TECHNICAL ARTICLE

Sulfur Distribution and Transformations in Everglades Agricultural Area Soil as Influenced by Sulfur Amendment

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Abstract: Nutrient export from the Everglades Agricultural Area (EAA) has been implicated in causing sulfur (S) enrichment of Everglades wetlands. However, quantification of the S budget and transformations in EAA soils is inadequate. The objective of this study was to quantify various S fractions and investigate how elemental S amendment affects S dynamics in EAA soils. Reduced S compounds were not detected in soil before elemental S application. Organic S was the major form of S, comprising 87% of total S, followed by extractable SO_4-S (13%). Extractable SO_4-S for soils receiving 448 kg S ha^{-1} was 36%, 131%, 201%, and 270% higher than for unamended soils at 2, 6, 9, and 13 months, respectively. Elemental S was significantly higher in soils receiving 448 kg S ha^{-1} (482 mg kg^{-1}) than in soils receiving 224 (111 mg kg^{-1}) and 112 kg S ha^{-1} (55 mg kg^{-1}) and unamended soil (0 mg kg^{-1}) at 2 months after S application. Similar to extractable SO_4-S, elemental S significantly decreased during the growing season. Sulfur application did not affect the sulfatase activity, however, mineralizable S increased concurrently with S application rate, and the effects continued throughout the growing season. This result was largely attributed to the oxidation of the applied elemental S. Our results suggest that large-scale S application in the EAA soils is likely to increase SO_4^{2-} concentrations in soils, which poses a potential risk of SO_4^{2-} export to sensitive Everglades wetlands.

Key words: Sulfur fractions, everglades, Everglades Agricultural Area, histosols.

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Sulfur (S) is a highly reactive element present in many forms that play important biological and chemical functions in the environment (Reddy and DeLaune, 2008). Sulfate is the most abundant form of inorganic S found in most soils, as well as the main form available to plants, although reduced forms, such as elemental S, thiosulfate, and sulfide, are important for anaerobic soils (Zhou et al., 2005). However, the bulk of soil S in natural and managed ecosystems is in organic form, which is directly impacted by microbial activity through decomposition processes (Solomon et al., 2001). Sulfur dynamics is variable among soils and often closely associated with other nutrient cycles. In aerobic agricultural soils, many microbial-mediated processes are responsible for S transformations, including mineralization, immobilization, and oxidation (McGill and Cole, 1981). Factors that influence the microbial activity also affect S transformations, such as moisture, substrate quality, and pH (McGill and Cole, 1981; Knauff et al., 2003).

The Everglades Agricultural Area (EAA) is located south of Lake Okeechobee and north of the Everglades water conservation areas (WCA) of south Florida. Historically, it was a seasonally flooded ecosystem but was converted to agricultural use by drainage in the early 1900s. The soils of the EAA are predominately Histosols, with high organic matter content but low P and micronutrient concentrations that require supplemental fertilization (Snyder, 2005; Ye et al., 2009). Because this area has changed from the wetland to agricultural ecosystem in the 1920s, several nutrient deficiencies became evident, mainly P but also micronutrients, such as Cu. Thus, $CuSO_4$ was applied to alleviate Cu deficiency to crops (Allison et al., 1927). Sulfur has also been applied to soils as part of pesticides used to support sugarcane and vegetable production. In recent years, formation of shallow soils resulting from soil subsidence (Snyder, 2005; Wright, 2009) and increasing pH because of incorporation of limestone bedrock into soils have increased the need for amendments to decrease soil pH. Elemental S is recommended to reduce soil pH when it exceeds 6.6 for the purpose of improving the availability of P and micronutrients to sugarcane (Anderson, 1985; Schueneman, 2001). The microbial oxidation of elemental S to SO_4^{2-} produces acidity that reacts with the soil and reduces pH and enhances P release from $CaCO_3$, which in turn increases P and micronutrient availability to crops. However, the SO_4^{2-} produced from elemental S addition is soluble in water and susceptible to export from the field as runoff during precipitation events to downstream Everglades wetlands.

