Impacts of Sulfidic Materials on the Selected Major Nutrient Uptake by Rice Plants Grown in Sulfur Deficient Soils under Pot Experiment

Abul Hasnat Md. Shamim[1, 2], Md. Harunor Rashid Khan[3] and Takeo Akae[1]

[1]Department of Environmental Management Engineering, Faculty of Environmental Science and Technology, Okayama University, Okayama 700-8530, Japan.
[2]School of Agriculture and Rural Development, Bangladesh Open University, Gazipur-1705.
[3]Department of Soil, Water and Environment, Dhaka University, Dhaka-100, Bangladesh.
E-mail: abulhasnats@yahoo.com, duharun@yahoo.com, akae@cc.okayama-u.ac.jp

Abstract: The impacts of sulfidic materials (SM) and Gypsum (G) application at the rates of 0, 40, 80, 120 and 160 kg S ha^{-1} on the selected major nutrient uptake by rice (*Oryza sativa* L.; var. BR 16: Shahi balam) cultivated in two sulfur deficient soils of Sirajgonj (Kamarkhond series) and Gazipur (Kalma series) were evaluated under pot experiment. The contents of N, P, K, Mg and S in rice shoot at different growth stages of rice were increased by the application of SM and G. But the increments were more striking in case of SM compared to G application. In addition, the applied SM increased the average organic matter and available sulfur contents in the soils by 20 to 43 % and 141 to 229 % increased over control (IOC), respectively, while these increments were 6 to 22 % and 88 to 187 % for gypsum treatments, indicating that the SM has potential and proved to be effective compared with gypsum not only as a source of fertilizer but also to enrich the fertility and productivity status of soils. Moreover, the SM treatment was found to be maintained the high nutrient status in both the soils till the final harvest at maturity of rice, reflecting a good indication for its long term use. [The Journal of American Science. 2009;5(2):9-15]. (ISSN: 1545-1003).

Key words: sulfur deficient soils, sulfidic materials, nutrient uptake of rice, pot.

1 Introduction

Sulfur is one of nature's super nutrients and one of the oldest elements known to man. It is the thirteenth most abundant element in the earth's crust. Although S is considered a secondary nutrient, it is often called the forth major nutrient ranking just below nitrogen, phosphorous and potassium (http://www. oznetksu.edu/library/CRPSL2/mf 2264.pdf. 21**)**. Sulfur is usually present in relatively small amounts in soils and a majority is in organic forms. Sulfur deficient soils are often low in organic matter, course-textured, well-drained, and subject to leaching. Recently, it has been reported that a large number of finer textured soils have shown sulfur deficiency. Historically, S was found as impurity in mineral fertilizers. However, current chemical fertilizers contain fewer if any impurities. There has also been a decline in the amount of S supplied through atmospheric deposition due to industrial reductions in SO_2 emissions. According to Environment Canada (2003), SO_2 emissions in Atlantic Canada have been reduced by >50 % for the period 1980 to 2000 (from~3.8 million to~1.6 million Mg yr^{-1}). Due to the reduction of anthropogenic SO_2 emission, the use of high purity fertilizers, and continuous cropping with high-yielding varieties, S deficiencies have been reported in Canada and Europe (MacGrath, et al., 1996; Riley, et al., 2002).

Plant nutrition is only one of more than fifty factors which directly affect both crop yield and quality. The availability of required nutrients, together with the degree of interaction between these nutrients and the soil, play a vital role in crop development. A deficiency in any one required nutrient or, a soil condition that limits or prevents a metabolic function from occurring can limit plant growth (http://www.ecochem.com/t_soil_nutrients.html-21**)**.

Deficiencies of S have become common in Bangladesh and worldwide. About 7 M ha (about 52 %) of agricultural lands are reported to consists of sulfur deficient soils in the northern region of Bangladesh (SRDI, 1999). The current intensive use of agricultural land for crop production has extended the sulfur deficient areas to about 80 % in the Northern region of Bangladesh (Khan, et al., 2007). Poor crop production as a result of acute sulfur deficiency has frequently been reported by many scientists in different regions of India (Tiwari, et al., 1985) and Bangladesh (Khan, 2000).

