

Acid Sulphate Soils and Their Management

Soil acidity is the result of excessive accumulation of H^+ ions over OH^- ions in the soil solution. Acid sulphate soils are soils with a pH below 4 that is directly or indirectly caused by sulphuric acid formed by oxidation of pyrite. Potential acid sulphate soils are poorly drained soils with a high content of pyrite. The pH of the soil will be neutral or slightly acid in the field. Upon drainage, the soil becomes strongly acidic, which directly affects the growth of plants as a result of aluminium and iron toxicity, and indirectly decreases the availability of phosphorus and other nutrients. In India, approximately 390000 hectare lands are found for acid sulphate soils. In general the area covered is 0.26 million hectare. Acid sulphate soils are unproductive or low productivity, it may be due to one or more of the unfavourable factors i.e. soil acidity, salinity, aluminium toxicity, iron toxicity, low content of major nutrients, low base status, and hydrogen sulphide toxicity. Acid sulphate soils are the major problem and require suitable reclamation and management practices, which are useful for enhancing agricultural productivity.

Introduction :

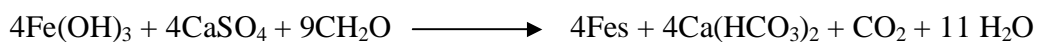
Acid sulphate soil is a name given to soils or sediments containing iron sulphides. Iron sulphides are micro-crystalline minerals such as pyrite that have formed naturally in soils where long-term water-logged conditions occur such as estuaries, wetlands and shallow groundwater in deep sands. Soil minerals containing sulfides (mainly pyrite) that become very acid on drying have been recognized for many years. Because of their pale yellow colour and infertile nature, Dutch farmers named them as Kattakali meaning *Cat Clays*. Chenery (1954) introduced the term Acid Sulphate Soils that have been drained, have adsorbed sulphate and pale yellow colour of Jarosite and usually have low pH (< 4.0) when in water. If the soils are drained or exposed to air by a lowering of the water table, the sulphides react with oxygen and form sulphuric acid. Undrained soils with sulfides also occur in situations where some forms of reclamation have been attempted. These are termed as Potential Acid Sulphate Soils.

Distribution of acid sulphate soils :

They occur in coastal areas under the influence of saline or brackish water or permanent fresh water swamps formerly brackish and in Pleistocene terraces as also in high water swamps with adjacent source of sulphur. In India these soils occur in extensive areas in coastal saline soil zone of West Bengal commonly known as Sunderbanr, Andman Nicobar Islands and in coastal areas of Kerala formed from deltic alluvium of four rivers namely Meenachil, Manimala, Achencoil and low laying area of Vemband lake. In general the area covered is 0.26 million hectare (Mohsin *et al.*, 1995). In India, approximately 390000 hectare lands are found for acid sulphate soils.

Genesis of acid sulphate soils :

The formation of acid sulphate soils consists of two main processes: formation and oxidation of pyrite. The accumulation of pyrite is brought about by the combined effect of somewhat unique conditions that occur in tropical coastal areas. The sulphur in pyrite is derived from the sulphate in sea water, which is biologically reduced to sulphide in the anaerobic mud. An energy source is necessary for bacterial sulphate reduction, and organic matter is usually readily available as a result of abundant plant growth in these coastal areas. Iron, sulphur and sometimes sea water plays an important role. Pyrite (FeS₂) and murcasite are the main source of iron. Sulphur is contributed by brackish and sea water (> 800 mg kg⁻¹ SO₄²⁻ sulphur), sediments containing large amount of sulfides and biological materials like algae and diatoms. Also, ferrous iron (Fe²⁺) must be available, and it is usually derived from the reduction of insoluble ferric compounds that result from the weathering of clay. Thus the combination of sulphate from sea water, organic matter from plant growth, anaerobic conditions caused by exclusion of atmospheric oxygen by the excess water, and the presence of Fe²⁺ result in the formation and accumulation of pyrite in tropical coastal wetlands (Figure 1). Ferrous sulfide is usually an important ingredient which is developed due to chemical reactions such as :



Where, CH₂O represents organic matter which is used as an energy source by microorganisms which bring about the reaction. This iron sulfide accumulates as ferrous sulfide or as iron polysulfide. The sulfide bearing soils usually have pH values near neutrality as long as anaerobic conditions prevail upon drainage, however, the sulfides are oxidized to sulphates due to combination of chemical and microbiological reactions (Somani, 1994).

