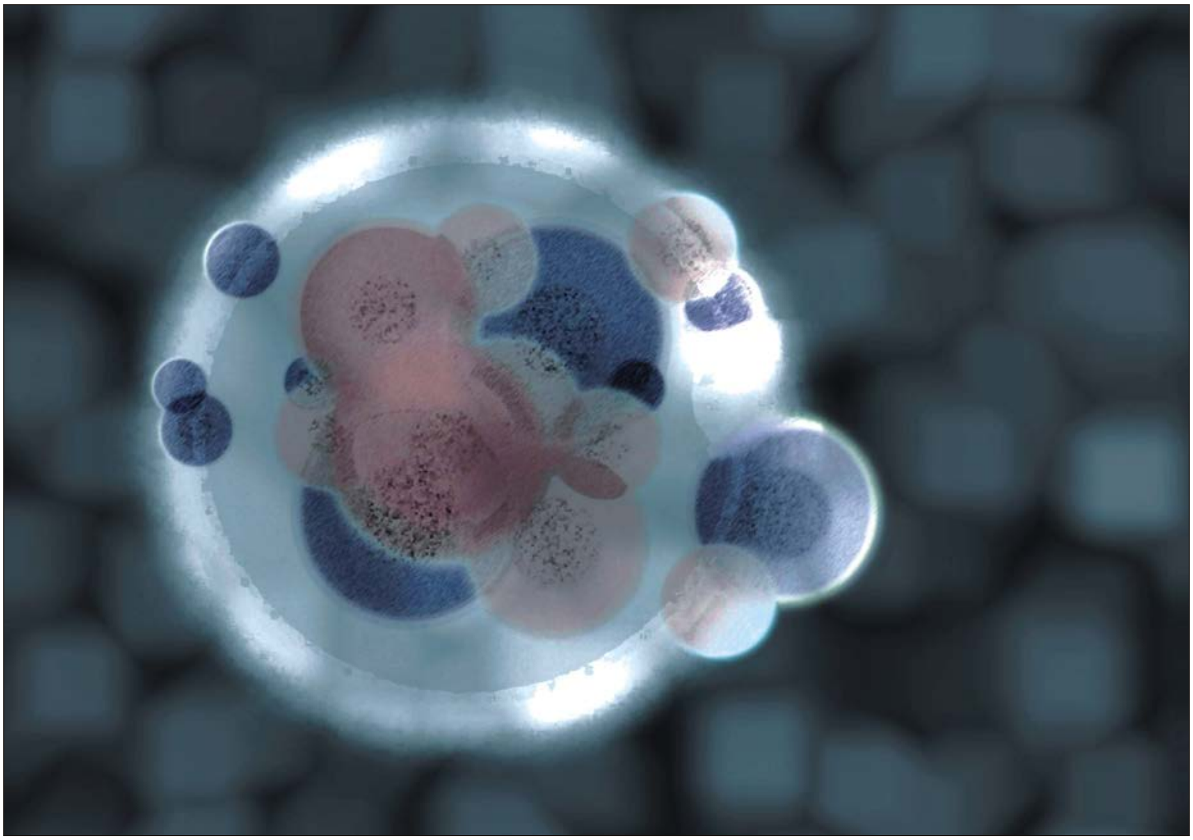

Journal of Biological Sciences

ISSN 1727-3048

Journal of Biological Sciences 7 (6): 896-903, 2007
ISSN 1727-3048

Consequences of Basic Slag on Soil pH, Calcium and Magnesium Status in Acid Sulfate Soils Under Various Water Contents

[1,2]Md. Harunor Rashid Khan, [2]Md. Mukaddas Ali Bhuiyan, [2]Syed Monzur Kabir,
[3]Hans-Peter Blume, [1]Yoko Oki and [1]Tadashi Adachi
[1]Department of Environmental Management Engineering,
Faculty of Environmental Science and Technology, Okayama University, Okayama, Japan
[2]Department of Soil, Water and Environment, University of Dhaka, Dhaka, Bangladesh
[3]Institute for Plant Nutrition and Soil Science, University of Kiel, Kiel, Germany

Abstract: Consequences of Basic Slag (BS) on soil pH, Ca and Mg status in acid sulfate soils under various water contents were studied for 30 months. The four doses of BS at the rates of 0, 10, 20 and 30 t ha^{-1} and three levels of water contents such as: (a) moisture at field capacity (50% water), (b) moisture at saturated condition (100% water) and (c) wetting-drying cycle (from saturation versus field capacity) were considered for this incubation study. Basic slag at 30 t ha^{-1} was found to be the best dose in order of the increment in soil pH, followed by the lower doses of BS_{20}>BS_{10}. The BS_{30} treatment increased the soil pH values by about 1.0, 1.5 and 1.2 units more compared with the control in the Sarisabari soil and 2.0, 1.7 and 1.5 units more in the Purbapukuria soil under the conditions of field capacity, saturated and wetting-drying cycle, respectively. Apart from the water contents and soil conditions, the values of soil pH were also increased significantly ($p \le 0.05$) at different periods of incubation compared with the control. Like soil pH, almost similar to and significant ($p \le 0.05$) increased levels of Ca and Mg were determined in both the soils; regardless of water contents and incubation time. The striking changes were recorded for the rate of increments of Ca and Mg, which were 4 to 5 times higher for Ca and more than 2 times higher for Mg compared with the control after 2 months of incubation. These results suggest that the application of basic slag not only increased the Ca to the higher amount than the increment of Mg in the soils but also improved one of the important criteria of imbalance between Ca and Mg status in the soils.

