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# EFFECTS OF ALKALINE SANDY LOAM ON SULFURIC SOIL ACIDITY AND SULFIDIC SOIL OXIDATION

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**Abstract**

In poor soils, addition of alkaline sandy loam containing an adequate proportion of sand, silt and clay would add value by improving the texture, structure and organic matter (OM) for general use of the soils. In acid sulfate soils (ASS), addition of alkaline sandy would improve the texture and leach out salts as well as add a sufficient proportion of OM for vegetation establishment. In this study, addition of alkaline sandy loam into sulfuric soil effectively increased the pH, lowered the redox and reduced the sulfate content, the magnitude of the effects dependent on moisture content. Addition of alkaline sandy loam in combination with OM was highly effective than the effects of the lone alkaline sandy loam. When alkaline sandy was added alone or in combination with OM into sulfidic soil, the effects on pH and the redox were similar as in the sulfuric soil but the effect on sulfate content was variable. The effects under aerobic conditions were higher than under anaerobic conditions. The findings of this study have important implications for the general management of ASS where lime availability is a concern and its application is limited.

Keywords: Alkaline sandy loam, acid sulfate soils, pH, redox potential, sulfate content

## Introduction

Acid sulfate soils are naturally occurring soils formed under reducing conditions (Wilson, 2005), which either contain sulfuric acid or have the potential to form it (Dent and Pons, 1995), in an amount that can have an impact on other soil properties (Fitzpatrick *et al.*, 2009) and the general environment (Robarge and Johnson, 1992; Hanhart *et al.*, 1997; Meda *et al.*, 2001). The process through which the ASS were formed (Dent, 1986; Cook *et al.*, 2000), the biochemical reactions involved (Lin *et al.*, 2000; Sullivan *et al.*, 2009), and the ecological impacts of ASS (Simpson and Pedini, 1985; Tang and Yu, 1999; Buschmann *et al.*, 2008; Ljung *et al.*, 2009) including the strategies available to manage the impacts were recently reviewed (Michael, 2013).

Among the established management strategies, addition of mineral lime is the common strategy used to manage sulfuric (actual) acidity while flooding (water table management) is used to prevent oxidation of sulfidic soil (Powell and Marten, 2005). Addition of phosphate rock has been found to be important to amend nutrients and raise the pH because of its $CaCO_3$ content (Owaid and Abed, 2015). In some places, such as in the tropics, however, availability of lime is a constraint and the need for large quantities is a major issue (Hue, 1992). In addition, under general soil use and management conditions, flooding is often undesirable except for cultivation of a few crop, such as rice (*Oryza sativa*) and taro (*Colocasia esculenta*). These limitations call for establishing of alternative strategies that are less costly and of wider applicability. We have demonstrated recently that neutralisation of sulfuric soil with alkaline sandy loam for general soil use (e.g. establishment of vegetation) is possible and sustainable (Michael *et al.*, 2015a, c).

In a short incubation study lasting 2 weeks, we also found that addition of alkaline sandy loam buffered the residual effects of sulfuric soil and prevented sulfidic soil oxidation under aerobic (75% field capacity) soil conditions (Michael *et al.*, 2012). This short study was extended to assess the long-term effects (6 month) of mixing alkaline sandy loam on sulfuric acidity and on sulfidic soil oxidation under aerobic and anaerobic conditions in this study. The combined effect of alkaline sandy loam and OM when incorporated forming a uniform soil texture was further investigated.

