Some Changes in Chemical Characteristics of a Paddy and Mangrove Soil Sample during Submergence in Water

J. MARCUS, M. FARIDAWATI, and M.L. ZALMA
Faculty of Science and Natural Resources
UKM Campus Sabah, 88996 Kota Kinabalu
Sabah, Malaysia.

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ABSTRACT

This study was conducted to determine the changes of some chemical characteristics of a dry paddy and mangrove soil sample when submerged in water for a 0 - to 10 - weeks period. The redox potential of the soils and the pH, EC, concentrations of cations (Na, K, Mg, Ca, Fe and Mn) and concentrations of nitrogen, phosphate and sulphate of the soil solutions changed due to submergence. The changes were most significant during the first two weeks of submergence.

INTRODUCTION

Under aerobic conditions, soil microorganisms such as aerobic bacteria use oxygen for respiration. Oxygen has a high affinity for electrons and thus acts as an electron acceptor during the respiration process. The oxygen is, however, reduced to water during the process (Rowell, 1981). When a soil is submerged in water, gas exchange between soil and air is drastically curtailed and therefore the oxygen supply to the soil is cut off. Within a few hours of submergence, microorganisms use up the oxygen present in the water or trapped in the soil and render a submerged soil practically devoid of oxygen (Evans and Scott, 1955; Scholander et al., 1955; Takal et al., 1956; Ponnampерума, 1965; Turner and Patrick, 1968). Due to this anaerobic condition the aerobic organisms can no longer function and so either die or go into a resting stage. However, soils contain a wide variety of microorganisms and, in the absence of oxygen, anaerobic bacteria proliferate. These anaerobes utilize oxidized soil components such as nitrate, manganic oxides, ferric oxides, sulphate, phosphate and dissimilation products of organic matter as electron acceptors in their respiration and thus reduce them (Ponnampemruma, 1965). The change from aerobic to anaerobic conditions causes changes in chemical properties of the soil and soil solution (Patrick, 1960; IRRI, 1964; Ponnampemruma, 1965, 1972, 1978; Patriek and Reddy, 1978; Yamane, 1978; Ponnampemruma, 1981).

The objective of this study was to investigate the changes in some chemical characteristics of a Malaysian paddy and mangrove soil sample when both were changed from aerobic to anaerobic condition through submergence under water.

MATERIALS AND METHODS

Waterlogged samples of both paddy and mangrove soils were taken from their respective locations in Sabah Malaysia and, on reaching the lab, the soils...
were filtered to get their respective soil solutions using filter paper No. 43 under vacuum conditions. The redox potential (Eh) of the wet soils and the pH as well as electrical conductivity (EC) of the soil solutions were later determined.

The wet soils were then air dried and their < 2 mm fractions were collected through sieving. The pH, Eh, EC, amounts of exchangeable cations (Na, Mg, Ca, Al, H, Fe and Mn) and amounts of water-soluble phosphate and sulphate were determined.

In order to investigate the effect of submergence, 400g of each soil sample were put in plastic containers and then filled with 300 ml of distilled water and mixed thoroughly to give a soil paste. Excess distilled water was then added until the water level was at least 4 cm above the soil surface. The soil was left in the submerged state for 0, 2, 4, 6, 8 and 10 weeks. Water level in the respective containers was maintained throughout the designated period without disturbing the soil. The above experiment was carried out in duplicate for both soil samples.

When each period of submergence was achieved (the "zero" week sample was taken immediately after mixing the soil with water), excess water above the soil surface in each plastic container was removed and discarded. The Eh of the wet soil was then measured before the soil was filtered to give a soil solution. The pH, EC, concentrations of cations (Na, K, Mg, Ca, Fe and Mn) and concentrations of nitrogen, phosphate and sulphate in the soil solution were then determined.