The use of sulfidic materials (SM) or layers obtaining from acid sulfate soils (ASSs) as sulfur fertilizer for crop production is very scanty. Khan, et al., (2002) reported that the high organic matter (2-9 %), total sulfur (3-7 %) and micronutrients in ASSs or SM deserve attention to use these soil materials for the reclamation of alkaline, calcareous or sulfur deficient soils and also for the amendment for ASSs themselves by the removal of SM from the soil. Khan, et al., (1994) also reported that the ASSs contained high Mg (1.3 to 2.6 c mol kg^{-1}) and Al (1 to 2 c mol kg^{-1}). But the use of high Al contained ASSs or SM did not notice any harmful effects when applied in the soils having pH > 4.5 (Khan, et al., 2002). The present studied SM in an ASS layer, which occupies 0.7 M ha land area, had low pH (< 3), high sulfate and organic matter (Khan, et al., 2006)

The removal of SM from the ASSs is not only reclaimed the ASSs for a long time but its use in sulfur deficient or non-fertile soils at the rate of about 300 to 1500 kg ha^{-1} may improve the fertility and productivity of the soils. Khan, et al. (2007) reported that the application of SM at the rate of 75 kg S ha^{-1} for sulfur deficient soils had no negative effect on soil pH, nutrient status in the soils and Sunflower production. They suggested that the application of SM was not only effective as sulfur fertilizer but also enriched the organic matter in the soils. Moreover, many studies have been conducted on the mineralization of elements such as N, P, and K from animal manures in various climates and soil conditions (Ebeling, et al., 2003; Egrinya-Eneji, et al., 2003; Eghball, et al., 2002; Schmitt, et al., 2001). However, there are relatively few that focus on nutrients such as Ca and S (Egrinya-Eneji, et al., 2003). Against this background, the present study was considered to evaluate the impacts of SM or ASSs compared with gypsum as sulfur fertilizer in relation to rice production in sulfur deficient soils under pot condition.

2. Materials and Methods

2.1 Soil collection and analyses

A large amount of two sulfur deficient soils (surface soil at depth of 0-20 cm) of Kamarkhond series (Sirajgonj soil) and Kalma series (Gazipur soil) were collected from the districts of Sirajgonj and Gazipur, respectively in Bangladesh. The SM (Cheringa acid sulfate soil) used for this study was obtained from the surface soil (depth of 0-20 cm) at Dulahazara in the Cox' Bazar district in Bangladesh. Soils were collected from each replicated pots using Cork borer (2 cm diameter), then air-dried and screened by 1 mm sieve. The soils were oven dried at 105°C before analysis. The particle size distribution of the initial soils was determined by the pipette method (Day, 1965) with 1 M CH_3COONH_4 (pH 5.0) and with 30 % H_2O_2 to remove free salts and organic matter. Soil pH was measured by the soil-water ratio 1:2.5 and for the oven dried soil 0.02M $CaCl_2$ (1:2.5) suspension (Jackson 1973) using a Corning pH meter Model-7. For saturation extract of soils, the electrical conductivity (soil solution has extracted from saturated soil paste through vacuum pump: Richards, 1954), water soluble Na and K (Gallenkamp flame photometry using 589 and 766 nm filters, respectively: Black 1965), Ca^{2+} and Mg^{2+} (Pye UniCam-SP 9 atomic absorption spectrometry: Hesse, 1971) were determined. Organic matter content was determined (Nelson and Somners, 1982) by wet combustion with $K_2Cr_2O_7$. Available N (1.3M KCl extraction, Jackson, 1973), available P (0.002 N H_2SO_4, pH 3 extraction, Olsen, et al., 1954) and available S ($BaCl_2$ turbidity, Sakai, 1978) were determined. Cation exchange capacity was determined by saturation with 1 M CH_3COONH_4 (pH 7.0), ethanol washing, NH_4^+ displacement with acidified 10 % NaCl, and subsequent analyses by steam (Kjeldhal method) distillation (Chapman, 1965). Exchangeable Na^+, K^+, Ca^{2+} and Mg^{2+} were extracted with 1 M CH_3COONH_4 (pH 7.0) and determined by flame photometry (Na^+, K^+) and atomic absorption spectrometry(Ca^{2+}, Mg^{2+}). Total sulfur was obtained by digestion with a mixture of concentrated HCl/HNO_3 (1:3) and determined by turbidity method (Sakai, 1978).