## Materials and Methods

*Descriptions of studies*

Two studies were conducted using either sulfuric or sulfidic soil in Falcon tubes (110 mm high, capacity 70 milliliters. The soils were thoroughly mixed in a proportion of 2:1 (ASS: alkaline sandy loam, w/w) in the plastic bowl of a cement mixture. In the treatments where OM was added, one gram of lucerne hay (3.2% N analyzed by ICP-OES using a triplicate 0.5 g sample) as OM source ground to pass a 0.5 mm sieve was mixed into 80 g soil previously set at 100% field capacity until a uniform texture was obtained. To assess the effects of OM under anaerobic conditions, water was added to completely fill the space between the top of the soil and the cap of the Falcon tube, thus ensuring anoxia. Similarly, to assess the effects under aerobic soil condition, the treatments were dried down to 75% field capacity and maintained on weight basis by adding water throughout the studies. All the treatments were replicated 3 times and incubated under glasshouse conditions in a completely randomized design (CRD) for 6 months.

*Measurements*

Data from the surface (10 mm) and depth (80 mm) profiles were collected based on the common knowledge that the possibility of the soils being either aerobic or anaerobic is at these profiles. Soil redox potential (Eh) and pH were measured from the surface and depth (top to bottom) as described by Michael *et al.* (2015a).The stability and accuracy of the electrodes were maintained as per Fiedler *et al.* (2007). In addition, sulfate content was estimated using soil samples obtained from the two profiles according to the method of Hoeft *et al.* (1973) for soluble soil sulfate.

*Data analysis*

The Eh values obtained over a 10 min period were averaged and a treatment average obtained by taking the mean of the three replicates. These values were corrected for the reference offset to be relative to the potential of a standard hydrogen electrode by adding 200 mV (Fiedler *et al.*, 2007). Similarly, treatment average pH and sulfate content were obtained by taking the mean of the three replicates. Significant differences ($p<0.05$) between treatments means of each profile was compared by two-way ANOVA using statistical software JMPIN, AS Institute Inc., SAS Campus Drive, Cary, NC, USA 27513. If an interaction between treatments and depths was found, one-way ANOVA with all combination was performed using Tukey's honest significant difference and pairwise comparisons.

## Results

*Effects of alkaline sandy loam on acid sulfate soils*

The changes in soil chemistry measured following the addition of the amendments into the sulfuric soils are shown in Figure 1. The initial pH of the sulfuric soil amended with alkaline sandy loam prior to incubation was 3.7. The unamended control soils under the two moisture conditions remained acidic (data not shown). Within the surfaces, pH of the sulfuric soils treated with alkaline sandy loam and maintained under both of the moisture conditions increased to moderate (near 5 units) only, whereas at depth increased to near 6. Comparatively, the changes in pH under aerobic condition were lower than the changes under anaerobic condition. When the amendments were made in combination with OM, the increase in pH was near 7 under anaerobic and near 8 under aerobic condition, respectively.

The changes in Eh of the unamended control soils were within the highly oxidised to oxidised range and corresponded well with the changes in pH of the unamended control soils (data not shown). In the absence of OM, all the surface soils were within the moderately reduced range, whereas at depth were within the reduced range (Fig. 1B). In the presence of OM, Eh was reduced at the surfaces to highly reduced at depth. Again, the magnitude of reduction was higher under aerobic conditions.

The initial sulfate content of the unamended sulfuric soil ranged between 21-32 µmol $g^{-1}$ soil. The sulfate content of the unamended control sulfuric soil under aerobic condition ranged between 26.3 µmol $g^{-1}$ soil at the surface and 27.5 µmol $g^{-1}$ soil at depth, whereas under anaerobic conditions ranged between 20.1 and 11.8 µmol $g^{-1}$ soil at the same profiles. The changes in sulfate content quantified of the amended treatments are shown in Figure 1C. Sulfate contents of the surface soils amended with alkaline sandy loam alone agreed with the reduced soil conditions but at depth were higher. When amendment was made in combination with OM, sulfate was significantly reduced to near 3 µmol $g^{-1}$ soil under both of the moisture conditions.