Key words: Acid sulfate soils, basic slag, calcium and magnesium status, water contents, incubation period

INTRODUCTION

Deficiency in plant base minerals especially Ca and Mg is an important factor when the reclamation and management practices are performed in acid sulfate soils (ASSs: Takai *et al.*, 1992; Jintaridth, 2006). Khan *et al.* (2006a) reported that the application of Basic Slag (BS) in ASSs significantly increased soil pH, Ca and Mg with an associated decrease in Na, Fe and Al concentrations over time. The composition and use of BS for the reclamation of ASSs were found to be harmless in Bangladesh since 1985 (Khan *et al.*, 2006b). The ASSs can cause severe environmental degradation (http://www.epa.vic.gov.au). It has been recently estimated that these affect some 100 million hectares (M ha) of land world-wide (Sheeran, 2003). Since the sulfide layers in ASSs can exert severe effects on surrounding ecosystems, immediate steps should be taken to consider these soils (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). The reclamation of these soils may be difficult but essential (Khan *et al.*, 2006b). 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.

Cook *et al.* (2006) reported that the progressive oxidation of organic matters, sulfides and increasing acidity in the profile of ASS is not only decreasing 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. One of the important problems in the coastal ASSs is its high Mg

Corresponding Author: Md. Harunor Rashid Khan, Department of Environmental Management Engineering, Faculty of Environmental Science and Technology, Okayama University, Okayama, Japan
Tel/Fax: +81-86-251-8993

than Ca contents as a result of progressive clay disintegration and release of Mg (Khan *et al*., 1993). On the other hand, water management in ASSs is the key to soil management and proper water management can limit acidification. Accordingly, for proper management, reclamation and use of ASSs require extensive studies (Dent and Pons, 1995). Against this background, the potentiality and effectiveness of basic slag for the rise of soil pH, the availability of Ca and Mg and the improvement of the vital problem of ionic imbalance between Ca and Mg in ASSs were considered to examine under different water contents.

MATERIALS AND METHODS

Sampling site: The series of Badarkhali and Cheringa ASSs occur in the coastal old mangrove floodplain areas were collected, respectively from Purbapukuria of Badarkhali and Sarisabari of Dulhazara in the Cox' Bazar district of Bangladesh (Fig. 1). Both the sites enjoy

