Characterization of Acidity in Acid Sulphate Soils of Kerala

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Abstract: The acidity characteristics of acid sulphate soils of Kuttanad, Kerala, were studied in detail by collecting surface, profile and subsurface soil samples from 20 locations of six soil series viz., Ambalapuzha, Purakkad, Thotapally, Thuravur, Kallara and Thakazhi that belonged to acid sulphate soils. The soils were extremely acidic showing a range of pH (H₂O) varying from 2.5 to 5.2. Lowest pH was recorded by Thakazhi series and the highest by Thotapally. The potential acidity of soils ranged from 14.71 cmol·kg⁻¹ to 110.5 cmol·kg⁻¹ with Thakazhi series showing the highest value. The contribution of hydrolytic acidity to potential acidity ranged from 70.2% to 97.2%. In all soil series, exchangeable Al³⁺ was greater than exchangeable H⁺. A significant correlation was observed among pH (KCl), pH (H₂O) and pH (CaCl₂) in all series.

Key words: Kuttanad, Kerala, acid sulphate soils, potential acidity, exchangeable acidity, hydrolytic acidity, pH.

1. Introduction

Kuttanad, the rice bowl of Kerala includes 50,000 ha of rice fields, out of which 14,227 ha belongs to acid sulphate soils (Typic Sulfaquent) which constituted the kari lands, the most problematic cultivated area. The largest wetlands of the country and is unique among rice ecologies of the world. The rice cultivation in this tract was always risky because of flood submergence during monsoons and saline water intrusion during summer. The above soils face the problems of extreme acidity and presence of toxic quantities of Fe, Al and S which usually limit the crop production and even crop choice in these soils. But these lands also have to be put under cultivation to cope up with the food requirement of the State, where the internal rice production accounts only less than 20% of the requirement. The total rice production of Kuttanad showed a declining trend for the past few decades despite the use of high yielding varieties and modern farming techniques, definitely due to loss of soil health and fall in cropped area. Hence information on the most severe soil problem viz., soil acidity is essential for managing and sustaining rice production and soil health in these soils. To evolve a suitable acidity amelioration/management technology, the characterization of soil acidity is most warranted here. Studies on characteristics of acid sulphate were done by many workers [1-3]. The present paper discusses the contribution of different components of acidity to potential acidity, which will help to sort out the most appropriate technology for managing acidity in Typic Sulfaquent soils.

2. Materials and Methods

Kuttanad, a deltaic formation lying 0.6-2.2 m below mean sea level on the west coast of India, criss-crossed by numerous water courses experiences
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A variety of problems related to soils, physiography, flooding during monsoon, salt water intrusion during summer, accumulation of toxic substances, drainage etc. resulting in drastic variation of morphological and physico-chemical properties of soil. The main crop of the region is paddy supported by fisheries, poultry, duck farming and livestock. Interpretation of the climatic data revealed that the region enjoys a humid tropical climate. The average rainfall recorded in the region was 2737.2 mm. Average maximum and minimum temperatures recorded in the area were 31.9 °C and 24.2 °C, respectively.

The two spells of monsoon prevalent in the area are south-west monsoon during June-September and north-east monsoon during October-November, as shown in Table 1. The region has average wind velocity of 2.4 km·h⁻¹ and sunshine hours 210 h. Four major rivers flowing through the area drain into Vembanad Lake forming an extensive lake-lagoon system opening into Arabian Sea at Kochi. Abundant quantities of partially decomposed fossil wood and organic matter were also present. Pyrites, pyrolites, jarosite, goethite and quartz were the predominant minerals in the area.