The changes in soil chemistry measured following the mixing of alkaline sandy loam into sulfidic soil are shown in Figure 2. The pH of the unamended sulfidic control treatment under aerobic condition was near 7 and under anaerobic condition was near 6. When amendment was made with alkaline sandy loam alone, the changes in pH under aerobic (sulfidic + SL - aerobic) and anaerobic (sulfidic + SL -anaerobic) conditions were similar but the unit changes were higher at depth (Figure 2A). When the amendment was made in combination with OM, the changes in pH were even significantly higher, and more so under aerobic conditions and at depth. The unamended sulfidic control soil Eh were within the reduced range under the two moisture conditions (data not shown). Although all the amended treatments were within the reduced range, the general pattern of reduction was: sulfidic+SL+LH-aerobic >sulfidic+SL+LH-anaerobic>sulfidic + SL- anaerobic > sulfidic + SL – aerobic (Figure 2B).

The initial sulfate content of the unamended sulfidic soil used ranged between 12-16 µmol $g^{-1}$ soil. The sulfate content of the unamended control sulfidic soil of this study under aerobic condition ranged between 11.8 µmol $g^{-1}$ soil at the surface and 11.7 µmol $g^{-1}$ soil at depth (Figure 2C). Under anaerobic condition it ranged between 8.9 and 7.2 µmol $g^{-1}$ soil at the same profiles. Under the two moisture conditions, the changes in sulfate content in the surface soils from the highest to the lowest were: sulfidic + SL-anaerobic > sulfidic + SL-aerobic > sulfidic + SL + LH-anaerobic > sulfidic + SL + LH–aerobic. Similarly, sulfate content of the treatments quantified at depth from the highest to lowest was: sulfidic + SL-aerobic > sulfidic + SL-anaerobic > sulfidic + SL + LH-anaerobic > sulfidic + SL + LH–aerobic. Compared to all the treatments, sulfate was significantly ($p<0.05$) reduced when amendment was made in combination of SL and OM under aerobic condition, more so at depth.