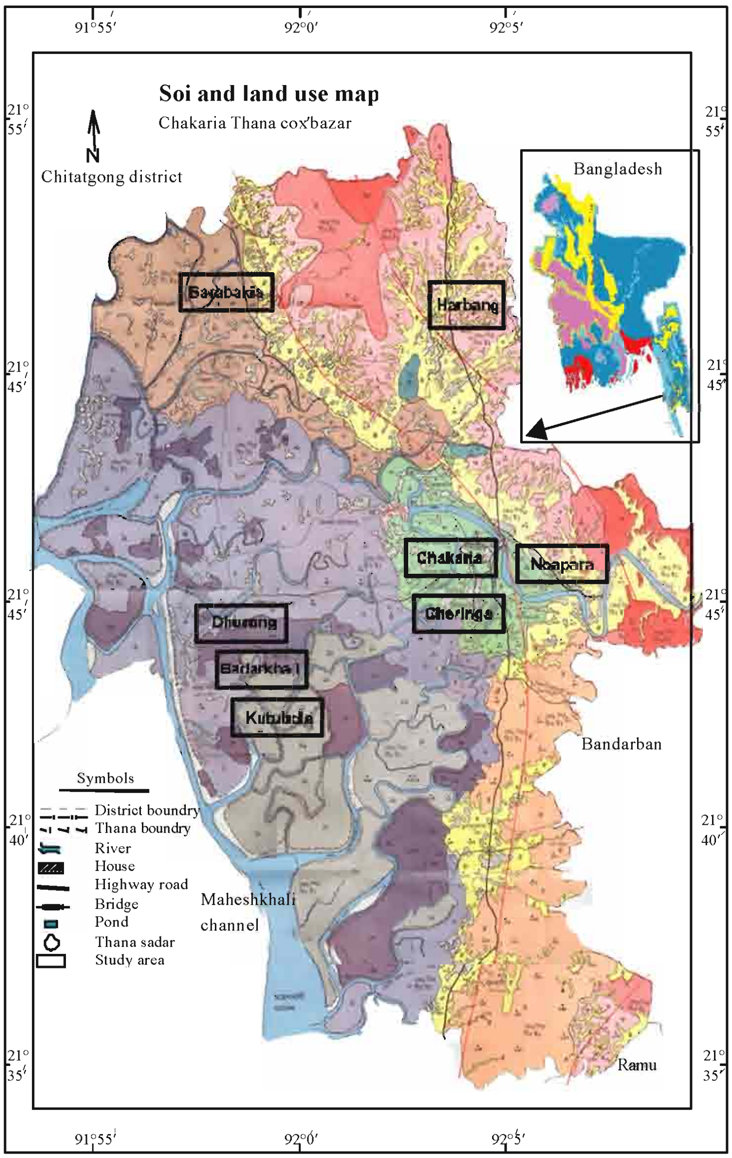

Fig. 1: Site map of the study area in Cox' Bazar, Bangladesh

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. These areas in Bangladesh were 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 acid sulfate soils have become actual acid sulfate soils 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 flood waters, 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 having the acid forming jarosite layer at different depths. Among these, the Purbapukuria (Badarkhali series) and Sarisabari (Cheringa series) ASSs were selected for further basic researches. Accordingly, the consequences of BS in the ASSs under various water contents were studied in a Laboratory of the Department of Soil, Water and Environment, University of Dhaka, Bangladesh during 2001 to 2003. The surface layer (0-20 cm) of the Purbapukuria and Sarisabari ASSs were collected during March, 2001. Both the soil series had a silty clay loam texture and contained yellow mottles of jarosite throughout the studied layers (Table 1). Selected physical and chemical properties of these soil layers were analyzed according to the methods of Klute (1986) (Table 1). Based on the field and laboratory investigations (Kabir, 2005), both soil series were classified into the Inceptisol order, Aquept suborder and Salidic Sulfaquept (Purbapukuria soil: Badarkhali series) and Typic Sulfic Halaquept (Sarisabari soil: Cheringa series) great group, according to the USDA Soil Taxonomy.

These soil samples were air-dried and grounded uniformly into <2 mm sizes. Fifty grams of each soil and its' respective treatments of water content and BS were taken in a plastic bottle (10 cm height and 4 cm diameter). The four doses of BS at the rate of 0, 10, 20 and 30 t ha^{-1} and three levels of water contents such as: (a) moisture at field capacity (50% water), (b) moisture at saturated condition (100% water) and (c) wetting-drying cycle (from saturation versus field capacity) were considered

Table 1: Some selected physical and chemical properties of soils used (0-20 cm depth)

	Values	
Properties	Purbapukuria soil	Sarisabari soil
Textural class	Silty clay loam	Silty clay loam
Bulk density ($Mg\ m^{-3}$)	1.10	1.03
Moisture under field condition (Vol.%)	46.00	49.00
Soil pH (Field; Soil:Water = 1:2.5)	4.20	3.90
Soil pH (Dry Soil:Water = 1:2.5)	3.90	3.60
Soil pH (Soil: 0.02 M $CaCl_2$ = 1:2.5)	3.40	3.20
#Pyrite content (%)	6.60	7.30
EC (1:5 Water) ($S\ m^{-1}$)	1.60	1.90
Organic Carbon (Wet oxidation, $K_2Cr_2O_7$) ($g\ kg^{-1}$)	18.20	23.40
C/N ratio	15.00	16.50
Available N (1.3 M KCl, Kjeldahl) ($m\ mol\ kg^{-1}$)	3.27	3.65
Available P (0.002N H_2SO_4, pH 3) ($m\ mol\ kg^{-1}$)	0.11	0.10
CEC (1 M NH_4Cl) ($cmol\ kg^{-1}$)	19.60	18.20
Base saturation at pH 7.0 (%)	24.90	22.20
Al-saturation (1 M KCl) (%)	43.20	42.40
Fe-saturation (1 M NH_4Cl) (%)	7.80	8.30
Na-saturation (1 M NH_4Cl) (%)	14.80	13.40
K-saturation (1 M NH_4Cl) (%)	1.50	1.40
Ca-saturation (1 M NH_4Cl) (%)	2.00	1.80
Mg-saturation (1 M NH_4Cl) (%)	6.60	5.60
Water soluble ions: ($cmol\ kg^{-1}$)		
Sodium (flame photometer)	4.09	4.84
Potassium (flame photometer)	0.18	0.21
Calcium (ASS*)	0.33	0.27
Magnesium (ASS)	3.66	3.34
Aluminum (ASS)	1.84	2.12
Iron (ASS)	0.30	0.33
Chloride (0.05 N $AgNO_3$)	3.60	3.86
Sulfate ($BaCl_2$, Spectrophotometry)	4.12	4.96

#Pyrite (FeS_2) content was calculated from the total content of Fe {(Fe content/46.7) × 100, i.e., FeS_2 was considered to contain 46.7% Fe} in the acid sulfate soils. *AAS = Atomic Absorption Spectrophotometer

Table 2: Comparison on soil pH, calcium and magnesium at selected incubation periods as influenced by the treatments of basic slag and water contents