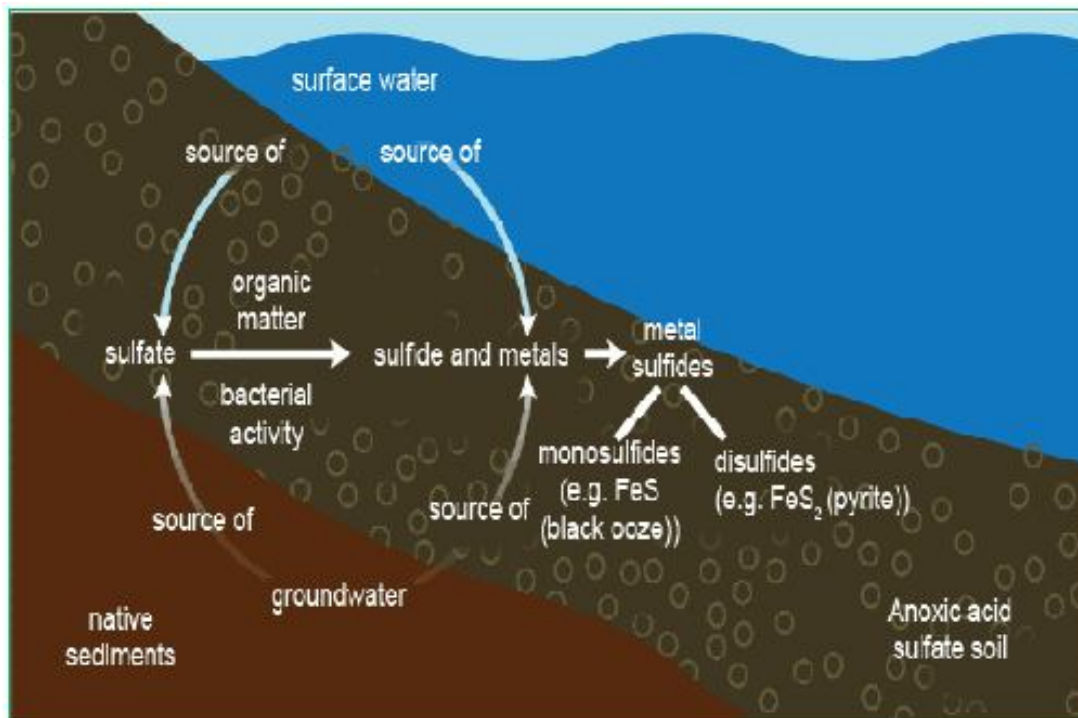
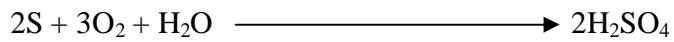
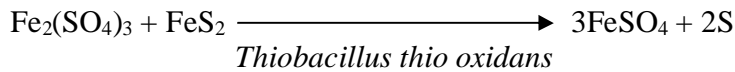
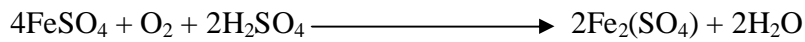
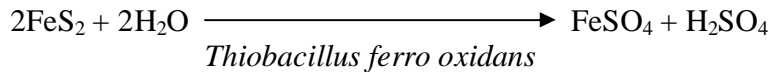


Figure 1 : Formation and accumulation of acid sulphate soil

Classification of acid sulphate soils :

Properties and main classes of acid sulphate soils are given in Table - 1 (Kevie, 1973). It make distinction of soil based on environmental characteristics like active and potential acidity, salinity, texture and composition, depth and seasonal variation of water table, quality of flood water and depth and duration of flooding.

Some of the iron sulphate is precipitated as Jarosite having a formula $(\text{AB})_3(\text{SO}_4)_3(\text{OH})_6$ where “A” may be K, Na, Pb, NH₄ or H₂O and “B” may be Fe³⁺ or Al³⁺. Jarosite is pale yellow in color and is insoluble in water. In presence of saline water some of the reaction products are neutralized and pH remains above 5.0. But, if Ca and Mg are not present extreme acidification occurs and pH may be as low as 1.2. The ferric iron (Fe³⁺) co-ordinates with water molecules like aluminum and behave as acid.

Table 1 : International classification of Acid Sulphate Soils.

