. 2. Effects of basic slag on the statuses water soluble iron under various water contents in two acid sulfate soils of the coastal plains of Cox's Bazar, Bangladesh.

The results revealed that the contents of exchangeable iron decreased a little with time (Fig. 3). The lowest content of Fe^{2+} was determined by the highest dose of BS (30 t ha^{-1}) under saturated conditions in both the soils. And these smallest amounts of exchangeable Fe^{2+} were recorded as 0.70 for Purbapukuria soil and 1.03 $cmol_c$ kg^{-1} for Sarisabari soil after 2 months of incubation (Fig. 3), where the corresponding pH rises at their highest levels of 5.8 at Purbapukuria and 5.2 at Sarisabari soil. At Sarisabari soil, an irregular trend of rise and fall was shown in the amounts of exchangeable Fe^{2+} throughout the incubation period, while under saturated conditions in both the soils. And these smallest amounts of exchangeable Fe^{2+} were recorded as 0.70 for Purbapukuria soil and 1.03 $cmol_c$ kg^{-1} for Sarisabari soil after 2 months of incubation (Fig. 3) where the corresponding pH rises at their highest levels of 5.8 at Purbapukuria and 5.2 at Sarisabari soil.

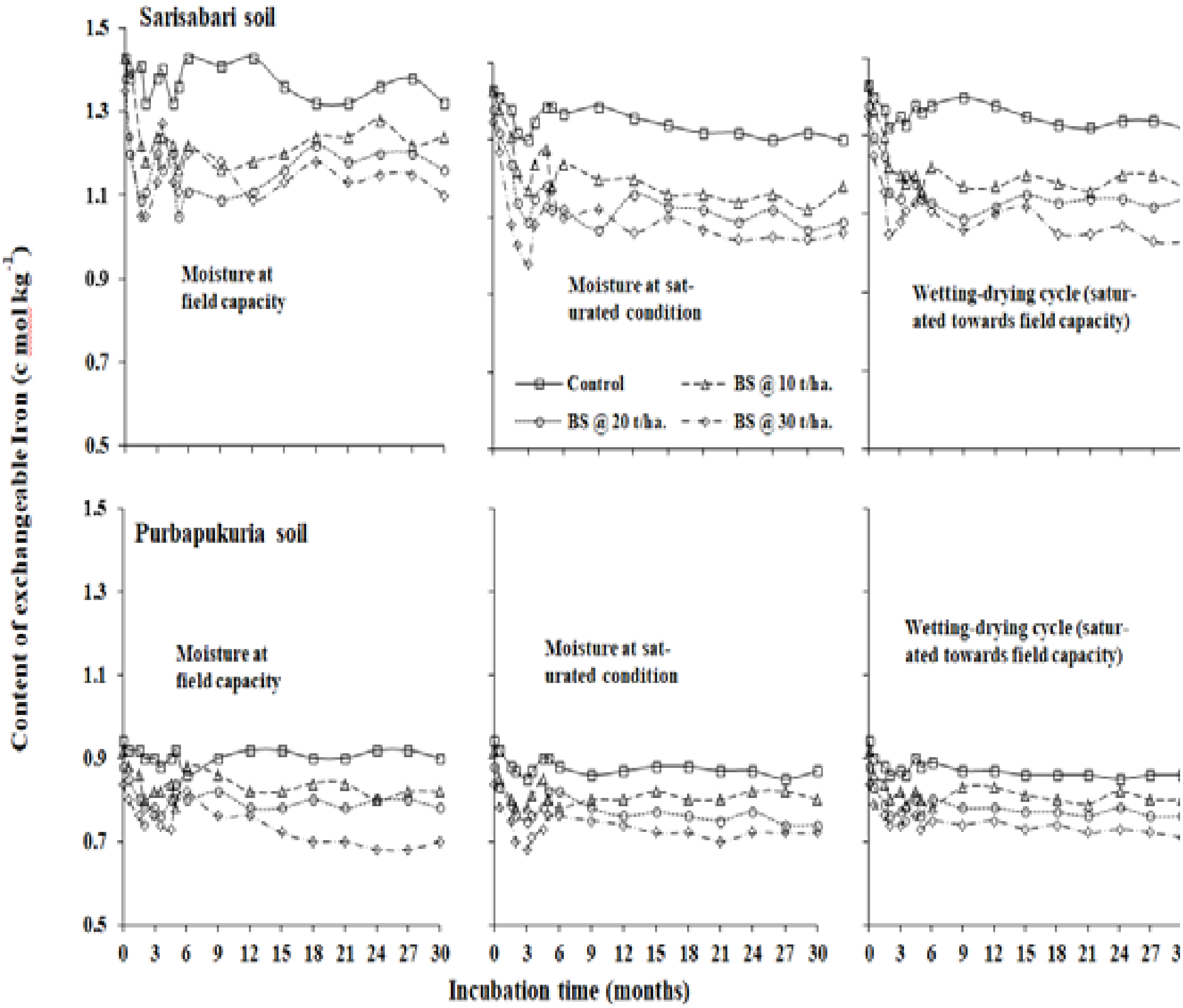

Fig. 3. Consequences of basic slag (BS) on exchangeable iron contents in two acid sulfate soils under various moisture conditions during 30 months of incubation time.

At Sarisabari soil, an irregular trend of rise and fall was found in the amounts of exchangeable Fe^{2+} throughout the incubation period. After 6 months at Purbapukuria soil, these trends were quite steady till the end of incubation. The steepest fall in the concentrations of the Fe^{2+} were observed with the application of lime(21). They also reported that the concentrations of K, Ca and Mg were increased while the concentration of Fe decreased with the application of basic slag in acid sulfate soils. The content of exchangeable Fe^{2+} was determined to have negative relationship with their corresponding pH values (Fig. 4).