	Sarisabari soil			Purbapukuria soil		
Treatments	Average water content (W)			Average water content (W)		
Average soil pH of all treatments	[a]FC	[b]SS	[c]WDC	FC	SS	WDC
Control	3.4c[#]	3.4c	3.4c	3.6c	3.6c	3.6c
Average pH at different incubation times (months)						
0 month	4.0b	4.0b	4.0b	4.3b	4.3bc	4.3b
2 months	4.4a	4.5a	4.3a	5.1a	5.2a	4.8a
6	4.2ab	4.3ab	4.2a	4.8ab	4.7b	4.4ab
15	4.2ab	4.4a	4.2a	4.9a	4.8ab	4.5ab
30	4.2ab	4.4a	4.3a	4.8ab	4.8ab	4.6ab
Mean-W	4.2m	4.3m	4.2m	4.8m	4.8m	4.5mn
LSD at 5%=	0.4	0.4	0.4	0.5	0.5	0.5
Average calcium content (cmol kg^{-1})) of all treatments						
Control	0.29d	0.29d	0.29d	0.31d	0.31d	0.31d
Average Ca at different incubation times (months)						
0 month	0.53c	0.53c	0.53c	0.53c	0.53c	0.53c
2 months	1.12a	1.20a	1.13a	1.32a	1.33a	1.23a
6	0.96b	1.08b	1.01b	1.15b	1.13b	1.10b
15	0.96b	1.11ab	0.99b	1.15b	1.11b	1.09b
30	0.95b	1.11ab	1.01b	1.14b	1.09b	1.09b
Mean-W	0.9y	1.01x	0.93xy	1.06x	1.04x	1.01x
LSD at 5%=	0.1	0.1	0.1	0.1	0.1	0.1
[d]IOC (%) after 32 m	228	283	248	268	252	252
Average magnesium content (cmol kg^{-1})) of all treatments						
Control	1.41d	1.41c	1.41c	1.10c	1.10c	1.10c
Average Mg at different incubation times (months)						
0 month	2.10c	1.92b	2.10b	1.66b	1.66b	1.66b
2 months	3.27a	3.37a	3.18a	2.85a	2.91a	2.69a
6	2.84b	3.12ab	2.99ab	2.59ab	2.63ab	2.48ab
15	2.79b	3.12ab	2.94ab	2.68a	2.67ab	2.47ab
30	2.81b	3.13ab	2.97ab	2.63ab	2.69ab	2.50a
Mean-W	2.76xy	2.93x	2.84x	2.48x	2.51x	2.36xy
LSD at 5%=	0.3	0.3	0.3	0.3	0.3	0.3
IOC (%) after 32 m	99	122	111	139	145	127

[a]FC = Field Capacity, [b]SS = Saturated Soil, [c]WDC = Wetting Drying Cycle. [d]IOC = Increased Over Control. [#]In a column and row, means followed by a common letter(s) are not significantly different at 5% level

for this incubation study. In wetting-drying cycle, the soil samples in the bottles were kept open to air under saturated condition for 15 days at room temperatures (25 to 30°C) for natural air drying towards field capacity for the next 30 days. The wetting-drying cycle was continuously repeated within every one and half months and maintained up to the end of the incubation period of 30 months.

The desired levels of water contents in the soils in each bottle were maintained by the addition of distilled water (pH 6.7, EC 0.05 S m^{-1}) when required. The soils were sampled in order to analyses the soil pH, calcium and magnesium contents 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. There were 15 sampling times and two replications for each 4 doses of BS and 3 levels of water treatments, i.e., each sampling set contained 24 bottles and the total number of bottles was 360 for this experiment. The level of significance of the different treatments was determined at different periods of incubation using Duncan's New Multiple Range Test (DMRT) and Least Significant Difference (LSD) techniques (Zaman *et al*., 1982). The selected typical analyses obtained during 0, 2, 6, 15 and 30 months after incubation are presented in Table 2.

RESULTS AND DISCUSSION

Changes in soil pH: Strong significant ($p \leq 0.05$) positive increments in the pH of both the Sarisabari and Purbapukuria soils were determined by the different treatments of BS and water contents compared with the control where no BS was applied but the water content was maintained at field capacity (Fig. 2). The largest values of soil pH ranged from 4.2 to 4.7, 4.8 to 5.1 and 4.3 to 4.6 were determined by the BS 30 t ha^{-1} treatment in Sarisabari soils under the water contents at field capacity, saturated condition and wetting-drying cycle, respectively (Fig. 2). In the similar water conditions in the Purbapukuria soil, the values of soil pH were ranged from 5.1 to 5.8, 5.1 to 5.5 and 4.8 to 5.2 by the same BS