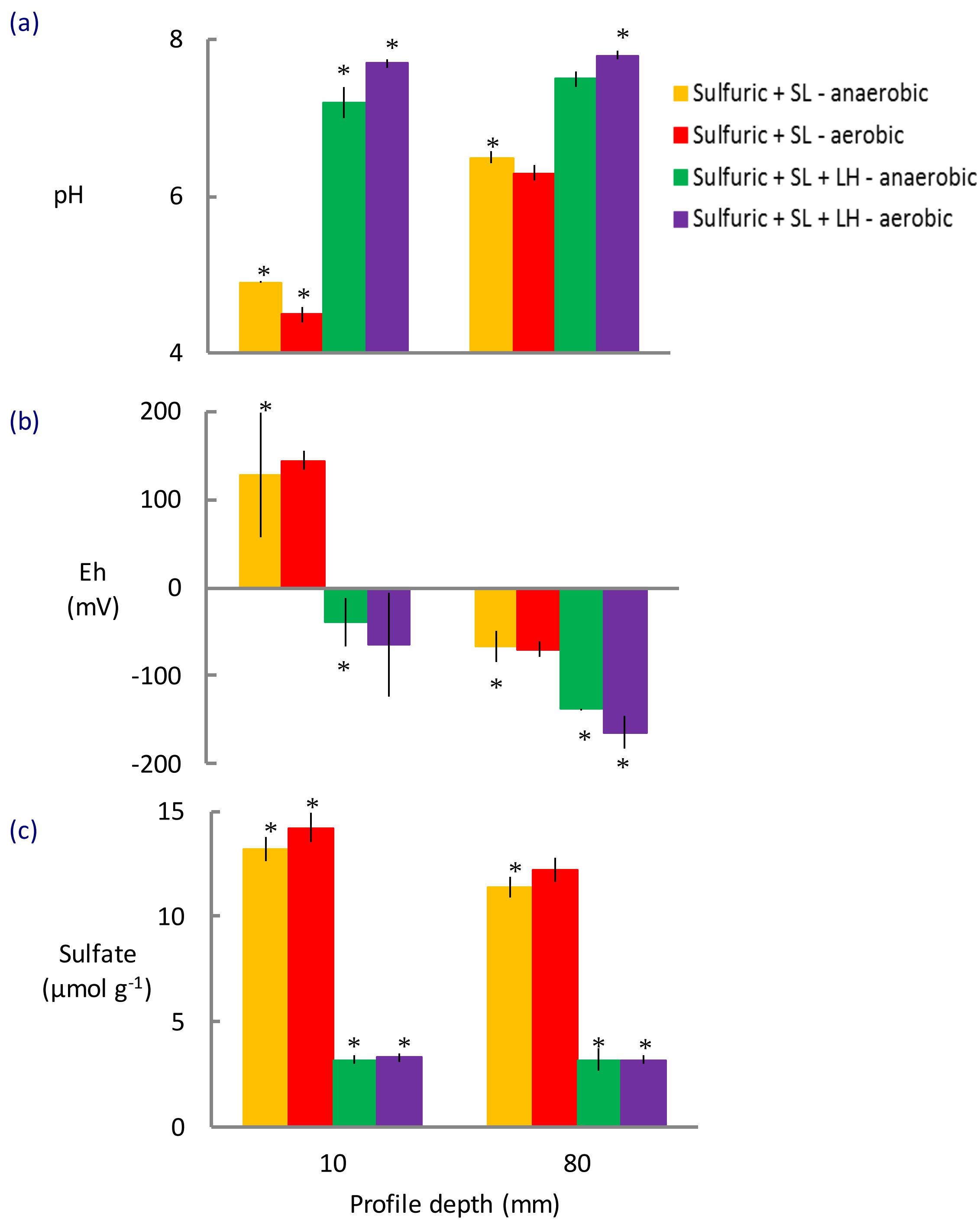


**Fig. 1:** Effects of alkaline sandy loam alone or in combination with OM on (a) pH, (b) redox and (c) sulfate content of sulfuric soil maintained under aerobic and anaerobic conditions for 6 months. The initial pH is 3.7. The initial sulfate content of the unamended sulfuric soil ranged between 21-32 µmol $g^{-1}$ soil. The values are means ± s.e. of three measurements (n=3). An asterisk either above or below a column indicates significant differences ($p<0.05$) between treatment means and the control at the same depth. The notations are alkaline sandy loam (SL) and lucerne hay (LH) respectivel