Water quality is a critical issue facing rehabilitation of the Florida Everglades (Gabriel at al., 2008), and SO_4^{2-} contamination of the northern Everglades has recently been recognized as an important water quality issue primarily through its role in the stimulating MeHg formation (Bates et al., 2002). Methylmercury is a neurotoxin that is bioaccumulated in higher organisms and found at high concentrations in fish and other wildlife in the Everglades (Axelrad et al., 2009). Potential sources contributing to the SO_4^{2-} enrichment in Everglades wetlands include groundwater, rainwater, sea aerosol, internal S flux from sediments, and surface water inputs from Lake Okeechobee and the EAA (Schueneman, 2001). It has been reported that S from the EAA is a likely key contributor (Bates et al., 2002; Orem, 2007).

In consideration of the adverse impacts that S may pose to Everglades wetlands, reducing potential S export from the EAA is essential for the emerging interests of protecting water quality and restoring south Florida ecosystems (Gabriel at al., 2008). Nonetheless, explicit quantification of S budgets and transformations within EAA soils is rare. Minimal research data are available on impacts of agricultural practices, such as elemental S application, on S biogeochemical processes in Everglades soils. Because of soil subsidence and the increasing pH trend for EAA soils, demand for elemental S application may continue to exist or increase in the future. Therefore, there is a need to address fundamental issues, such as pool sizes of S fractions, S

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seasonal dynamics, and their responses to S application in EAA soils, which were also the objectives of the present study.

MATERIALS AND METHODS

Site Description

The experimental field is located in the central EAA on Dania muck (euic, hyperthermic, shallow Lithic Haplosaprist) with a depth to bedrock of approximately 50 cm. The experimental design was a randomized complete block with four blocks consisting of four field plots each, with four S application rates and four sampling times encompassing the entire sugarcane-growing season. Each field plot measured 9 m × 13 m and consisted of six rows of sugarcane (*Saccharum* species) cultivar CP 89-2143 planted in November 2007 and harvested in February 2009. Elemental granular S (90%) was applied at rates of 0, 112, 224, and 448 kg S ha^{-1} to the furrow and covered after planting. Other fertilization was provided using typical recommendations and guidelines for this region and soil type (Gilbert and Rice, 2006). Fertilizers were soil applied before planting, and all field plots received 17 kg N ha^{-1} and 37 kg P ha^{-1} as monoammonium phosphate, 228 kg K ha^{-1} as KCl, 8.5 kg Mn ha^{-1}, 4.5 kg Cu ha^{-1}, 5.6 kg Fe ha^{-1}, 2.8 kg Zn ha^{-1}, and 1.1 kg B ha^{-1}. All plots received common cultural practices including tillage and herbicide application. Water was applied as needed via seepage irrigation in field ditches approximately 182 m apart.

Soil Sampling and Laboratory Analysis

Soil samples were collected before planting and fertilizer application and then in January 2008, May 2008, August 2008, and December 2008, corresponding to approximately 0, 2, 6, 9, and 13 months after planting, respectively. Twelve soil cores (0–15 cm in depth, 2.54 cm in diameter) were randomly collected from rows within each field plot and composited to yield one sample per plot. Soils were homogenized after the removal of visible plant residues and stored at 4°C until analysis.

Soil pH was measured with a soil-to-water ratio of 1:3 after equilibration for 30 min. Total organic C was measured by loss-on-ignition at 550°C for 4 h after conversion to organic C with a coefficient factor of 0.51 (Wright et al., 2008). Total N was measured by Kjeldahl digestion followed by NH_4^+ analysis (Bremner, 1996). Extractable NH_4-N and NO_3-N were determined by extraction with 2 *M* KCl followed by colorimetric analysis (Ye et al., 2009). Total P was measured using the ascorbic acid–molybdenum blue method after Kjeldahl digestion, and labile inorganic P was measured after Mehlich-3 extraction (Ye et al., 2009). Acetic acid extractable nutrients were measured according to guidelines for muck soils (Sanchez, 1990) by extracting 4 g of soil with 25 mL of 0.5*N* acetic acid for 1 h, then filtering through Whatman no. 42 filters. Extracts were analyzed for metal concentrations by inductively coupled plasma using EPA method 200.7. Select soil nutrient concentrations and properties before S application are listed in Table 1.