After conducting detailed soil survey of the area, six acid sulphate soil series were identified viz., Ambalapuzha, Purakkad, Thottapally, Thuravur, Kallara and Thakazhi constituting a total area of 14,277.51 ha [4]. Surface, subsurface and profile samples were drawn from these six soils series and were analyzed for pH in H₂O, 1 M KCl and 0.01 M CaCl₂ [5]. Exchangeable acidity, exchangeable Al³⁺ and exchangeable H⁺ were determined as per standard procedures described by Page et al. [6] and Hesse [7]. Other chemical properties viz. org. C, N, P, K, Ca, Mg, S, micronutrients were studied [8]. The soils of the study area were classified according to Soil Survey Staff [9]. As per USDA classification the entire study area came under the order Entisols, with suborder Aquent, great group Sulfaquent, subgroup Typic Sulfaquent with six soil series.

3. Results and Discussion

3.1 Confirmation of Acid Sulphate Condition

The entire study area was tested for confirmation of acid sulphate condition by incubating soil samples from different series and their pH was estimated after three months. The entire study area has potential acid sulphate condition since the drop in pH on incubation was greater than 0.5 units.

3.2 Acidity Characteristics of Profile Samples

The acidity characteristics are given in Table 2. The potential acidity of the soils ranged from 13.32 to 112.1 cmol·kg⁻¹. The subsoil showed higher potential acidity compared to surface soils. In the surface horizon, potential acidity varied from 32.87 to 110.5 cmol·kg⁻¹. The highest value was shown by Thakazhi series. The potential acidity is comprised of hydrolytic acidity and exchangeable acidity, the dominant form being hydrolytic acidity. The contribution of hydrolytic acidity to potential acidity ranged from 70.22% to 97.2%. The contribution of exchangeable acidity to potential acidity was very meagre. The exchangeable acidity of soils ranged from 1.23 cmol·kg⁻¹ to 8.1 cmol·kg⁻¹. The contribution of exchangeable H⁺ and exchangeable Al³⁺ to exchangeable acidity did not show a definite pattern.

Table 1  Month wise distribution of rainfall during the study period.

| Month | 1st year | 2nd year | 3rd year |
|-------|----------|----------|----------|
| Jan.  | 80.2     | NIL      | NIL      |
| Feb.  | 63.6     | 3.0      | 59       |
| Mar.  | 13.0     | 3.2      | 60       |
| April | 177.6    | 96.2     | 161.7    |
| May   | 293.0    | 455.7    | 110.4    |
| June  | 612.6    | 650.6    | 504.2    |
| July  | 452.1    | 220.2    | 430.2    |
| Aug.  | 248.0    | 406.2    | 345.2    |
| Sept. | 516.4    | 85.0     | 93.8     |
| Oct.  | 340.8    | 448.5    | 496.9    |
| Nov.  | 122.0    | 302.0    | 95.4     |
| Dec.  | 14.2     | NIL      | NIL      |
| Total | 2933.5   | 2580.6   | 2356.8   |
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Table 2  Acidity parameters of profile samples.