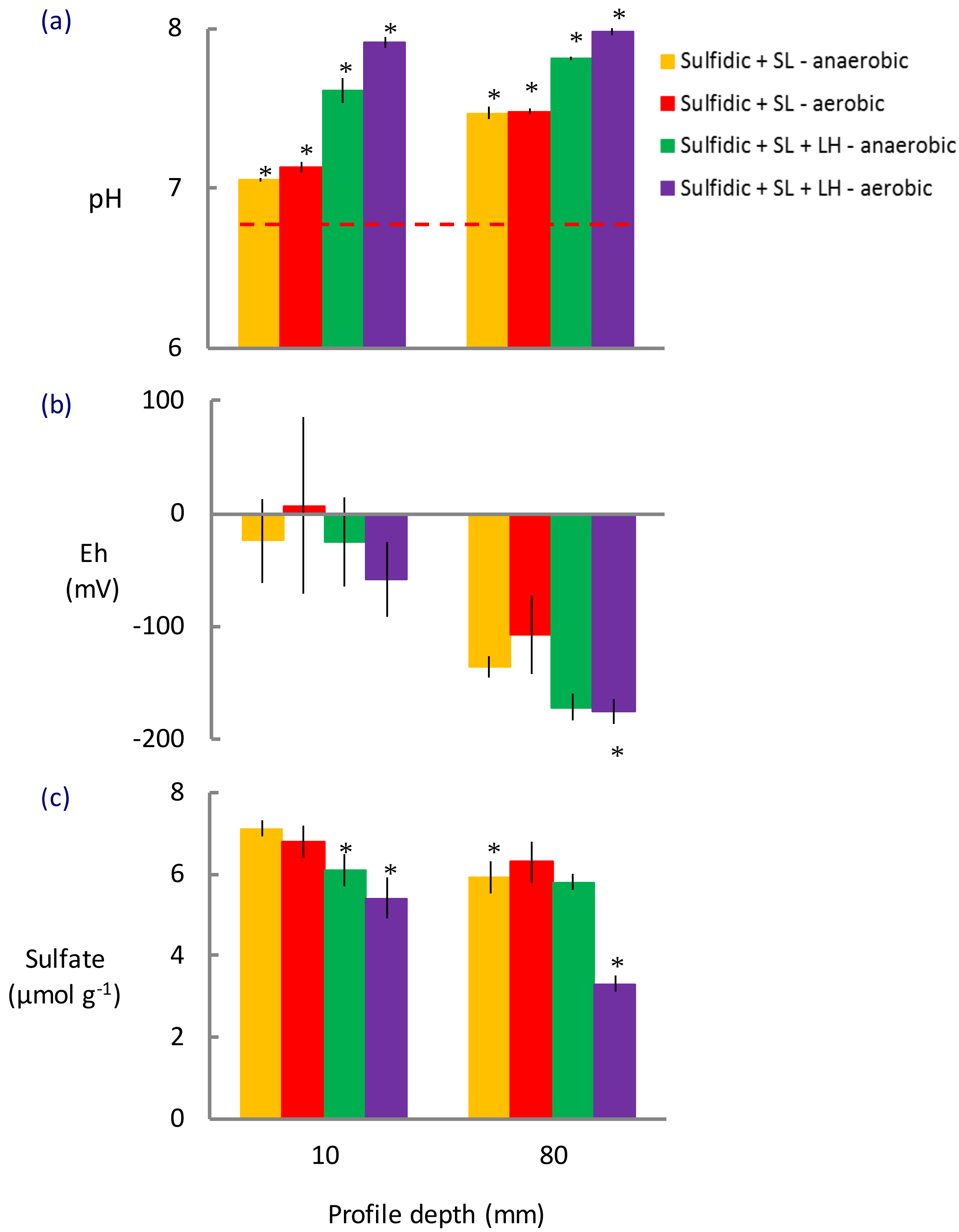


**Fig. 2:** Effects of alkaline sandy loam alone or in combination with OM on (a) pH, (b) redox and (c) sulfate content of sulfidic soil maintained under aerobic and anaerobic conditions for 6 months. The dotted line is the initial pH. The initial sulfate content of the sulfidic soil range between 12-16 µmol $g^{-1}$ soil. The values are means ± s.e. of three measurements (n=3). An asterisk either above or below a column indicates significant differences ($p<0.05$) between treatment means and the control at the same depth. The notations are alkaline sandy loam (SL) and lucerne hay (LH) respectively

Discussion

*Effects of alkaline sandy loam on sulfuric soil acidity*

In many developing countries (e.g. Papua New Guinea), farming is an important component of the daily lives of the majority of the people and many households depend entirely on farm produce. In such areas, availability of arable land is limited due to high population densities coupled with urbanisation. As a result, more wastelands (e.g. wetlands) are converted to farms and plantations. Where ASS is present as shown in Michael (2013), this is a serious problem as a result of soil acidification and toxicity of oxidised acidic minerals, which have an ultimate impact on crop productivity and socio-economic security including livelihood of the people. Although application of lime is quite effective in treating acid soils and is the most established soil acidity management strategy, availability and the need for larger quantities are major issues in the developing countries (Hue, 1992; Powell and Marten, 2005). In addition, application of lime under certain conditions such as in Ramsar wetlands is not feasible and permitted (Michael *et al.*, 2015a).