Water-extractable SO_4-S was analyzed by ion chromatography (Perkin-Elmer, Waltham, MA) after shaking 2 g of field soil with 25 mL of water for 0.5 h, followed by filtering through Whatman no. 42 filters. Aliquots of extracts were analyzed for total extractable S by inductively coupled plasma. Extractable organic S was calculated by subtracting extractable SO_4-S from total extractable S. Elemental S was determined as described by Pansu and Gautheyrou (2006), with slight modification. Approximately 5 g of soil was extracted with 10 mL of acetone for 30 min and centrifuged at 5,000 g for 15 min. Extracts were then analyzed for S content colorimetrically at 420 nm. To avoid interference by organic matter, unamended soils were used as controls to calibrate all readings. Dissolved sulfide, ferrous monosulfide, and pyrite were determined by diffusion methods (Hsieh and Yang, 1989). Total S was determined in duplicate on dried (60°C) and powdered soil samples by high-temperature combustion and nondispersive infrared detection of the resulting SO_2 using a Leco TruSpec Sulfur Analyzer (Leco Corporation, St Joseph, MI). The percentage relative S.D. of the total S analysis was ±1%. Total organic S was estimated as the difference between the total S and total inorganic S (Solomon et al., 2001; Wang et al., 2006).

TABLE 1. Chemical Properties of the Histosols in the Everglades Agricultural Area Before Fertilizer Application

Soil Property	Unit	Concentration
Total organic C	g kg^{-1}	416
Total N	g kg^{-1}	38
Total P	mg kg^{-1}	850
Extractable NO_3-N	mg kg^{-1}	290
Extractable NH_4-N	mg kg^{-1}	16
Extractable P	mg kg^{-1}	48
Extractable Ca	mg kg^{-1}	720
Extractable Mg	mg kg^{-1}	105
Extractable Fe	mg kg^{-1}	13
Extractable Al	mg kg^{-1}	1.1

A 10-day incubation method is commonly used to measure potential organic C, N, and P mineralization in Everglades organic soils, and therefore was used, with some modifications, to estimate potentially mineralizable S in the present study (White and Reddy, 2000; Castillo and Wright, 2008; Wright et al., 2009). Approximately 2 g of fresh soil was incubated aerobically in the dark at 22°C for 10 days, followed by extraction with water and analysis for SO_4-S as previously described. Mineralizable S was calculated as SO_4-S produced during incubation. The arylsulfatase activity (EC 3.1.6.1) in soils was assayed using the colorimetric methods described by Tabatabai and Bremner (1970).

Statistical Analysis

A mixed model was fit using restricted maximum likelihood in the MIXED procedure of SAS (Littell et al., 2006). The fixed effects were S application rate, time, and their interaction, with block as a random effect. Degrees of freedom were adjusted using the Kenward-Roger adjustment. An exponential covariance structure was used to model the correlation among observations taken from the same plot over time. Significant differences among individual treatments and time intervals were analyzed with Tukey test at $\alpha = 0.05$. Pearson correlation and stepwise multiple regression were used to evaluate relationships between variables. A value of $P = 0.1$ and $P = 0.05$ was used as the entry and staying values, respectively, in the stepwise selection method. All statistical analyses were carried out with SAS 9.1 (SAS Institute).