2.3 Pot experiment

A pot experiment was carried out at the premises of the Department of Soil, Water and Environment, University of Dhaka during the period for January to May, 2001 to evaluate the impacts of SM compared with G as a source of sulfur fertilizer in relation to rice production grown in two sulfur deficient soils. Two sets of experiments were set up in a completely randomized design having three replications and three sampling time for each treatment. The experimental treatments on the basis of furrow slice of the soils were: Control, 0 (no application of SM and G); SM_{40}, SM_{80}, SM_{120}, SM_{160} (SM 40, 80, 120, 160 kg S ha^{-1}) and G_{40}, G_{80}, G_{120}, G_{160} (G 40, 80, 120, 160 kg S ha^{-1}).

Six kg of air-dried and screened (5 mm sieve) soil was placed in each earthen pot (size: 36 cm height/28 cm diameter). The soil in each pot was fertilized with N, P and K at the rates of 80, 40 and 60 kg ha^{-1} as urea, triple super phosphate (TSP) and murate of potash (MP), respectively. The full dose of TSP and MP and half of urea were mixed with the soil during pot preparation. The remaining urea was applied in equal splits, one at the active tillering stage of rice and the other at the panicle initiation stage. As per treatments, the soils in the pot were also subjected to the application of SM and G at the rates of 0, 40, 80, 120 and 160 kg S ha^{-1} during pot preparation. Both the SM and G were dried, milled and sieved (1 mm sieve). Thirty days old healthy and uniform seedlings (*Oryza sativa* L., var. BR 16 Shahi balam) were transplanted at the rate of three plants per hill and four hills per pot. The soils in the pots were irrigated by tap water (pH 6.5, EC 0.5 dS m^{-1} and S 0.01 c mol kg^{-1}) whenever necessary to maintain the soil under moist to wet conditions required for the production of rice. Seedlings were collected by the courtesy of Bangladesh Rich Research Institute (BRRI), Gazipur, Bangladesh.

2.4 Plant collection and Analysis

The nutrients content at different stages of growth of rice shoot were determined at 30 (20-35 early tillering stage = ETS), 60 (36-65 maximum tillering stage = MTS) and 110 (harvesting at maturity) days after transplanting (DT). The N contents were analyzed by the H_2SO_4 digestion through the micro-Kjeldhal method (Jackson, 1973) and P contents by spectrometry (Jackson, 1973); K content by Gallenkamp flame photometry (Black, 1965); S contents by turbidometry (Jackson, 1973) and Mg contents by atomic absorption spectrometry (Hesse, 1971) in HNO_3-$HClO_4$ acid (2:1) digest. The level of significance of the different treatments was determined at different stages of growth using Duncan's New

Multiple Range Test (DMRT) and least significance different (LSD) techniques (Zaman, et al., 1982).

3. Results and Discussions

3.1 Sulfidic Materials (SM)

The SM was collected from the surface (depth: 0-20 cm) of an acid sulfate soil (Typic Sulfic Halaquept, detailed: Khan, et al., 2006) showed a silty clay loam texture with pH values of 3.3 (0.02 M $CaCl_2$) and 3.8 (field), indicating that the SM had probably accumulated a large amount of pyrite which had produced H_2SO_4 in the laboratory by oxidation. The EC, available and total sulfur and organic matter content in the SM were very high (Table 1). The content of Ca in SM was low compared with the Mg content, which might be due to occasional flooding with sea water rich in Mg. The Na content was also high due to the flooding with high saline water. The SM was in fact a fertile but unproductive soil due to its high acidity, salinity and imbalance of nutrients.