Climate zone	Soil Taxonomy	Main characteristics
Potential acid sulphate soils		
World Wide	Typic Sulfaquents	pH (1:1 water) of dried soil < 3.5 within 50 cm if n > 1.0 within 30 cm if n < 0.7
World Wide	Sulfic Hydraquents	pH (1:1 water) of dried soil < 4.5 in upper 25 cm, or more acid between 50 and 100 cm; in n > 0.7 between 20 and 50 cm
Wet tropics & monsoon	Sulfic Trapaquents	Acidity requirements of sulfic hydraquents, but n < 0.7 between 20 and 50 cm
Temperate	Sulfic Fluvaquents	Same as Sulfic Trapaquents
World wide	Typic Sulfihemists	Sulfidic materials within 100 cm; pH (1:1 water) of dried soil <3.5

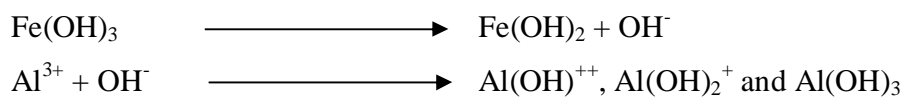
Mineralogy of acid sulphate soils :

Studies conducted by Ghosh *et al.*, (1976) on Kari soils of Kerala reveal that Kaolinite is the dominant clay mineral (34.3%) associated with Smectite (18.32%). Besides these Illite (6-12%), Chlorite (0-11%), Vermiculite (0-5%), Amphibole (0-4%), Gibbsite (0-17%), Quartz (0-2%) and Fledspar (0-2%) were also present.

Causes of low productivity in acid soils :

- Low productivity of these soils is due to -
 1. Injury of hydrogen ions.
 2. Low pH causing
 - Impaired availability and absorption of plant nutrients.
 - Increased solubility of iron, aluminum and manganese resulting in toxicity.
 - Decreased availability of phosphorus and molybdenum.
 3. Low base saturation due to leaching.
 4. Abnormal biotic factors causing impaired mycorrhiza and virulence of plant diseases.
 5. Salt injury.
 6. Telicity due to hydrogen sulphide (H₂S).
 7. Production of organic acids.

- Plant roots are directly injured due to high concentration of hydrogen ions particularly if the pH is < 4.0 . But plants can tolerate concentration of hydrogen ions (H^+) if concentration of polyvalent cations is less. It causes suppressed root growth and root branching because of adverse effect on cell cytoplasm and cell permeability. Numbers of plant roots are less, thick and dull grey to brown in colour. Nutrient absorption capacity of root is reduced. If the pH is around 4.0 rubber, oil palm, coconut, cassava and banana can be grown. Paddy can also be grown under submergence as, it can tolerate high concentration of aluminum (1.2 to 25 mg kg^{-1}) if supply of other nutrients can be maintained because concurrent increase in pH due to continuous submergence lowers the concentration of aluminum. The concentration of aluminum which was 74.5 mg kg^{-1} at pH 3.11 is reduced to 0.3 mg kg^{-1} at pH 4.0. This may be because ferric hydro oxide is reduced to ferrous hydro oxide and the OH released causes the precipitation of aluminum.



- Paddy can also tolerate high concentration of Fe^{2+} (200 mg kg^{-1}). But excess of H_2S present in this range causes Akiochi disease as a result of which respiratory activity of root is reduced, plants become deficient in K, N, Si and bases, iron content in the plant increases to toxic levels and plants are infected with *Helminthosporium* which causes wide spread damage. H_2S can also cause suffocation disease which can be corrected by application of nitrate nitrogen. Another disease called Brusone also develops which is caused by *Piricularia oryzae* and the plant suffers.
- High concentration of aluminum makes the plant roots brittle, devoid of branching with thick root tips and brown lateral roots. Aluminum is attached to phosphate in the DNA structure which inhibits cell division and protein synthesis. It also causes precipitation of nucleic acids and increases the water potential of plants.
- High concentration of manganese decreases translocation of calcium to leaves and increases oxidation of Indole Acetic Acid (IAA) and hence growth of plant tops is affected. Activity and functioning of Mn activated enzyme system is reduced. Excess of Mn causes marginal chlorosis of young leaves and necrotic spots on leaves. However, since considerable quantities of Mn is lost during formation of these soils (due to leaching) very few of these soils suffer from Mn toxicity.

- Organic acids, such as acetic acid, n-butyric acid and propionic acid accumulate in these soils. These acids are phytotoxic.
- The concentration of soluble salts also increases particularly when pyritic soils undergo oxidation and drying. The electrical conductivity (EC) may be as high as 10 dSm^{-1} . Periodic flooding of acid sulphate soils with sea water may further accelerate the salt problem. Because of these reasons the productivity is low and –
 1. Lower yield of crops
 2. Lower chances of increasing yields due to fertilizer application
 3. Further complications arising out of dry spells accentuating the soil acidity.
 4. Drains are blocked due to ochre.
 5. Inundation due to sea water.
 6. Continuous water logging causing H_2S toxicity.