In this research, a practical and alternative strategy of neutralising sulfuric acidity and preventing sulfidic soil from oxidation using alkaline sandy loam as a replacement for lime and flooding of soil, especially from an agricultural soil perspective was studied by assessing the changes in soil pH, redox and sulfate content. These three soil chemical factors were studied based on the common understanding that their association influence the stability and availability of soil nutrients, mineral solubility and other important biochemical reactions in the soil. The effect of mixing sulfuric soil with alkaline sandy loam alone on the surface soil pH under the two moisture conditions were minimal, indicating that presence of sand still facilitated oxygen to penetrate into the soil, whereas at depth the opposite happened. These results are similar to what we found in another study where the sulfuric soil pH was raised to neutral level by mixing alkaline sandy loam (Michael *et al.*, 2015a).

Mixing of alkaline sandy loam in combination with OM however increased the pH, reduced the redox and soil sulfate content. In a separate study involving addition of dead OM into sulfuric soil of ASS, Reid and Butcher (2011) and Michael *et al*. (2015a, b) found similar effects on pH, the higher effects resulting from the oxidation of the OM by soil microbes which consumed the acidity. In addition to maintaining a higher pH, OM addition would supplement nutrients and detoxify oxidised acidic mineral toxicity in sulfuric soils through secretion of organic acids (Hue, 1992; Hue et al., 1986) and deactivate them by adsorption (Hoyt and Turner, 1975), which are important for growth of plants. Addition of alkaline sandy loam itself would leach out salts in saline sulfuric soils and improve the soil texture and structure needed for plant growth as well as to facilitate water and air to the roots of plants (Michael *et al*., 2012).

*Effects of alkaline sandy loam on sulfidic soil oxidation*

Sulfuric soil acidity is a problem when sulfidic soil is oxidised but oxidation of sulfidic soil is effectively curtailed by water table management through flooding (Fitzpatrick *et al*., 2008). Under conditions where the soil is often subjected to continuous tillage and use, such as in farms, inundated and waterlogged soils are undesirable for cultivation of most crops (Michael *et al*., 2015a). As pointed out previously, although lime can be applied effectively to manage the by-products of sulfidic soil oxidation, the need for larger quantities is still an issue in many areas, and there is a need to establish cost effective management strategies with wider applicability. One of the options would be to consider using soil materials that would sustain the sulfidic soil alkalinity even when exposed and add values and offset the high cost involved.

When alkaline sandy loam was evenly mixed into sulfidic soil in this study, the soil pH was raised well above the initial pH even under aerobic soil condition where the sulfidic soil was expected to oxidise and generate sulfuric acidity, consistent with what we found previously in the short-term study (Michel *et al*., 2012). Addition of alkaline sandy loam in combination with LH was even far more effective in increasing the pH, although effects on redox and sulfate content were variable. As found in the sulfuric, this result confirms that OM plays an important role in sustaining sulfidic soil alkalinity under exposed soil conditions, possibly by engaging a wide range of microbial ecology, such as sulfate reducing bacteria (Michael, 2015c). The effects being consistent in both the sulfuric and sulfidic soil show that addition of OM with alkaline sandy loam is an important strategy to prevent sulfidic soil oxidation.

## Conclusion

Addition of alkaline sandy into the sulfuric soil increased the pH but moisture content higher than 75% field capacity was needed for higher increase in pH. Addition of alkaline sandy loam in combination with OM was highly effective in increasing pH, reducing the redox and sulfate content. When alkaline sandy soil was added alone or in combination with OM into sulfidic soil, the pH was higher and the redox was reduced, however, the effect on sulfate content was variable. The effects were higher under aerobic conditions than under anaerobic conditions. In all the studies, addition of alkaline sandy loam in combination with OM was found to be the most effective strategy in raising the pH of the sulfuric soil and to curtail oxidation of sulfidic soil. These studies point out an important alternative strategy in management of ASS where availability of lime is an issue and its application is limited, such as in Ramsar wetlands, and flooding of soil to maintain water table to prevent sulfidic soil oxidation is undesirable.

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