3.2 Conditions of initial and post harvested soils

The Sirajgonj and Gazipur soil had silty loam and silty clay loam textures, initial pH values of 5.8 to 6.2 and 5.2 to 5.8, respectively as determined by the different conditions. These sulfur deficient soils were subjected to the application of SM and G in relation to rice production. The pH values at different conditions of the average soil data of all the treatments at post harvesting were found to be decreased by 0.1 to 0.3 pH units compared with the initial Sirajgonj and Gazipur soil, indicating that the application of acidic SM on these soils had negligible influences on the pH of the soils. On the other hand, the SM strikingly increased the initial low content of organic matter, N, P, K, Ca, Mg, available and total sulfur in both the soils up to 200 % compared with the initial soils (Table 1), which was due to the high nutrient status of the applied SM though there might be a little contribution from the plant roots. The base saturation of the initial Sirajgonj soil was 74 % which was increased to 80 % at the final harvesting of rice, while this increment was 66 to 72 % for Gazipur soil (Table 1). These increases of base saturation were attributed to the high content of basic cations in the applied SM. The EC values of the soils were found to be increased from 1.1 to 1.8 dS m^{-1} for Sirajgonj soil and 1.3 to 2.2 for Gazipur soil, which are attributed to the higher EC values of the SM used. However, these increased levels of EC values might not have remarkable influence on the production of rice.

3.3 Sulfur and organic matters in the soils

By the application of SM and G, the available S contents of the soils were found to be increased but the effects were more pronounced in case of SM and the increments were significantly ($p \leq 0.05$) stronger with the passes of time. Apart from fertilizer rates, the applied SM and G increased the available S contents by 228 and 187 % IOC for Sirajgonj soil; 140 and 88 % for Gazipur soil, respectively at post harvesting of rice at maturity. The SM exerted better response for the increment of sulfur in both the soils (Table 2). This might be due to the contents of other essential nutrients especially N in SM (Table 1), which enhanced sulfur uptake by the rice compared with the G treated pots. On the other hand, S content was found to be increased by the treatments but decreased by the passes of time was attributed to the uptake of rice plant (Table 2).The content of organic matter in both the soils throughout the experimental period was found to be improved a little by the different rates of gypsum fertilization, whereas almost all the doses of SM significantly increased the organic matter status in the both the soils and the increments were more striking with the higher doses of SM (Table 2). The application of SM increased the average organic matter in the soil by 20 to 43 % IOC at post harvesting of rice at maturity, while these increments were 6 to 22 % for G treatments and the increments were more pronounced in Gazipur soil. These increments in organic matter status in the soils were attributed to the high content of organic matter in the applied SM and the little enrichment of organic matter by the G treatments were attributed to the contribution of cultivation processes.

3.4 Nutrition of rice

The contents of N, P, K, Mg and S in rice shoot at different growth stages of rice were increased by the SM and G application. The increments were more striking in case of SM compared to G application (Table 3). The lowest contents of these nutrients were observed for the control treatments in both the soils. The average S contents in plant tissue of all the SM treatments at the final harvesting (110 DT) of rice were increased by 142 % in the Sirajgonj soil and 108 % in the Gazipur soil compared with the control treatments. But these increments of S by the average of all G treatments were 96 % and 45 % for the rice plants grown in Sirajgonj and Gazipur soils, respectively. These findings suggest that the impacts of SM as S-fertilizer were much higher than G and would also be effective for the subsequent crops as indicated by the high contents of nutrient in rice plants at final harvesting (110 DT) stages. The use of SM from ASSs not only recover S deficiency of rice plants but also enhanced the growth of rice and improved the fertility status of the studied soils compared to gypsum. Moreover, the removal of SM from ASSs may lead the reclamation of acute problem of the ASSs. Khan, et al., (2002, 2007) reported that the nutrient uptake by tomato, onion and sunflower were strikingly increased by the application of SM compared to G and $MgSO_4$.