Soil quality problems of acid sulphate soils :

In general, acid sulphate soils are unproductive or low productivity, it may be due to one or more of the unfavourable factors i.e. soil acidity, salinity, aluminium toxicity, iron toxicity, low content of major nutrients, low base status, and hydrogen sulphide toxicity.

- **Soil Acidity :** The acid sulphate soils may be due to the direct effect of hydrogen (H^+) ions, especially below pH 3.5 to 4. However, aluminum toxicity is probably more important in this pH range.
- **Soil Salinity :** Acid sulphate soils in tidal areas are often affected by salinity. Salinity shows the toxicity, by weakening the plants and increasing iron and aluminium concentration in solution.
- **Aluminium Toxicity :** One cause of stress on the growth of certain plant species is aluminium toxicity. A high Al level affects cell division, disrupts certain enzyme systems, and hampers uptake of phosphorus, calcium and potassium. Most plants grown on acid sulphate soils which have a pH below 4 suffer from Al toxicity.
- **Iron Toxicity :** Dissolved iron in excess of 300-400 mg kg^{-1} is toxic to rice crop.
- **Low Nutrient Contents :** In the absence of iron and aluminium toxicity and harmful salinity, phosphorus deficiency is the most important problem of acid sulphate soils. Supply of nitrogen increases the phosphate response.

- **Low Base Status** : During the formation of acid sulphate soils, bases are removed as sulphate and most of the exchange complex is occupied by aluminium. Therefore, acid sulphate soils are likely to be deficient in Ca and K.
- **Hydrogen Sulphide Toxicity** : Hydrogen sulphide has been shown to be toxic to the rice plant through its suppression of the oxidizing power of the roots.

Reclamation and management of acid sulphate soils :

Various important factors which govern reclamation and improved use of these soils are : the degree of acidity developing upon the drainage, depth of non acid top soil covering acid and potential acid sulphate soil horizon buried below, case of controlling water table during dry season besides intensity of dry season.

1. Prolonged submergence.
2. Leaching with rain water, sea water or in succession with these.
3. Addition of lime and manganese dioxide.
4. Ridging, growing of tolerant crops, deep ploughing to mix calcareous horizons, liming fertilizer application and water table control.
5. Improvement of drainage and leaching out of soluble salts repeatedly.

Bandopadhyay (1989) and Mongia and Bandopadhyay (1993) have also reported beneficial effects of liming, leaching and MnO₂ application singly and in combination in improving acid sulphate soils. Mongia *et al.*, (1998) found additive effect of liming and superphosphate application on yield of rice in acid sulphate soils. Manorama *et al.* (1998) suggests that lime should be added in small quantities at short intervals to obtain better rice yield by minimizing the effect of potential acidity.

References :

- Bandopadhyay, A.K. (1989). Leaching of acid saline soils of Sunderbans. *Journal of the Indian Society of Soil Science*, **37**: 416-17.
- Chenery, E.M. (1954). Acid sulphate soils in central Afric. Trans. 5th International Congress Soil Science, Lepoldville.
- Ghosh S.K., Das D.K. and Deb D.L. (1976). Acid soils of India : their genesis characteristics and management, Bulletin – 11, *Indian Society of Soil Science*, New Delhi , 117:133.
- Keve, W.V.D. (1973). Physiography, classifications and mapping of acid sulphate soils. Proceeding International Symposium on Acid Sulphate Soils, IIRL 18, I : 204-231.

- Manorama T.K.C., Cherian, S. and Iyer M.S. (1998). Influence of liming material on soil acidity characteristics of an acid sulphate soils. *Journal of the Indian Society of Soil Science*, 46(2): 296-299.
- Mohsin M.A., Sarkar A.K. and Mahur B.S. (1995). Mineralogy of acid soils. Kalyani Publishers, New Delhi, pp.-69-81.
- Mongia A.D. and Bandopadhyay A.K. (1993). Management of two acid sulphate soils for low land rice cultivation. *Journal of the Indian Society of Soil Science*, 41(2): 400-412.
- Mongia A.D., Singh N.T., Mandal L.N. and Guha A. (1998). Effect of liming super phosphate and rock phosphate application to rice on yield and uptake of nutrients on acid sulphate soils. *Journal of the Indian Society of Soil Science*, 46 (1) : 61-66.
- Somani, L.L. (1994) Use of pyrite in agriculture. Agrotech Publishing Academy, Udaipur, pp 255.