| Series      | Profile | pH   | Exch. acidity | Exch. Al\(^{3+}\) | Exch. H\(^+\) | Potl. acidity | Hydro. acidity |
|-------------|---------|------|---------------|--------------------|---------------|---------------|---------------|
|             |         | H\(_2\)O | KCl | CaCl\(_2\) |                     |               |               |
| Ambalapuzha | Pedon 1 | Ap    | 4.5 | 3.9 | 4.1 | 3.21 | 2.83 | 3.92 | 2.32 | 2.76 | 1.96 | 3.99 | 32.87 | 4.31 | 61.22 | 43.94 |
|             |         | C1    | 4.1 | 3.6 | 3.7 | 2.83 | 1.21 | 3.12 | 4.73 | 7.52 | 5.31 | 2.21 | 4.21 | 38.56 | 2.13 | 49.21 | 38.56 |
|             |         | C2    | 3.8 | 3.1 | 3.4 | 6.67 | 5.32 | 1.35 | 6.31 | 3.29 | 2.12 | 1.17 | 2.83 | 70.87 | 2.13 | 49.21 | 38.56 |
|             |         | C3    | 3.6 | 3.0 | 3.2 | 3.24 | 1.58 | 4.82 | 3.42 | 2.27 | 1.21 | 0.94 | 1.62 | 10.08 | 4.17 | 69.44 | 40.52 |
| Purakkadu   | Pedon 1 | Ap    | 3.6 | 3.2 | 3.4 | 6.31 | 2.97 | 3.34 | 3.92 | 1.96 | 2.76 | 3.63 | 32.13 | 43.51 | 51.23 | 43.94 |
|             |         | C1    | 3.5 | 2.9 | 3.2 | 3.29 | 2.12 | 1.17 | 4.73 | 3.12 | 1.61 | 0.38 | 78.42 | 76.29 | 67.31 | 64.02 |
|             |         | C2    | 3.1 | 2.7 | 2.9 | 2.13 | 1.75 | 0.38 | 6.31 | 3.29 | 2.12 | 5.31 | 32.87 | 38.56 | 70.87 | 76.29 |
|             |         | C3    | 2.8 | 2.4 | 2.6 | 7.52 | 5.31 | 6.67 | 3.92 | 2.27 | 1.21 | 0.94 | 1.62 | 10.08 | 32.13 | 43.51 | 51.23 |
| Thotapally  | Pedon 1 | Ap    | 4.1 | 3.1 | 3.8 | 3.92 | 1.96 | 2.76 | 4.73 | 3.12 | 1.61 | 0.38 | 78.42 | 76.29 | 67.31 | 64.02 |
|             |         | C1    | 3.8 | 3.2 | 3.6 | 4.73 | 3.12 | 1.61 | 7.52 | 5.31 | 6.67 | 3.92 | 32.87 | 38.56 | 70.87 | 76.29 |
|             |         | C2    | 3.5 | 2.9 | 3.3 | 6.21 | 1.31 | 4.9 | 4.73 | 3.12 | 1.61 | 0.38 | 78.42 | 76.29 | 67.31 | 64.02 |
|             |         | C3    | 2.4 | 2.2 | 2.3 | 1.23 | 0.98 | 0.25 | 1.23 | 0.98 | 0.25 | 15.94 | 14.71 | 84.93 | 59.48 |
| Thuravur    | Pedon 1 | Ap    | 3.2 | 2.6 | 3.0 | 5.31 | 1.99 | 3.22 | 7.25 | 2.23 | 5.02 | 2.67 | 63.5 | 58.89 |
|             |         | C1    | 2.8 | 2.4 | 3.2 | 7.25 | 2.23 | 5.02 | 4.56 | 1.89 | 2.67 | 63.5 | 58.89 |
|             |         | C2    | 2.6 | 2.3 | 3.4 | 4.56 | 1.89 | 2.67 | 4.56 | 1.89 | 2.67 | 63.5 | 58.89 |
| Kallara     | Pedon 1 | Ap    | 4.1 | 3.6 | 2.7 | 6.31 | 2.32 | 3.99 | 5.76 | 1.73 | 4.03 | 75.3 | 69.54 |
|             |         | C1    | 3.7 | 3.1 | 2.7 | 5.76 | 1.73 | 4.03 | 7.22 | 4.21 | 3.01 | 109.5 | 84.37 | 96.3 | 90.48 |
|             |         | C2    | 3.8 | 2.8 | 2.5 | 7.22 | 4.21 | 3.01 | 4.96 | 3.72 | 1.24 | 84.4 | 79.44 |
|             |         | C3    | 3.1 | 2.6 | 2.2 | 4.96 | 3.72 | 1.24 | 4.96 | 3.72 | 1.24 | 84.4 | 79.44 |
| Thakazhi    | Pedon 1 | Ap    | 3.5 | 2.8 | 3.0 | 5.82 | 4.31 | 1.51 | 8.1 | 6.12 | 1.98 | 81.3 | 76.9 |
|             |         | C1    | 3.2 | 2.8 | 2.9 | 8.1 | 6.12 | 1.98 | 4.31 | 2.13 | 2.19 | 104.51 |
|             |         | C2    | 3.3 | 2.6 | 2.6 | 4.31 | 2.13 | 2.19 | 4.31 | 2.13 | 2.19 | 81.3 | 76.9 |