Table1. Some selected properties of initial soils (depth 0-20 cm, oven dry basis), sulfidic materials and the average soils of all the treatments at post harvesting of rice used during pot experiment

Soil properties	**Sirajgonj soil**			**Gazipur soil**			**Sulfidic Materials ([‡]ASSs)**
	Before use	After use	% [†]IOC	Before use	After use	% IOC	
Textural class		Silty loam			Silty clay loam		Silty clay loam
Soil pH (Field)	6.20	6.10	-	5.80	5.60	-	3.80
Soil pH (Soil:Water=1: 2.	6.10	5.90	-	5.50	5.20	-	3.60
Soil pH ($CaCl_2$=1.2.5)	5.80	5.60	-	5.20	4.90	-	3.30
E C (1: 5 dS m^{-1})	1.10	1.80	63.64	1.30	2.20	69.23	18.50
Organic matter (g kg^{-1})	12.20	16.10	31.97	7.10	9.20	29.58	39.10
Extractable N (mM kg^{-1})	0.23	0.30	30.43	0.20	0.25	25.00	3.60
Available P (mM kg^{-1})	0.10	0.12	20.00	0.12	0.14	16.67	0.10
CEC (c mol kg^{-1})	16.85	17.30	2.67	17.10	17.80	4.09	17.20
Base saturation (%)	74.40	80.20	7.80	66.50	72.10	8.42	24.30
Exchangeable cations (c mol kg^{-1})							
Sodium	0.41	0.75	82.93	0.37	0.65	75.68	2.13
Potassium	0.08	0.15	87.50	0.07	0.14	100.00	0.24
Calcium	6.48	6.63	2.31	6.45	6.62	2.64	0.31
Magnesium	3.98	4.52	13.57	3.61	3.99	10.53	0.95
Water soluble ions (c mol kg^{-1})							
Sodium	0.14	0.19	35.71	0.12	0.21	75.00	3.01
Potassium	0.28	0.40	42.86	0.24	0.32	33.33	0.30
Calcium	6.43	6.66	3.58	3.80	3.94	3.68	0.30
Magnesium	2.88	4.22	46.53	2.64	3.60	36.36	3.34
Available sulfur	0.03	0.09	200.00	0.04	0.10	150.00	24.40
Total sulfur	1.40	1.96	40.00	1.56	2.87	83.97	165.60

[†]IOC = Increased over control, [‡]ASS = Acid sulfate soil

Table 2. Sulfur and organic matter contents of the soils at different growth stages of rice as influenced by the application of sulfidic material (SM: kg S ha^{-1}) and gypsum (G: kg S ha^{-1}) in the sulfur deficient soils.

Treatment	Available sulfur (m M kg^{-1})			Total sulfur (m M kg^{-1})			Organic matter (g kg^{-1})		
denotation	30 DT[†]	60 DT	110 DT	30 DT	60 DT	110 DT	30 DT	60 DT	110 DT
Sirajgonj soil: Silty loam, pH 6.1, Organic matter=12.2 g kg^{-1}, Total S=14.0 and available-S=0.30 m M kg^{-1}									
Control	0.29e	0.29d	0.27e	13f	12.6d	11.2e	15.7c	14.3c	13.8c
SM_{40}	0.38d	0.46c	0.72c	16.1e	14.2d	12.4e	16.4b	15.7b	14.3b
SM_{80}	0.45c	0.57b	0.85b	28.3c	24.5c	25.6c	17.9b	17.1b	16.6a
SM_{120}	0.51c	0.79a	0.96a	38.4b	33.1b	31.9b	19a	18.1a	17.3a
SM_{160}	0.67a	0.82a	1.02a	43.8a	41.2a	40a	20.5a	19.2a	17.8a
G_{40}	0.34e	0.43c	0.55d	14.7e	13.8d	12.6e	15.8c	14.2c	13.9c
G_{80}	0.42d	0.59b	0.76b	21.2d	20.3c	19.4d	16.4b	14.5c	14.3b
G_{120}	0.48c	0.74a	0.88b	35.1b	34.3b	31.2b	16.6b	15.4b	14.8b
G_{160}	0.60a	0.78a	0.91a	39.7a	37.6a	36a	17.2b	15.6b	15.7b
LSD (5%)	0.06	0.08	0.10	4.10	4.00	3.80	2.00	1.90	1.70
SM-IOC (%)	73.28	127.59	228.70	143.46	124.21	145.31	17.52	22.55	19.57
G-IOC (%)	58.62	118.97	187.04	112.88	110.32	121.43	5.10	4.37	6.34
Gazipur soil: Silty clay loam, pH 5.5, Organic matter=7.1 g kg^{-1}, Total S=15.6 and available-S=0.40 m M kg^{-1}									
Control	0.42d	0.41e	0.41e	16.1c	16e	15.4e	7.3c	6.9c	6.3d
SM_{40}	0.51c	0.69c	0.82c	27.3d	24.5d	22.8d	7.8b	7.5b	7.5c
SM_{80}	0.58b	0.73c	0.87b	35.2c	33.6c	30c	8.4b	8.2a	9.6a
SM_{120}	0.66b	0.82b	0.96b	44.7b	41.8b	37.1b	8.7a	8.2a	9.1a
SM_{160}	0.77a	0.97a	1.3a	49.4a	46.3a	42.5a	9.5a	9.1a	9.8a
G_{40}	0.48c	0.56d	0.63d	19.10	17.30	15e	7.4c	7.1c	6.8c
G_{80}	0.51c	0.59d	0.67d	25.5d	23.10	22.7d	7.5b	7.4b	7.5c
G_{120}	0.62b	0.71c	0.82c	28.6d	26.1d	24.2d	7.8b	7.6b	8b
G_{160}	0.73a	0.85b	0.97b	36.4c	34.3c	31.2c	8.1b	8.1b	8.5b
LSD (5%)	0.07	0.09	0.12	4.20	4.10	4.00	0.90	0.90	0.90
SM-IOC (%)	50.00	95.73	140.85	143.17	128.44	114.94	17.81	19.57	42.86
G-IOC (%)	39.29	65.24	88.41	70.19	57.50	51.14	5.48	9.42	22.22