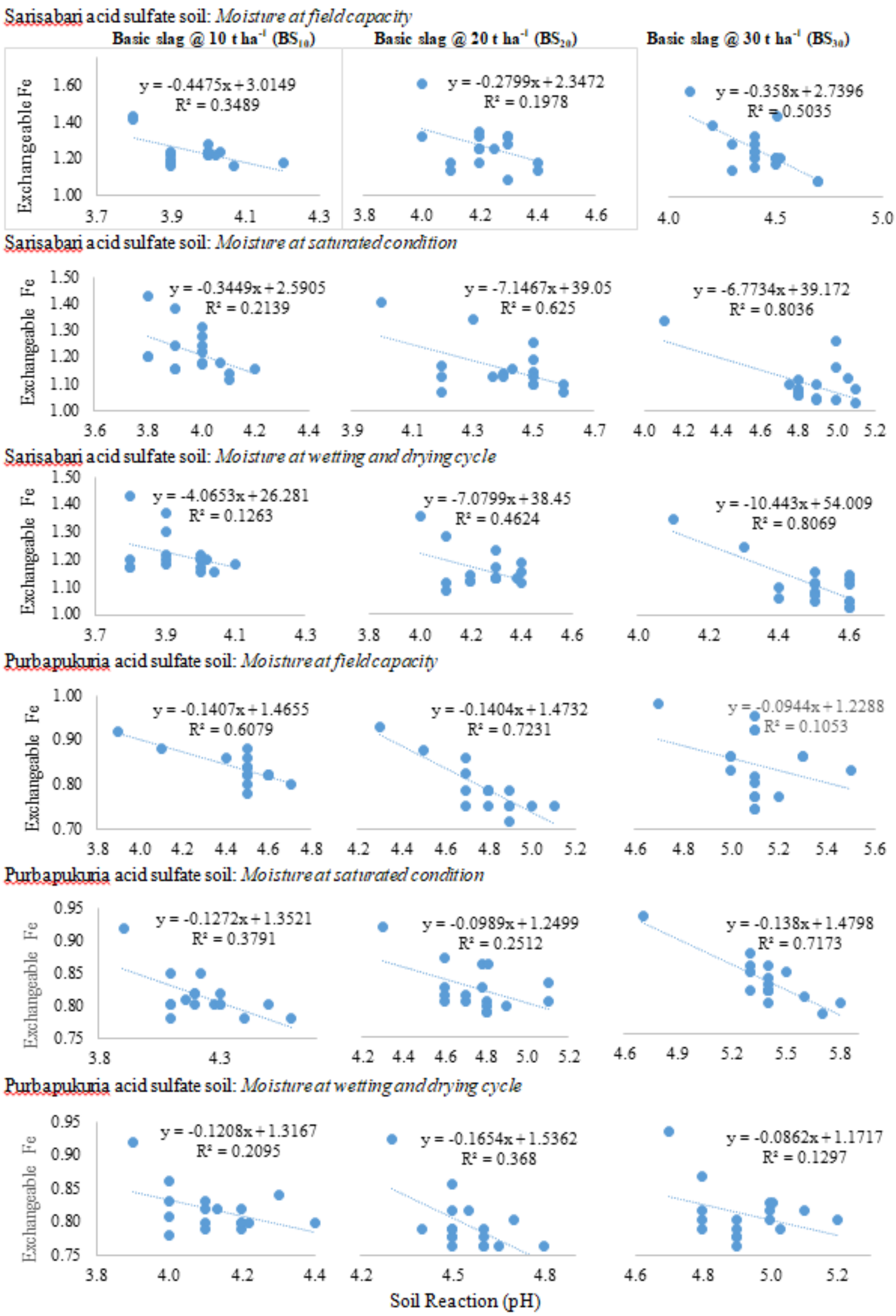

Fig. 4. Relationships between soil pHs and exchangeable Fe contents in two acid sulfate soils during 30 months of incubation with different rates of basic slag under various moisture levels.

Correlation studies between the selected parameters during 30 months of experiment demonstrated that the soil pH was found to have strong positive relationship with time and the effect was more pronounced with Sarisabari soil (Table 2). While the Fe contents showed strong negative relationship with the corresponding pHs of the soils and these effects were more pronounced with Sarisabari soils.

Table 2. Pearson correlation coefficient (r) and probability (p) values between pH and exchangeable Fe contents in two acid sulfate soils during 30 months of incubation under various moisture conditions.

Treatment	Moisture at field capacity		Moisture at saturation		Moist. at wetting-drying cycle	
Sarisabari acid sulfate soil						
Denotation	r value	p value	r value	p value	r value	p value
#BS_{10}	-0.5906**	0.0125	-0.4625NS	0.0616	-0.3652NS	0.1494
BS_{20}	-0.4448NS	0.0736	-0.5302*	0.0286	-0.3979NS	0.1137
BS_{30}	-0.7096***	0.0014	-0.5553*	0.0207	-0.7821***	0.0002
Purbapukuria acid sulfate soil						
BS_{10}	-0.7797***	0.0002	-0.6157**	0.0085	-0.4577NS	0.0647
BS_{20}	-0.8503***	0.0001	-0.5012*	0.0404	-0.6067**	0.0098
BS_{30}	-0.3246NS	0.2037	-0.8470***	0.0001	-0.3602NS	0.1555

#BS = Basic slag, applied at rates of 10, 20 and 30 t ha^{-1}.

The present findings conclude that the application of BS in ASSs were found to be increased the soil pH by about 1.2 to 2.2 units irrespective of moisture conditions and followed the order of increment of soil pH is BS_{30}>BS_{20}>BS_{10}. The high contents of Fe in the ASSs were decreased strikingly by the higher doses of BS suggested that the amelioration of acid sulfate soils by the application of basic slag is a sustainable reclamation and improvement measures regarding Fe toxicity of the soils. The application of BS_{30} under saturated soil moisture condition was the most suitable practice to decrease pHs and Fe contents in both the ASSs followed by moisture at field capacity and wetting-drying cycle.

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