and showed wide variation among pedons. The pH(H\(_2\)O) in general showed a regular variation with depth in pedons of Ambalapuzha, Purakkad, Thotapally, Thuravur and Thakazhi. The lowest pH recorded was 2.4. The pH(KCl) showed a regular variation with depth in Ambalapuzha, Purakkad, Thuravur and Kallara series. For pH(CaCl\(_2\)) a regular pattern of decrease in pH with depth was observed in Ambalapuzha and Thakazhi series. In pedons of Kallara, Thuravur and Purakkad also showed a regular decrease in pH with depth was noticed. Soils of the study area were extremely acidic in nature due to the presence of large quantities of sulphides which on oxidation produces sulphuric acid. Generation of organic acids during the decomposition of organic matter aggravat ed the extent of acidity. The pH (H\(_2\)O) of acid sulphate soils is depicted in Fig. 1.

3.3 Acidity Characteristics of Surface and Subsurface Samples (Tables 3-5)

While considering the acidity parameters of different surface samples, as shown in Table 3, potential acidity showed very high values compared to exchangeable acidity. The exchangeable acidity of surface soil samples was highest for Thuravur series (6.15 cmol·kg\(^{-1}\)). The potential acidity showed the highest value (89.34 cmol·kg\(^{-1}\)) in the case of Purakkad series, the lowest being in case of Ambalapuzha series (35.78 cmol·kg\(^{-1}\)). The hydrolytic acidity was highest for Purakkad series (84.37 cmol·kg\(^{-1}\)). All the acidity parameters showed wide variation among different surface samples. In all series, exchangeable Al\(^{3+}\) was greater than exchangeable H\(^+\). The exchangeable Al\(^{3+}\) was the highest for Thuravur series (3.91 cmol·kg\(^{-1}\)) and the lowest value was noticed for Ambalapuzha series (1.41 cmol·kg\(^{-1}\)). Exchangeable H\(^+\) was also the highest in Thuravur series (2.43 cmol·kg\(^{-1}\)).

The subsurface samples were highly acidic. The exchangeable acidity varied from 1.78 cmol·kg\(^{-1}\) to 9.83 cmol·kg\(^{-1}\). The exchangeable Al\(^{3+}\) content varied from 0.67 cmol·kg\(^{-1}\) to 6.64 cmol·kg\(^{-1}\) and the highest
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Table 3  Acidity parameters of surface samples of different series (average value) (cmol·kg⁻¹).

| Series     | Ex. acidity | Ex. Al | Ex. H⁺ | Pot. acidity | Hyd. acidity | Contribution to pot. acid | Contribution to Hyd. acid |
|------------|-------------|--------|--------|--------------|--------------|---------------------------|---------------------------|
|            |             |        |        |              |              |                           |                           |
| Ambalapuzha| 2.06        | 1.41   | 0.65   | 35.78        | 31.75        | 87.00                      | 13.00                     |
|            |             |        |        |              |              |                           |                           |
| Purakkad   | 4.96        | 2.90   | 2.05   | 89.34        | 84.37        | 94.45                      | 5.55                      |
|            |             |        |        |              |              |                           |                           |
| Thitapally | 3.09        | 2.03   | 1.02   | 38.57        | 35.49        | 92.00                      | 8.00                      |
|            |             |        |        |              |              |                           |                           |
| Thuravur   | 6.15        | 3.91   | 2.43   | 78.23        | 72.07        | 92.14                      | 7.86                      |
|            |             |        |        |              |              |                           |                           |
| Kallara    | 5.08        | 3.15   | 1.93   | 88.56        | 81.62        | 94.14                      | 5.86                      |
|            |             |        |        |              |              |                           |                           |
| Thakazhi   | 4.06        | 2.32   | 1.82   | 40.74        | 36.69        | 90.05                      | 9.95                      |

Table 4  pH of subsurface samples.