[†] DT = days after transplanting, [‡] In a column, means followed by a common letter are not significantly different at 5 % level. IOC = Increased over control.

Table 3. Effects of sulfidic materials (SM) and Gypsum (G) on the nutrients contents (g kg^{-1}) at different stages of growth of rice shoot on two sulfur deficient soils

Sirajgonj soil:

Treatment	Nitrogen		Phosphorus		Potassium		Magnesium		Sulfur	
denotation	60 DT†	110 DT	60 DT	110 DT	60 DT	110 DT	60 DT	110 DT	60 DT	110 DT
	(‡MTS)	(¶Maturity)	(MTS)	(Maturity)	(MTS)	(Maturity)	(MTS)	(Maturity)	(MTS)	(Maturity)
Control	23.00	10.1c	1.50	1.2e	29.50	15.2b	6.20	3.2c	2.10	1.3f
SM_{40}	24.30	10.7b	1.80	1.4d	30.20	17a	6.50	3.6b	2.60	1.7e
SM_{80}	24.90	11.6b	2.50	2.3b	32.10	17.4a	7.20	3.7b	3.80	3.1c
SM_{120}	25.40	12.8a	2.90	2.5b	32.60	17.5a	7.80	3.9b	4.10	3.6b
SM_{160}	26.30	13.5a	3.20	2.8a	33.00	18.4a	9.00	4.8a	4.80	4.2a
G_{40}	23.40	10.6b	1.60	1.3d	29.70	16.3b	6.40	3.1c	2.50	2.1e
G_{80}	23.90	11.2b	1.80	1.5d	30.10	16.5b	6.90	3.5b	2.80	2.5d
G_{120}	24.50	11.8b	2.60	2.1c	30.50	17.1a	7.60	3.6b	3.30	2.8c
G_{160}	25.20	12.4a	2.90	2.5b	31.20	17.5a	8.20	4.6a	3.60	3c
LSD (5%)		1.30		0.26		1.80		0.50		0.40
SM-IOC (%	9.67	20.30	73.33	87.50	8.39	15.63	22.98	25.00	82.14	142.31
G-IOC (%)	5.43	13.86	48.33	54.17	2.97	10.86	17.34	15.63	45.24	96.15
Gazipur soil:										
Control	22.10	8.2e	1.40	1.1d	25.50	17.5b	6.10	3.2c	2.20	1.6d
SM_{40}	23.20	9.5c	1.80	1.5c	28.30	18.4a	6.50	3.3b	2.80	2.3c
SM_{80}	23.80	11b	2.30	1.9b	28.70	18.5a	7.00	3.7b	3.50	3.1b
SM_{120}	24.30	12.2a	2.60	2.2a	29.60	19.6a	7.60	3.7b	4.10	3.7a
SM_{160}	25.50	12.6a	2.70	2.3a	30.90	20a	8.70	4.2a	4.60	4a
G_{40}	22.50	9.1d	1.50	1.1d	27.80	17.8b	6.30	3.4b	2.40	2d
G_{80}	22.80	9.7c	1.80	1.6c	28.60	17.40	6.60	3.7b	2.50	2.3c
G_{120}	23.40	10.5c	2.00	1.7b	28.90	18.5a	7.10	3.8a	2.90	2.4c
G_{160}	24.10	11.4a	2.20	1.8b	29.20	18.9a	7.80	3.9a	3.40	2.8b
LSD (5%)		1.20		0.22		1.90		0.40		0.38
SM-IOC (%	9.50	38.11	67.86	79.55	15.20	9.29	22.13	16.41	70.45	104.69
G-IOC (%)	4.98	24.09	33.93	40.91	12.25	3.71	13.93	15.63	27.27	45.31