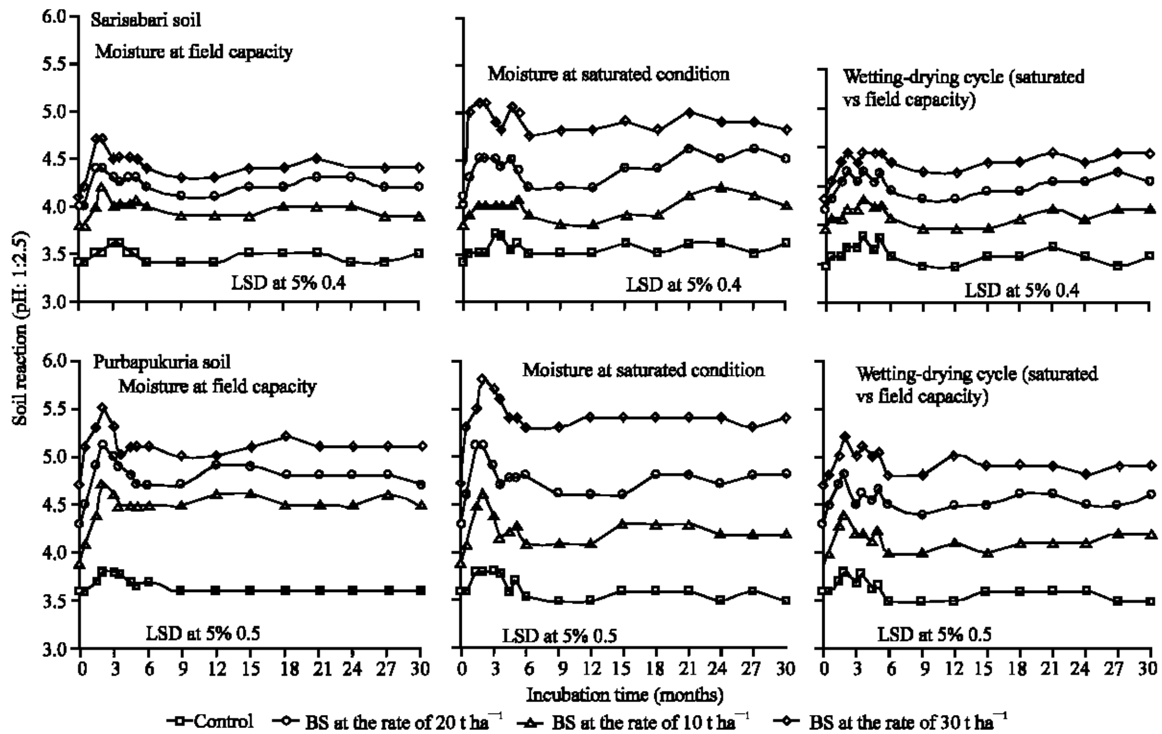

Fig. 2: Effects of basic slag (BS) on soil pH at different periods of incubation with acid sulfate soils under various water contents

treatment. Both the soils were found to be attained the higher pH values under saturated soil condition compared with those values obtained from the treatments of field capacity and wetting-drying cycle. In the wetting-drying cycle, the value of soil pH was found to be increased during wetting while decreased during drying periods of the incubation in both the soils. This might be due to the privilege of more oxidized condition during drying at field capacity than that of the other soil water conditions. The oxidation of pyrite under more dried conditions released more acidity from the ASSs, which required additional liming materials to neutralize the acidity in both the soils. The saturated conditions in both the soils might protected the pyrite from more oxidation and resulted less acidity, which finally required less amount of BS to be neutralized and thus induced the increment of soil pH than that observed for the lower water contents of the soils. Application of the BS increased the soil pH with the higher doses, regardless of water contents and soil conditions. In comparison to the control (pH 3.4 for the Sarisabari and 3.6 for the Purbapukuria soils at 0 month) and BS_{30} treatments in both the soils after 30 months of incubation, the pH values were increased by about 1.0, 1.5 and 1.2 units more in the Sarisabari soil and 2.0, 1.7 and 1.5 units more in the Purbapukuria soil under the conditions of field capacity, saturated and wetting-drying cycle, respectively. These trends were also followed by the BS_{20} and BS_{10} but not so pronounced as that of the BS_{30} (Fig. 2). These higher values of pH in the Purbapukuria soil might be due to its' initial low potential acidity compared with the Sarisabari soil. Khan *et al.* (1996) reported that the application of BS at the rate of 12 t ha^{-1} in ASSs increased the soil pH value from 5.3 to 7.4. Except for the couple of initial months, the rise of soil pH in the present study were also remained almost similar till 30 months after incubation, which might be due to the dilution effect of sulfate and/or in the formation of insoluble sulfate compounds like gypsum, akaganeite (Bigham *et al.*, 1990).

The highest values of soil pH were observed after 2 months of incubation and thereafter it decreased till 6 months of incubation and then remained almost similar with the passes of time, though these values of soil pH were significantly higher than those of the pH values obtained from the control treatment in both the soils. This indicated that the potentiality of BS as a liming material will be effective for the neutralization of the acidity in ASSs for long time. The initial increments of soil pH might be due to the quick release of soluble basic cations that resulted neutralization of acidity in the ASSs and finally increased the values of soil pH. On the other hand, with the passes of time, the production of acids and the processes of neutralization through the release of basic cations from the BS were might be in equilibrium, which helped the increased soil pH in a steady state. Apart from the water contents and soil conditions, the values of soil pH were also increased significantly ($p \leq 0.05$) at different periods after incubation compared with the control where no BS was made (Table 2). Irrespective of BS treatments and incubation times, the saturated soil condition was observed best for the increment of soil pH in both the soil (Table 2). The BS was also reported to be effective in increasing soil pH as well as maintained favorable soil condition (Anderson *et al.*, 1987; Khan *et al.*, 2006b).