| Series     | pH(H₂O) | pH(KCl) | pH(CaCl₂) |
|------------|---------|---------|-----------|
| Ambalapuzha| 2.9-4.3 | 2.8-3.9 | 2.5-3.9   |
|            | 3.7     | 3.3     | 3.5       |
| Purakkad   | 2.5-3.4 | 2.6-3.9 | 2.6-4.4   |
|            | 2.9     | 2.8     | 3         |
| Thotappally| 2.8-4.2 | 2.9-4.0 | 3.2-4.7   |
|            | 3.6     | 3.5     | 4.1       |
| Thuravur   | 2.4-3.8 | 2.3-3.6 | 2.9-4.4   |
|            | 2.8     | 2.5     | 3.1       |
| Kallara    | 2.9-3.8 | 2.4-4.2 | 2.6-4.3   |
|            | 3.4     | 2.6     | 2.7       |

Table 5  Acidity parameters of subsurface samples (cmol·kg⁻¹).

| Series     | Ex. acidity | Ex. Al⁴⁺ | Ex. H⁺ | Potl. acidity | Hyd. acidity |
|------------|-------------|----------|--------|--------------|--------------|
| Ambalapuzha| 3.20        | 1.83     | 1.37   | 40.67        | 37.47        |
|            | 1.78-4.83   | 0.86-2.75| 0.92-2.08| 16.35-68.18  | 14.57-63.35  |
| Purakkad   | 4.76        | 3.53     | 1.23   | 21.32-100.5  | 19.09-93.14  |
|            | 2.23-7.36   | 1.71-5.4 | 0.52-1.96| 51.40        | 32.32-87.96  |
| Thotapally | 4.20        | 2.83     | 1.37   | 34.30-96.40  | 45.80        |
|            | 1.98-8.44   | 0.67-6.64| 1.37-1.80| 34.30-96.40  | 45.80        |
| Thuravur   | 7.96        | 2.25     | 5.71   | 53.76        | 45.80        |
|            | 2.10-9.36   | 1.99-3.48| 0.11-5.88| 21.20-89.50  | 19.1-80.14   |
| Kallara    | 6.94        | 1.93     | 5.01   | 96.40        | 89.46        |
|            | 1.98-8.76   | 0.76-2.65| 1.22-6.11| 22.64-116.8  | 20.36-108.04 |
| Thakazhi   | 6.76        | 4.51     | 2.25   | 100.50       | 93.74        |
|            | 2.01-9.83   | 1.31-6.16| 0.70-3.67| 28.3-110.5   | 26.29-100.67 |

A significant positive correlation was observed among pH(H₂O), pH(CaCl₂) and pH(KCl) in the surface and profile samples of all the series. pH was negatively correlated with exchangeable acidity in Ambalapuzha series and negative correlation was seen between potential acidity and pH(H₂O) in Thakazhi series. A significant positive correlation was observed among exchangeable Al, exchangeable H⁺ and exchangeable acidity in Purakkad series. A positive correlation was observed between exchangeable Al⁴⁺,

value was noticed in Thakazhi series. For exchangeable H⁺, the values ranged from 0.11 cmol·kg⁻¹ to 6.11 cmol·kg⁻¹. Among the different series, for potential acidity and hydrolytic acidity, Thakazhi series recorded highest value being 100.5 cmol·kg⁻¹ and 93.74 cmol·kg⁻¹, respectively. The four series that showed higher contribution of exchangeable Al⁴⁺ towards exchangeable acidity were Ambalapuzha, Purakkad, Thotapally and Thakazhi series. Among the sub surface samples, the lowest value for pH(H₂O) was shown in Kallara series, the value being 2.9. The pH(KCl) was lower as compared to the pH(CaCl₂) and pH(H₂O).

3.5 Corelation Studies

A significant positive correlation was observed among pH(H₂O), pH(CaCl₂) and pH(KCl) in the surface and profile samples of all the series. pH was negatively correlated with exchangeable acidity in Ambalapuzha series and negative correlation was seen between potential acidity and pH(H₂O) in Thakazhi series. A significant positive correlation was observed among exchangeable Al, exchangeable H⁺ and exchangeable acidity in Purakkad series. A positive correlation was observed between exchangeable Al⁴⁺,
potential acidity and hydrolytic acidity in profile samples of all the series.