† DT = days after transplantation of rice, ‡MTS = maximum tillering stage of rice, ¶Maturity = maturity stages of rice, In a column, means followed by a common letter are not significantly different at 5% level. IOC = Increased over control.

4. Conclusion

The contents of N, P, K, Mg and S in rice shoot were increased by the application of sulfidic materials (SM) and gypsum (G). But the increments were more striking in case of SM compared to than that of G. The use of SM and G increased the available S by 228 and 187 % IOC for Sirajgonj soil; 140 and 88 % for Gazipur soil, respectively at post harvesting of rice at maturity, suggesting that the SM compared with G as a source of S-fertilizer was potential and effective for the recovery of S deficiency as well as fertility status of the soils. But further field research is essential to find out the optimum doses of SM for different soils under variable conditions. The high organic matter (39.1 g kg^{-1}), available- S (24.4 c mol kg^{-1}) and total S (165.6 c mol kg^{-1}) and other nutrients specially micro-nutrient of the SM deserve attention to use these soil materials for the reclamation of poor soils like saline, alkaline, calcareous and s deficient soils, etc.

Acknowledgement

The research is carried out by the financial and technical supports of the Volkswagen Foundation (Ref.: 1/73802 dated 03.08.98) and Alexander von Humboldt (AvH) Foundation of Germany. The senior author gratefully acknowledges to Japanese Government (Monbukagakusho: MEXT) Scholarship and the Graduate School of Environmental Science, Okayama University, Japan.

Correspondence to:

Abul Hasnat Md. Shamim, Ph. D Student
Department of Environmental Management Engineering,

Faculty of Environmental Science and Technology,
Okayama University, Okayama 700-8530, Japan.
Telephone and fax number: 0081-086-251-8874; E-mail: abulhasnats@yahoo.com