Changes in water soluble calcium and magnesium: The amounts of water soluble ions depend on their solubility in water in the soil matrix. Some parts of adsorbed cations and anions are easily dissolved in water but the portions absorbed by soils are not so easily dissolved. The nutrition of plants mainly depends on these water soluble elements in the soil. Moreover, the studied coastal ASSs had high Mg than Ca, which requires improving. Accordingly, the present study was conducted to evaluate the changes in water soluble Ca and Mg at different periods of incubation with the different treatments of BS under variable water contents in order to predict the maximum availability condition and ionic balance between Ca and Mg in the soils for plant growth.

Water soluble calcium: The influences of BS and various water contents regarding to the neutralization of acid sulfate soils were studied and found interesting for the changes in the water soluble Ca content. As the changes of soil pH moved from strongly acid to slightly acidic range (pH 5.5: Donahue *et al.*, 1987), the amounts of water soluble Ca contents in different treatments were also increased strikingly compared to that of the control treatment in both the soils (Fig. 3). The highest contents of Ca were recorded after 2 months of incubation and the values were 1.51, 1.57 and 1.40 cmol kg^{-1} in the Purbapukuria soil and 1.40, 1.50 and 1.42 cmol kg^{-1} in the Sarisabari soils, both the soils received the BS_{30} treatment under the water contents at field capacity, saturated and wetting-drying cycle, respectively. The amounts of soluble Ca contents were increased with the higher rates of BS treatments (Fig. 3). These increments of Ca might be due to the rapid release of Ca from the BS and decomposed organic matter in the soils as a result of their initial crashing process. After that, the trends of availability of water soluble Ca were gradually decreased for several months and then remained almost steady state of Ca status in the soils during 24 to 30 months of incubation. The lower amounts of Ca as determined in the soils after several months might be due to the formation of insoluble Ca compounds like gypsum, akaganeite (Bigham *et al.*, 1990) upon reacting with the acidic

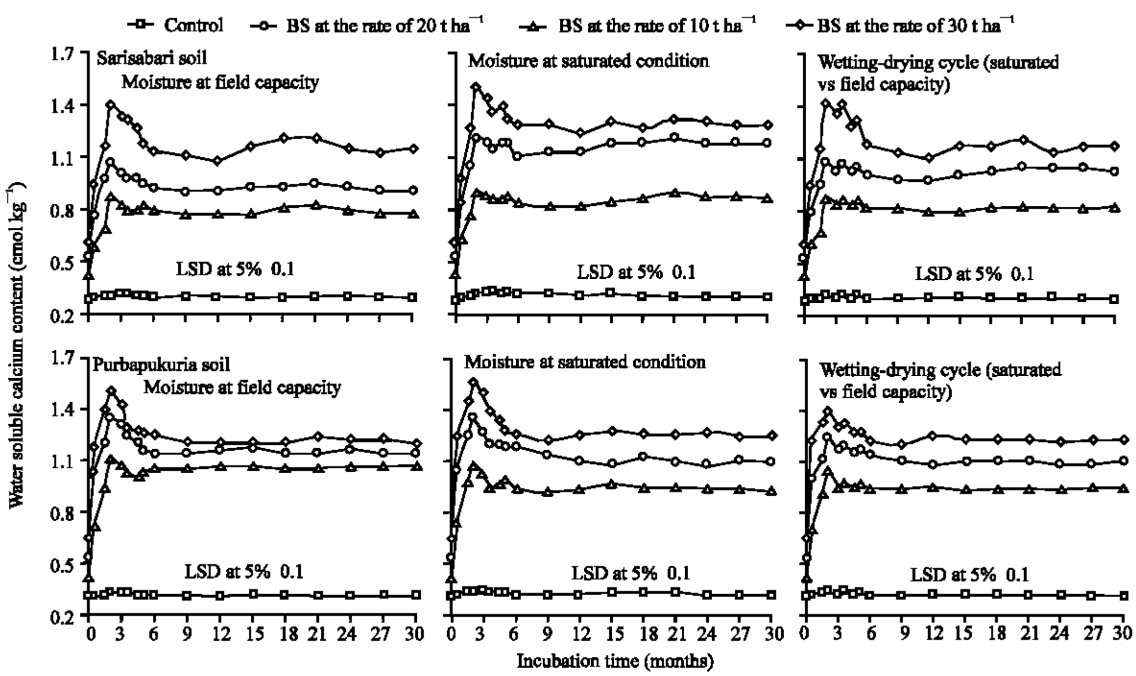

Fig. 3: Effects of basic slag (BS) on water soluble calcium content at different periods of incubation with acid sulfate soils under various water contents