RESULTS AND DISCUSSION

Soil pH

Oxidation of elemental S to SO_4^{2-} produces H^+ and therefore acts to reduce soil pH, although results may be temporary depending on the soil's buffering capacity (Bloom 2000). Overall,

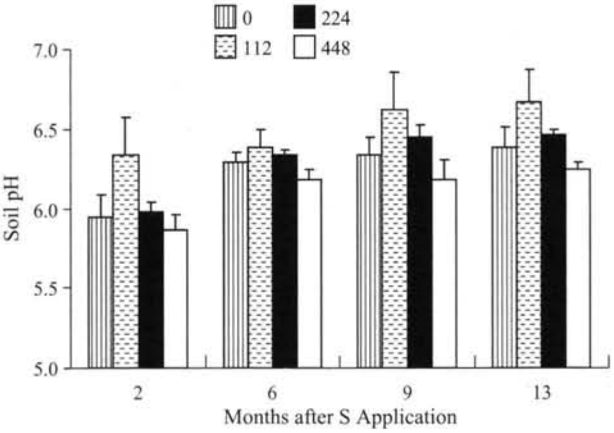

FIG. 1. Soil pH changes in response to different elemental S application rates (0, 112, 224, and 448 kg S ha^{-1}) throughout the sugarcane-growing season. Error bars represent the SEM.

application within the range of 0 to 448 kg S ha^{-1} did not significantly reduce soil pH ($P = 0.14$) (Fig. 1). The background soil pH before S application was 6.2, which was not significantly different from soils collected at any time of the growing season. However, soil pH dropped slightly at 2 months after S addition for the highest S application rate and increased thereafter from 6.0 to 6.4 at the end of growing season, which indicated a lag effect of soil buffering. The limited effect of acidification may result from the relatively low rates of S application and from the high buffering capacity of this organic soil (Bloom 2000; Jaggi et al., 2005; Deubel et al., 2007). Soils with high concentrations of carbonates and bicarbonates are highly buffered against acidification (Bloom 2000; Rogovska et al., 2007). The buffering effects often take place more slowly than the formation of sulfuric acid, therefore, a later increase of soil pH is possible (Bloom 2000; Deubel et al., 2007). A limited reduction in soil pH after S application was observed in other studies of calcareous soils (Hassan and Olson 1966).

Sulfur Fractions

Dissolved sulfide, ferrous monosulfide, and pyrite were not detected at any time for the present study (data not shown), which was similar to results from other aerobic agricultural soils (Solomon et al., 2001; Wang et al., 2006). Statistical analysis demonstrated that the time effect was significant across all S fractions, indicating significant seasonal changes in S distribution. The main effect of S application rate was solely found significant on fractions of extractable SO_4-S. Meanwhile, significant interaction effects of S application rate and time were observed for elemental S and total organic S.

TABLE 2. Different S forms in the Everglades Agricultural Area soil before S applications[†]

S Fraction	Concentration, mg kg^{-1}	% of Total S
Extractable inorganic SO4-S	243 ± 46	13.3
Extractable organic S	62 ± 4	3.4
Nonextractable organic S	1,521 ± 30	83.3
Elemental S	Undetectable	0
Total S	1,827 ± 35	

[†]Data are presented as mean ± S.D. ($n = 4$).

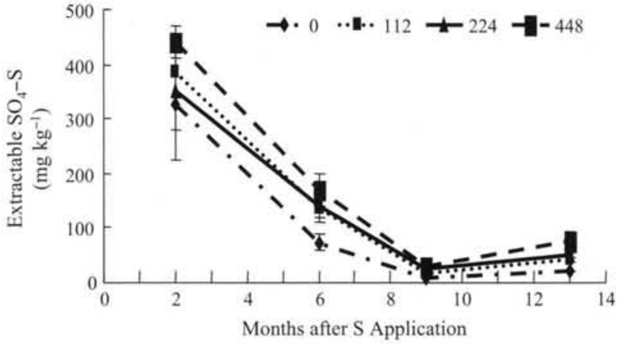

FIG. 2. Seasonal dynamics of extractable SO_4-S after elemental S application at 0, 112, 224, and 448 kg S ha^{-1}. Error bars represent the SEM.