References

1. Black CA. Methods of Soil Analysis, Part 2, Series 9, Am Soc. Agron. Inst. Publ., Madison, WI. 1965; 894-1372.
2. Chapman HD. Cation exchange capacity. In: Methods of Soil Analysis. Part 2, Agron. Series 9. C.A. Black (ed.). Am. Soc. Agron., Publ. Madison, WI, USA. 1965: 891-900.
3. Day PR. Particle fractionation and particle size analysis. In: Methods of Soil Analysis. Part 2, Agron. Series 9. C.A. Black (ed.). Am. Soc. Agron., Publ. Madison, WI, USA. 1965: 545-566.
4. Ebeling AM, Cooperband LR, and Bundy LG. Phosphorus source effects on soil test phosphorus and forms of phosphorus in soil. Commun. Soil Sci. Plant Anal. 2003; 34: 1897–1917.
5. Eghball B and Power JF. Phosphorus and nitrogen based manure and compost applications: Corn production and soil phosphorus. Soil Sci. Soc. Am. J. 1999; 63: 895–901.
6. Eghball B, Wienhold Gilley JE and Eigenberg RA. Mineralization of manure nutrients. J. Soil Water Conserv. 2002;57: 470–4 B.J.73.
7. Egrinya-Eneji, AM, Irshad T, Honna S, Yamamoto T, Endo and Masuada T. Potassium, calcium and magnesium mineralization in manure treated soils. Commun. Soil Sci. Plant Anal. 2003; 34: 1669–1679.
8. Environment Canada. Key Commitments of the acid rain annex. SO_2 emission reduction requirements. Environment Canada: Canada–US Air Quality Agreement: Cleaner Air through Cooperation. Avail. at www.ec.gc.ca/pdb/can_us/canus_Brochure/ canus_bro_p3_e.cfm [updated 9 Feb. 2003; accessed July 2007; verified 19 July 2007]. Environment Canada, Gatineau, QC, Canada.
9. Hesse PR. A text Book of Soil Chemical Analysis. John Murry Publ., London, 1971.
10. Jackson ML. Soil Chemical Analysis. Prentice Hall of India Pvt. Ltd., New Delhi, 1973: 41-330.
11. Khan HR, Blume H.-P, Kabir SM, Bhuiyan MMA, Ahmed F, Syeed SMA. Quantification of the severity, reserve and extent of acidity in the twenty profiles of acid sulfate soils and their threats to environment. Soil & Environ., 2007:26 (in press).
12. Khan HR, Kabir SM, Bhuiyan MMA, Blume H.-P, Adachi T, Oki Y and Islam KR. 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. 2006: 682.
13. Khan HR, Bhuiyan MMA, Kabir SM, Oki Y and Adachi T. Effects of selected treatments on the production of rice in acid sulfate soils in a simulation study. Jpn. J. Trop. Agr. 2006;50: 109-115.
14. Khan H R, Bhuiyan MMA., Kabir S M, Ahmed F, Syeed SMA and Blume H.-P. The assessment and management of acid sulfate soils in Bangladesh in relation to crop production. In: The restoration and management of derelict land, M. H. Wong and A. D. Bradshaw (Ed.), World Scientific Publishing Co. Pte. Ltd. UK. 2002: 254-262.
15. Khan HR. Problem, prospects and future directions of acid sulfate soils. Proc. Inter. Conference on Remade Lands 2000: 66-67. A. Brion and R.W. Bell (ed.). Nov. 30 to Dec. 2, 2000, Perth, Australia.
16. MacGrath SP, Zhao FJ.and Withers PJA. Development of sulfur deficiency in crops and its treatment. Proc. Fertilizer Soc. 1996; No 379. The Fertilizer Society, London.
17. Nelson DW and Sommers LE. Total carbon, organic carbon and organic matter. In: Methods of Soil Analysis. Part 2, Agron. Series 9. A.L. Page (ed.). Am. Soc. Agron., Publ. Madison, WI, USA. 1982: 539-579.
18. Olsen SR, Cale CV, Watanabe FS and Dean LA. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circ. Washington, USA, 1954:939.
19. Richards LA. Diagnosis and improvement of saline and alkali soils. In: USDA Handbook No. 60. US Govt. Print. Office, Washington, USA. 1954: 84-156.
20. Riley NG, Zhao FJ and McGrath SP. Leaching losses of sulfur from different forms of sulfur fertilizers: A field lysimeter study. Soil Use Manage. 2002;18: 120–126.
21. Sakai H. Some analytical results of sulfur deficient plant, soil and water. Workshop on sulfur nutrition in rice, December, BRRI, Publication no. 41: 1978: 35-59
22. Schmitt MA, Schmidt JP, Randall GW, Lamb JA,. Orf JH and. Gollany HT. Effect of manure on accumulation of dry matter, nitrogen, and phosphorus by soybean. Commun. Soil Sci. Plant Anal. 2001;32: 1931–1941.
23. Tiwari KN, Dwivedi BS, and Pathak A N. Iron pyrites as sulfur fertilizer for legumes. Plant soil 1985;86: 295-298.
24. Zaman SMH, Rahman K and Howlader M. Simple lessons from biometry. Bangladesh Rice Research Institute, Gazipur, Bangladesh. 1982:Publ. No. 54.

Received: 10/8/2008