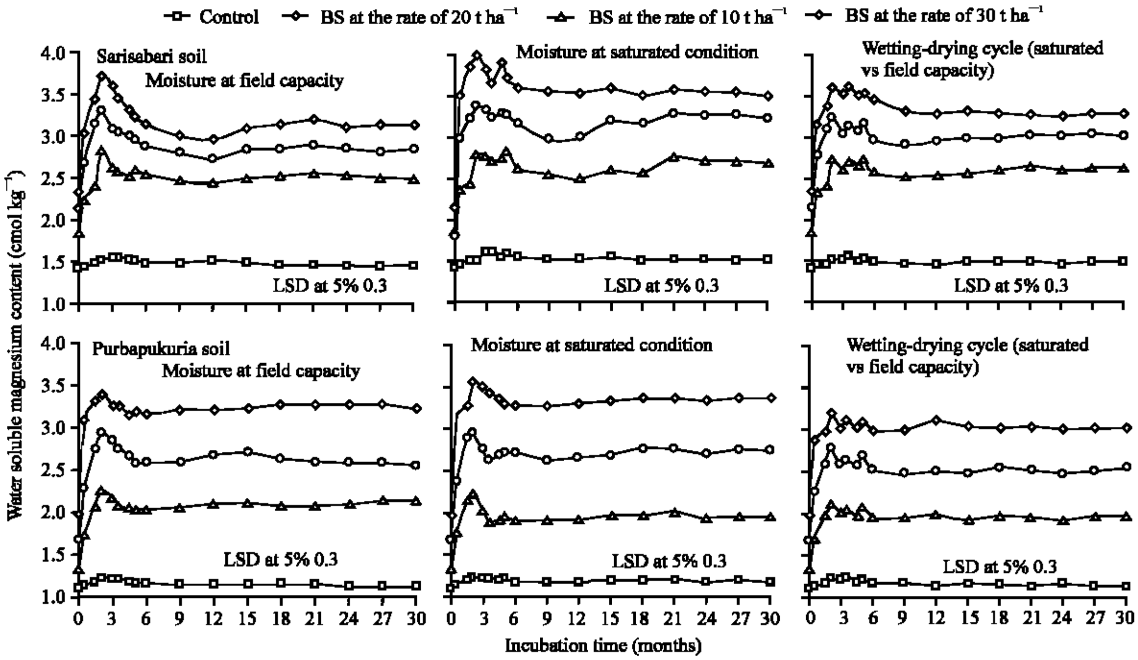

Fig. 4: Effects of basic slag (BS) on water soluble magnesium content at different periods of incubation with acid sulfate soils under various water contents

materials in both the soils. The application of BS was found to be effective for long time (32 months) in order to the increment in Ca content (228-283% IOC = increased over control for Sarisabari soil and 252-268% IOC for Purbapukuria soil), agreeing with the results of Anderson *et al.* (1987) and Khan *et al.* (2006b).

Water soluble magnesium: The contents of water soluble Mg in the studied soils showed almost similar trends as those observed for Ca contents in both the soils (Fig. 4). The highest Mg contents during 30 months of the incubation were obtained after 2 months by the highest rate of BS_{30} treatment and the values were 3.38, 3.56 and 3.18 cmol kg^{-1} at the Purbapukuria soil and 3.71, 3.97 and 3.59 cmol kg^{-1} at the Sarisabari soil under the water contents at field capacity, saturated and wetting-drying cycle, respectively. During 15 to 30 months of incubation, Mg content in the soils was also higher by the same BS_{30} treatment under similar water contents, followed by the BS_{20}>BS_{10} treatments (Fig. 4). The causes of fluctuation in Mg contents were same as those stated for the Ca contents. Like soil pH, almost similar to and significant ($p\leq 0.05$) positive effects of Ca and Mg were determined in both the soils; regardless of water contents and incubation time (Table 2). The striking changes were recorded for the rates of increments of Ca and Mg, which were 4 to 5 times higher for Ca and more than 2 times higher for Mg compared with the control after 2 months of incubation and the effects were more pronounced with the Purbapukuria soil (Table 2). These results suggest that the application of BS was very effective not only for increasing the Ca to higher amount than the increment of Mg but also to improve ionic balance between Ca and Mg, one of the important problems in the ASSs. The present findings have some similarities with the results of several scientists (Khan *et al.*, 1994; Khan and Adachi, 1999).

CONCLUSIONS

The present results conclude that the BS exerted almost similar and significant ($p\leq 0.05$) effects in increasing the soil pH, the availability of Ca and Mg in both the ASSs, irrespective of BS rates, moisture levels and incubation times. The highest dose of BS_{30} under saturated water contents of the soils was observed most effective for the improvement of those parameters of the ASSs after 2 months of incubation, suggesting that these ASSs could be improved under saturated water condition following the application of BS_{30} before a couple of months of crop cultivation. The rate of increment of Ca was almost double compared with the Mg, regardless of BS rates and soil conditions, suggesting that the application of BS was very effective not only for the increase in Ca to the higher amount than the increment of Mg but also to improve ionic balance between Ca and Mg, one of the vital problems in the ASSs.