Extractable SO_4-S

The concentration of SO_4-S in soils before planting and fertilization averaged 243 mg kg^{-1}, comprising about 13% of total S (Table 2). Elemental S application significantly increased SO_4-S concentrations in soils throughout the growing season (Fig. 2). Extractable SO_4-S in soils receiving 448 kg S ha^{-1} was 36%, 131%, 201%, and 270% greater than in unamended soils at 2, 6, 9, and 13 months, respectively. Sulfate-S concentrations significantly decreased from 2 (376 mg kg^{-1}) to 6 months (129 mg kg^{-1}) and continuing to 9 months (21 mg kg^{-1}). The percentage of SO_4-S to total S also decreased from 19% at 2 months to 1% at 9 months (Table 3). The declining trend in SO_4-S concentrations was likely caused by SO_4^{2-} uptake by sugarcane and loss as runoff or leaching during precipitation events. Extractable SO_4-S was significantly correlated to extractable organic S ($r = 0.89$), elemental S ($r = 0.52$), total organic S ($r = -0.61$), and potentially mineralizable S ($r = 0.39$), which may suggest that microbial oxidation of elemental S and mineralization of organic S were two major sources of soil SO_4-S (Jaggi et al., 2005; Zhou et al., 2005). Stepwise regression analysis also suggested that elemental S, total organic S, and total S together explained 99.97% ($P < 0.001$, C [p] = 4) of variances in SO_4-S. In the EAA, soil oxidation generally supplies sufficient SO_4^{2-} to satisfy sugarcane nutrient requirements (Gilbert and Rice, 2006), therefore S application at high rates is likely to contribute to SO_4^{2-} accumulation in the soil and thus the risk of export from fields into sensitive Everglades wetlands.

Extractable Organic S

Extractable organic S contains S associated with particulate organic matter and generally accounts for only a small proportion of the total soil S (Dias et al., 2003). However, it is likely to be readily mineralized to SO_4^{2-}, and as such, this pool is considered an important source of available S to crops, especially in soils containing low inorganic SO_4^{2-} (Dias et al., 2003; Kaiser and Guggenberger, 2005). Extractable organic S comprised 3% of total S initially (Table 2) and was not affected by S application but exhibited a similar decreasing pattern as extractable SO_4-S during the growing season, indicating that extractable organic S was as mobile as SO_4^{2-} in these organic soils (Fig. 3, Table 3). The primary reasons for the decrease in extractable organic S and SO_4^{2-} were uptake by sugarcane and runoff or leaching during precipitation events. Extractable organic S averaged 58, 22, 4, and 16 mg kg^{-1} at 2, 6, 9, and 13 months, respectively, and

TABLE 3. Percentage of Basic S Fractions to Total S in Soils of Everglades Agricultural Area During the Sugarcane-Growing Season[†]

	Months After S Application				S Application Rates, kg S ha^{-1}			
	2	6	9	13	0	112	224	448
Extractable SO_4-S	19 ± 6	7 ± 3	1 ± 1	3 ± 2	6 ± 8	8 ± 8	8 ± 7	9 ± 8
Extractable organic S	3 ± 0	1 ± 0	0 ± 0	1 ± 0	1 ± 1	1 ± 1	1 ± 1	1 ± 1
Elemental S	7 ± 10	3 ± 6	1 ± 3	0 ± 0	0 ± 0	1 ± 2	2 ± 4	9 ± 10
Nonextractable organic S	71 ± 13	88 ± 8	97 ± 3	96 ± 2	93 ± 9	89 ± 11	89 ± 11	80 ± 19

[†] Data are presented as mean ± S.D. (n = 16).

was significantly correlated to elemental S (r = 0.44), total organic S (r = −0.56), potentially mineralizable S (r = 0.26), and extractable SO_4-S (r = 0.89), suggesting that production of extractable organic S and S mineralization were controlled by the same factors (Valeur et al., 2000).