Throughout the above analyses, redox potential was measured directly using a Pt redox electrode. The electrode was initially standardised using a standard redox buffer which has an Eh of 430 mV (Light, 1972). The electrode was inserted into the respective wet soils up to a 6 cm depth and the Eh reading was recorded after 10 minutes. The pH and EC of the soil solutions were determined using a pH electrode and a conductivity electrode respectively. The pH and EC of the soils were, however, measured in a 1:2 suspension of distilled water. Exchangeable cations (Na, Mg, Ca, Al, H, Fe and Mn) of the soils were extracted using 1.0 M KCl and then determined by atomic absorption spectrophotometry (AAS). Cations in the soil solutions were determined directly by AAS. Water-soluble phosphate and sulphate in the soils and soil solutions were determined colourimetrically (Murphy and Riley, 1962) and by the turbidity method (using BaCl₂) respectively. Total nitrogen in the soil solutions was determined using a micro-Kjeldhal method (Page et al, 1982), while ammonium was directly measured using a ammonium electrode.

RESULTS AND DISCUSSION
Some chemical properties of the paddy and mangrove soil samples studied are shown in Table 1. The wet (freshly taken from the field) and dry samples had negative and positive potentials, respectively. Soils with a negative Eh were considered to be in a reduced state, while those with positive Eh were considered to be in an oxidized state (Patrick and Mahapatra, 1968; Ponnamperuma, 1972). Therefore the wet and dry soils were in a reduced and oxidized state, respectively. The pH of the wet soils was always about pH 7. This value is common for soils under reduced conditions (Patrick and Reddy, 1978). The dry soils were, however, acidic. The EC of the mangrove soil was relatively high compared to the paddy soil, which might be due to the influence of sea water on the mangrove soil. Similarly organic matter content, water - soluble sulphate and exchangeable basic cations were significantly higher in the mangrove soil.

Changes in Eh of the soil samples upon submergence are shown in Figure 1(a). The Eh values of both soils decreased to a stable value of about — 200 mV after two weeks of submergence. Similar changes in Eh of submerged soils have been shown by IRRI (1964), Ponnamperuma (1965, 1972), and Yamane (1978). The rapid decrease in Eh was apparently due to a release of reducing substances accompanying oxygen depletion before Mn (IV) and Fe (III) oxide hydrates could mobilize their respective buffer capacities (Ponnamperuma, 1972, 1981). The decrease in Eh of most acid soils can be explained quantitatively in terms of the potential of the Fe(OH)₃ - Fe²⁺ redox system (Ponnamperuma et al, 1966; Yamane, 1978). The rapid decrease could also be related to the high organic matter contents of the soils (Yamane, 1978).

The pH of soil solutions from both soils increased to a stable value after two weeks of submergence. The final pH of the paddy soil
CHANGES IN CHEMICAL CHARACTERISTICS OF A PADDY AND MANGROVE SOIL DURING SUBMERGENCE

TABLE 1
Some chemical properties of the paddy and mangrove soil samples

<table>
<thead>
<tr>
<th></th>
<th>PADDY</th>
<th></th>
<th>MANGROVE</th>
<th></th>
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<tbody>
<tr>
<td></td>
<td>wet</td>
<td>dry</td>
<td>wet</td>
<td>dry</td>
</tr>
<tr>
<td>pH (1 : 2)</td>
<td>6.7</td>
<td>4.5</td>
<td>7.2</td>
<td>5.9</td>
</tr>
<tr>
<td>Eh (mV)</td>
<td>-180</td>
<td>360</td>
<td>-200</td>
<td>420</td>
</tr>
<tr>
<td>EC (mmhos cm⁻¹)</td>
<td>1.8</td>
<td>0.9</td>
<td>52.5</td>
<td>19.5</td>
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<tr>
<td>Exchangeable cations (meq 100 g⁻¹)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na</td>
<td>0.2</td>
<td></td>
<td>62.5</td>
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<tr>
<td>K</td>
<td>0.7</td>
<td></td>
<td>2.6</td>
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<tr>
<td>Ca</td>
<td>0.4</td>
<td></td>
<td>10.8</td>
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<tr>
<td>Mg</td>
<td>0.9</td>
<td></td>
<td>38.9</td>
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<tr>
<td>Al</td>
<td>1.0</td>
<td></td>
<td>0.0</td>
<td></td>
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<tr>
<td>H</td>
<td>1.1</td>
<td></td>
<td>0.1</td>
<td></td>
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<tr>
<td>Exchangeable (% g⁻¹)</td>
<td></td>
<td></td>
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<tr>
<td>Fe</td>
<td>178.0</td>
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<td>278.0</td>
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<tr>
<td>Mn</td>
<td>74.0</td>
<td></td>
<td>6.4</td>
<td></td>
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<tr>
<td>Water soluble (µL/g g⁻¹)</td>
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<td></td>
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<td></td>
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<tr>
<td>Phosphate</td>
<td>25.0</td>
<td></td>
<td>0.6</td>
<td></td>
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<tr>
<td>Sulphate</td>
<td>1450</td>
<td></td>
<td>3125</td>
<td></td>
</tr>
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</table>