ACKNOWLEDGMENTS

The study was carried out under the financial and technical support (1998-2005) of the Volkswagen (Ref. 1/73 802, dated 03-08-98) and the Alexander von Humboldt (AvH) foundations, respectively. We are also grateful to the DAAD for providing two sandwich Scholarships for the Ph.D program of S.M. Kabir and M.M.A. Bhuiyan.

REFERENCES

Anderson, D.L., D.B. Jones and G.H. Snuder, 1987. Response of rice-sugarcane rotation to calcium silicate slag on Everglades Histosols. Agron. J., 79: 531-536.

Bigham, J.M., U. Schwertmann, L. Carlson and E. Murad, 1990. A poorly crystallized oxihydroxysulfate of iron formed by bacterial oxidation of Fe (II) in acid mine waters. Geo. Chim. Coso. Acta, 54: 2743-2758.

Cook, T.J., R. Watkins, S. Appleyard and R.J. Vogwill, 2006. Acidification of groundwater caused by a falling water table in a sandy aquifer in the Perth Region, Western Australia. The 18th World Congress of Soil Science Abstract. July 9-15, 2006. Philadelphia, Pennsylvania, USA., pp: 680.

Dent, D.L. and L.J. Pons, 1995. Acid sulfate soils: A world view. Geoderma, 67: 263-276.

Donahue, R.L., R.W. Miller and J.C. Shickluma, 1987. Soils: An Introduction to Soils and Plant Growth. 5th Edn. Prentice-Hall of India Pvt. Ltd., New Delhi- 110001, India, pp: 667.

Jintaridth, B., 2006. The role and effectiveness of Phospho-microorganisms with rock phosphate. The 18th World Congress of Soil Science Abstract, July 9-15, 2006. Philadelphia, Pennsylvania, USA., pp: 681.

Kabir, S.M., 2005. Acid sulfate soil ecosystems and their sustainable management. Unpublished Ph.D Thesis University of Dhaka, Bangladesh.

Khan, H.R., S. Rahman, M.S. Hussain and T. Adachi, 1993. Morphology and characterization of an acid sulfate soil from Mangrove Floodplain area of Bangladesh. Soil Phys. Cond. Plant Growth, 68: 25-36.

Khan, H.R., S. Rahman, M.S. Hussain and T. Adachi, 1994. Growth and yield response of rice to selected amendments in an acid sulfate soil. Soil Sci. Plant Nutr., 40: 231-242.

Khan, H.R., S. Rahman, M.S. Hussain and H.P. Blume, 1996. Response of rice to basic slag, lime and leaching in two saline-acid sulfate soils in pot experiments. Z. Pflanzenernahr Bodenk, 159: 549-555.

Khan, H.R. and T. Adachi, 1999. Effects of selected natural factors on soil pH and element dynamics studied in columns of pyretic sediments. Soil Sci. Plant Nutr., 45: 783-793.

Khan, H.R., M.M.A. Bhuiyan, S.M. Kabir, F. Ahmed, S.M.A. Syeed and H.P. Blume, 2002. The Assessment and Management of Acid Sulfate Soils in Bangladesh in Relation to Crop Production. Chapter 22, In: The Restoration and Management of Derelict Land: Modern Approaches. Wong, M.H. and A.D. Bradshaw (Eds.), World Scientific, www.worldscientific.com, pp: 254-263.

Khan, H.R., S.M. Kabir, M.M.A. Bhuiyan, H.P. Blume, T. Adachi, Y. Oki and K.R. Islam, 2006a. Physico-chemical amendments of acid sulfate soils for rice production in Bangladesh. The 18th World Congress of Soil Science Abstract, July 9-15, 2006. Philadelphia, Pennsylvania, USA., pp: 682.

Khan, H.R., M.M.A. Bhuiyan, S.M. Kabir, Y. Oki and T. Adachi, 2006b. Effects of selected treatments on the production of rice in acid sulfate soils in a simulation study. Jap. J. Trop. Agric., 50: 109-115.

Klute, A., 1986. Methods of Soil Analysis. Agron. Series 9. Am. Soc. Agron., Publ. Madison, WI, USA.

Sheeran, B., 2003. Virotec. International Ltd. www.virotec.com

Takai, Y., P. Vijarnsorn, C. Stittbush, A. Boonson, T. Adachi, S. Matsumoto, M. Okazaki and J. Sugi, 1992. Soil Amelioration Trials in Peat and Acid Sulfate Soils. In: Coastal Low Land Ecosystems in the Southern Thailand and Malaysia. Kyuma, K. *et al.* (Eds.), Publ. By Showado Printing Co., Sakyoku, Kyoto, Japan, pp: 318-335.

Zaman, S.M.H., K. Rahman and M. Howlader, 1982. Simple Lessons from Biometry. Publ. No. 54, Bangladesh Rice Research Institute, Gazipur, Bangladesh.