Elemental S

Elemental S was not detected in unamended soils during the growing season. At 2 months after S application, elemental S content in soils receiving the highest S rate was 771% and 334% greater than in soils amended with 112 and 224 kg S ha^{-1}, respectively (Fig. 4). However, at 13 months, elemental S was only detected in soils receiving 448 (9 mg kg^{-1}) and 224 kg S ha^{-1} (0.5 mg kg^{-1}). The decreasing patterns of elemental S in soils throughout the season were caused by the oxidation of elemental S to SO_4^{2-}. It has been reported that oxidation of elemental S in some calcareous soils is slow and may take several years (Lindemann et al., 1991; Cifuentes and Lindermann, 1993). Our results showed that a relatively high concentration of elemental S persisted in soils receiving 448 kg S ha^{-1} by 13 months after application, suggesting that higher S application in these calcareous organic soils is likely to maintain high levels of elemental S and SO_4^{2-} in soils for long periods.

Total Organic S

Organic S in soils is a heterogeneous mixture of soil organisms and partially decomposed plants, animals, and microbial residues, and represents the majority of total S in most agricultural soils (Eriksen et al., 1998; Solomon et al., 2001). In the present study, total organic S averaged 1,583 mg kg^{-1} and contributed to 87% of total S before planting and fertilization. However, it accounted for 74%, 89%, 97%, and 97% of total S at 2, 6, 9, and 13 months after S application. The amounts of total organic S ranged from 1,424 to 1,723 mg kg^{-1}, which was much higher than those found in most temperate, subtropical, and tropical soils, respectively (Reddy et al., 2001; Solomon et al., 2001; Wang et al., 2006). Correlation analysis revealed that total organic S was significantly correlated with organic matter content (r = 0.27) and total organic C (r = 0.25). Similar results were also found in other studies, suggesting close associations between these two elements (Wang et al., 2006).

Total S

Total S in the top 15 cm of soil averaged 1,827 mg kg^{-1} before planting and fertilization. No significant effects of S addition were found on total S (Fig. 5). It was possible that the effects of S addition were confounded by the large pool size of organic S, which comprised the majority of total S (Table 2). The total S significantly decreased from 1,938 mg kg^{-1} at 2 months to 1,668 mg kg^{-1} at 13 months after S application, which was probably attributable to the reduction in SO_4-S, extractable organic S, and elemental S during the growing season (Figs. 2–4). Under natural conditions, S contents in soils vary from 20 to 3,500 mg kg^{-1}, being highest in wetland soils (Ribeiro et al., 2001). Our results indicated that total S in the EAA soils ranged from 1,414 to 2,017 mg kg^{-1}, which was 10-fold less than that found in S-enriched WCA-2A sediments (Bates et al., 1998). The WCA-2A is one of the hydrologic units in the Everglades that has been most impacted by nutrient inputs from the EAA (Rivero et al., 2007). It is possible that SO_4^{2-} loading from the EAA and other surface water inputs resulted in accumulation of S in the sediments since the establishment of the WCAs (Bates et al., 1998; 2002).

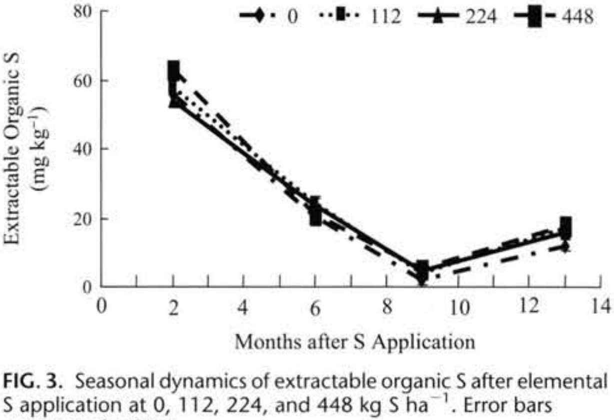

FIG. 3. Seasonal dynamics of extractable organic S after elemental S application at 0, 112, 224, and 448 kg S ha^{-1}. Error bars represent the SEM.