The lowest pH was recorded by Thakazhi series and highest by Thotapally series. pH(KCl) was lowest than pH(H$_2$O) and pH(CaCl$_2$) as in the case of profile samples. Ferruginous soils formed under humid tropical climate having high rainfall are characterized by depletion of bases from the solum due to intense leaching and accumulation of acid forming ions like H$^+$ and Al$^{3+}$ leading to development of soil acidity. High concentration of CO$_2$ and reduced redox potential (Eh) influenced the soil pH. Organic acids are produced by the anaerobic decomposition of organic matter. pH values of Kuttanad varied from 2.6 to 5.9 as reported by Thampatti [10]. The pH(KCl) recorded the lowest value indicating the very high influence of salt.

Soil organic matter possesses number of functional groups containing H$^+$ ions that contribute to different kinds of acidity. It was observed that values of pH dependent acidity were higher than that of exchangeable acidity. The pH dependent acidity increased linearly with clay, organic carbon and free oxides of Fe and Al content of soil [11]. KCl acidity was attributed to isomorphous substitution whereas pH dependent acidity can be attributed to polymers of Fe and Al and soil organic matter. Acid sulphate soils were found to be highest in total acidity, since the contents of organic matter and exchangeable Al were very high in acid sulphate soils. Compared to total acidity, the values of exchangeable acidity were very low in these soils. Relatively low contribution of exchangeable acidity towards total acidity is similar to the findings of many workers [12-15]. Exchangeable acidity as a part of total acidity varies with the nature of soil and base saturation. H$^+$ and Al$^{3+}$ are not the only ions that contribute to soil acidity, Fe and Mn, the major hydrolysable ions in the exchange sites of soil complex, also produce soil acidity remained unaccounted, on the basis of these two forms of acidity.

### 3.6 Available Nutrient Content

Organic carbon contents of soil samples were high. Due to high P fixation, these soils were deficient in available P. The potassium content was high and ranged from 142.1 mg·kg$^{-1}$ to 326.4 mg·kg$^{-1}$. Ca, Mg, Na and S content were also high. Fe, Mn and Al toxicity were prevalent in the region, as shown in Table 6.
Table 6  Salient chemical properties of soils studied.

| Series      | Org. C (%) | Avail. P (mg·kg⁻¹) | Avail. K (mg·kg⁻¹) | Avail. Ca (mg·kg⁻¹) | Avail. Mg (mg·kg⁻¹) | Avail. S (mg·kg⁻¹) | CEC (mg·kg⁻¹) |
|-------------|------------|---------------------|--------------------|---------------------|---------------------|-------------------|---------------|
| Ambalapuzha | 2.73       | 3.72                | 219.3              | 744                 | 514                 | 1295              | 28.4          |
| Purakkad    | 4.76       | 4.26                | 142.1              | 872                 | 674                 | 2931              | 30.60         |
| Thitapally  | 3.32       | 3.11                | 221.2              | 674                 | 486                 | 1966              | 23.32         |
| Thuravur    | 4.45       | 2.85                | 326.4              | 635                 | 486                 | 3114              | 29.35         |
| Thakazhi    | 5.35       | 2.12                | 199.9              | 915                 | 536                 | 2695              | 31.60         |
| Kallara     | 4.41       | 3.59                | 162.7              | 781                 | 518                 | 1776              | 19.63         |

4. Conclusion

The acid sulphate soils of Kuttanad region recorded very low pH of 3 to 5.2. The potential acidity was very high compared to exchangeable acidity. For amelioration of acidity special management practices such as liming and washing out of water, bunding, providing subsurface drainage etc. can be undertaken. Most ideal land use model which can be suggested for the area is rice-fish rotational farming. Thus the knowledge obtained on the soils through methodological investigation and data base generated can be utilized for sustainable development of these acid sulphate soils.

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