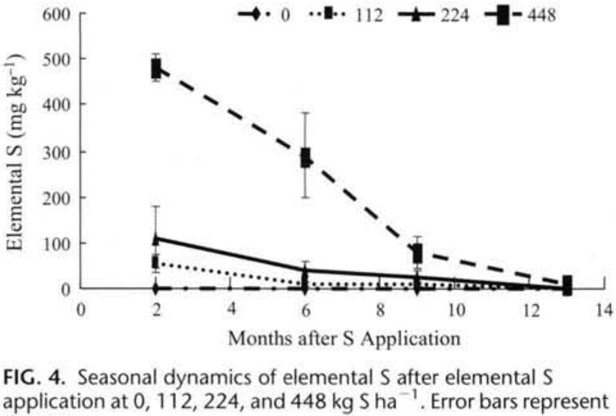

FIG. 4. Seasonal dynamics of elemental S after elemental S application at 0, 112, 224, and 448 kg S ha^{-1}. Error bars represent the SEM.

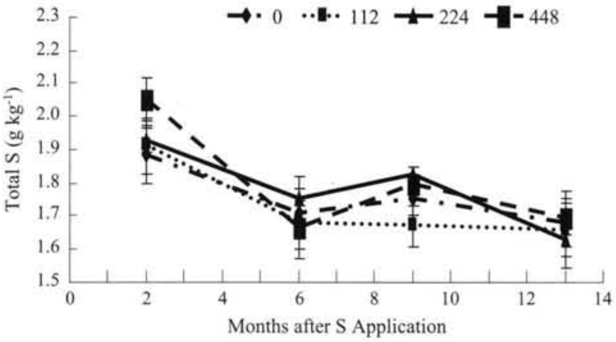

FIG. 5. Seasonal dynamics of total S after elemental S application at 0, 112, 224, and 448 kg S ha^{-1}. Error bars represent the SEM.

Arylsulfatase Activity

Arylsulfatase is an enzyme that hydrolyzes organic S esters and releases SO_4^{2-}, and hence plays an important role in organic S mineralization (Chen et al., 2001). Arylsulfatase activity can be affected by several soil properties, such as SO_4^{2-} concentration, pH, temperature, and seasonal variations in soil moisture (Tabatabai and Bremner, 1970; Knauff et al., 2003). Therefore, elemental S is capable of influencing the enzyme activity through its oxidation to SO_4^{2-} and impacts on soil pH. However, in the present study, S application at a range from 0 to 448 kg ha^{-1} had minimal effects on arylsulfatase activity during the growing season (Fig. 6). Meanwhile, arylsulfatase activity was not significantly correlated with soil pH and SO_4-S concentrations. Decomposition of organic matter in this Histosol typically supplies enough S needed for crop growth (Snyder, 2005), thus before S addition, SO_4^{2-} is probably at a concentration high enough to minimize sulfatase activity (Wright and Reddy, 2001). Our results also indicated that soil pH was not affected by S application and did not significantly change during the growing season (Fig. 1). Averaged across treatments, arylsulfatase activity was 240, 157, 223, and 216 mg *p*-nitrophenol kg^{-1} h^{-1} at 2, 6, 9, and 13 months after S application. The seasonal variations in enzyme activity may result from the variations in soil temperature and moisture.

Potentially Mineralizable S

Several microbial-mediated processes are involved in S transformation in soils, including mineralization, immobilization, and oxidation (Reddy and DeLaune, 2008). In aerobic agricultural soils, the main interest in these processes is the release of inorganic SO_4^{2-} (Eriksen et al., 1998), which was also the interest of the present study. Because mineralization, immobilization, and oxidation of S may occur concurrently, the measured mineralized S in the present study was a net result of these processes (Eriksen et al., 1998).

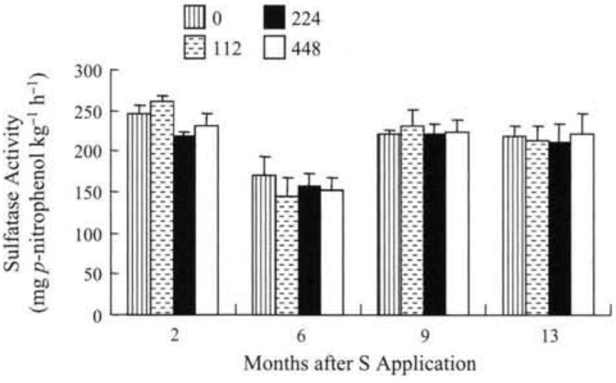

FIG. 6. Sulfatase activity in response to different elemental S application rates (0, 112, 224, and 448 kg S ha^{-1}) throughout the sugarcane-growing season. Error bars represent the SEM.

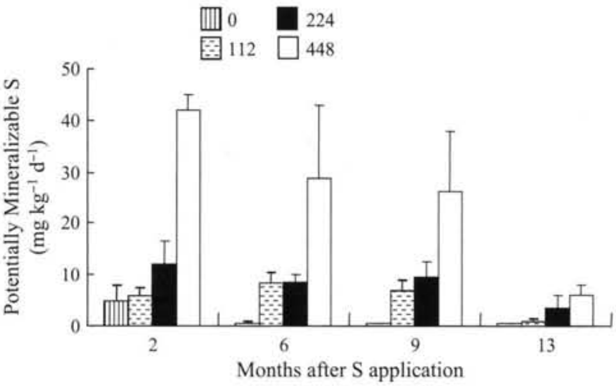

FIG. 7. Potentially mineralizable S in soils at 2, 6, 9, and 13 months after elemental S application at different rates (0, 112, 224, and 448 S kg ha^{-1}). Error bars represent the SEM.

Mineralizable S increased concurrently with increasing S application rates, and the effects continued throughout the growing season (Fig. 7). Overall, mineralized S was 1,421% greater for soils receiving 448 kg S ha^{-1} than unamended soil, 375% greater than soils receiving 112 kg S ha^{-1}, and 219% greater for soils receiving 224 kg S ha^{-1}. However, mineralized S rates significantly decreased from 2 (16 mg kg^{-1} d^{-1}) to 6 months (12 mg kg^{-1} d^{-1}) and continued to decrease from 9 (11 mg kg^{-1} d^{-1}) to 13 months (3 mg kg^{-1} d^{-1}), which was similar to the background rates before planting and fertilization (3 mg kg^{-1} d^{-1}). It has been well recognized that organic S is mineralized to SO_4^{2-} by hydrolysis of ester S catalyzed by sulfatase or by mineralization of C-bound S caused by microbiological activity (McGill and Cole, 1981; Chen et al., 2001; Gharmakher et al., 2009). In the present study, no significant correlation between mineralized S and both sulfatase activity and C mineralization rates was found. Instead, mineralized S was significantly correlated with the application rate (r = 0.60), elemental S concentration (r = 0.85), extractable SO_4-S (r = 0.39), and extractable organic S (r = 0.26). Stepwise multiple regression analysis also revealed that element S was the only significant component in explaining the variances in mineralized S concentration (R^2 = 0.76, C [p] = 2). It was plausible that oxidation of elemental S to SO_4^{2-} was primarily responsible for the increased mineralized S rather than organic S mineralization.

CONCLUSIONS

No reduced forms of S were detected in the investigated soil before planting and S application. Organic S was the major form of S in this soil, averaging 87% of total S, followed by extractable SO_4-S (13%). Sulfur application at 448 kg ha^{-1} significantly increased elemental S content and SO_4^{2-} concentrations in soil solution. However, S application did not stimulate arylsulfatase activities during the growing season. Conversely, it significantly enhanced potentially mineralizable S, which was largely attributed to the oxidation of elemental S. Both extractable SO_4^{2-} and dissolved organic S decreased significantly throughout the growing season likely caused by uptake by sugarcane, but also potentially by runoff or leaching through the shallow soils. Large-scale elemental S application to EAA soils, or an increase in S application rates, is likely to increase SO_4-S accumulation in soil, which may enhance the potential for S export to sensitive Everglades wetlands during field drainage or precipitation events, leading to S enrichment of downgradient wetlands and resulting impacts on the ecosystem such as stimulation of MeHg production and bioaccumulation.

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