was higher than for the mangrove soil, as shown in Figure 1(b). Similar changes in the pH of submerged acid soils have been shown by Tomlinson (1957) and Ponnampereuma (1965, 1972). During reduction of the inorganic components of the soil under anaerobic condition, protons were used and therefore the pH increased. The increase in pH of most acid soils upon submergence is largely due to the reduction of Fe (III) to Fe(II) (Ponnampereuma et al, 1966). The fairly stable pH attained after two weeks of submergence was due to the consumption of initially present electron acceptors and the sustained production of carbon dioxide. The significantly lower pH of the mangrove soil could reflect a small amount of acid-sulphate property for this soil with its high organic matter content.

Changes in EC of the soil solutions of the two submerged soils are shown in Figure 2(a). Note the break in scale between the two soil curves. The EC of the submerged paddy soil attained a maximum during the second week, and then declined to a fairly stable value. Ponnampereuma (1965, 1972) obtained similar results.

The EC of the mangrove soil, however, reduced rapidly to a fairly stable value during submergence. The changes in conductance reflect the balance between reactions that produce ions and those which inactivate them, and it seems that inactivation of ions was prevalent in the mangrove soil. There was a close similarity between the changes in EC and the changes in total soluble cations (Na, K, Ca, Mg, Fe and Mn) in the soil solutions as shown in Figure 2(b). The cations were mainly Na and Mg for the mangrove soil, reflecting seawater influence.

The EC increased as the total cation concentration increased, and vice versa. The increase in cations of the soil solution was due to the release of soluble Fe(II) and Mn(II) during the reduction of Fe(III) and Mn(IV), respectively, with some of these cations then being displaced from exchange sites on soil colloids into the soil solution (Ponnampereuma, 1972).

Figure 3(a) and Figure 3(b), respectively, show the changes in Mn and Fe concentrations of the soil solutions during submergence. Concentrations of both Mn and Fe in the soil solution of
the submerged paddy soil attained a maximum during the second week and then gradually declined to a fairly stable value. Similar changes were observed by Ponnamperuma (1965, 1972, 1981). The initial increase in Mn and Fe was due to the reduction of solid-phase Mn(IV) and Fe (III) compounds, functioning as electron acceptors, during respiration of anaerobic bacteria. The reduction produced more-soluble Mn(II) and Fe (II) compounds and therefore the amounts of these ions in solution increased (IRRI, 1964; Ponnamperuma, 1972). The decrease in concentration might similarly be due to immobilization of Mn and Fe. The soluble Mn and Fe could pre-
Changes in Chemical Characteristics of a Paddy and Mangrove Soil During Submergence

Fig. 3: Changes in Mn and Fe concentrations in the soil solutions, paddy (x) and mangrove (*), during submergence.

Comparison between the total nitrogen and ammonium-N in the soil solutions indicates that ammonium-N contributed significantly to the total nitrogen. Higher amounts of ammonium-N were detected in the mangrove soil, which could be related to its high content of organic matter. One of the main factors affecting the production of ammonium-N is the organic matter content of a submerged soil (Ponnampерума, 1965). The subsequent decrease in ammonium-N concentration could be due to fixation by soil colloids.

Phosphate and sulphate contents of soil solutions also change during submergence, as shown in Figure 4(b) and Figure 4(c). Phosphate concentration decreased to a minimum during the first four weeks of submergence and then later increased slightly once more. These changes were not similar to the results obtained by Ponnampерума (1965, 1972), where phosphate concentration increased initially and then decreased once more. The principal effect of anaerobic conditions on phosphorus in soils is a change in the solubility of phosphate (Ponnampерума, 1972). The increase in pH during submergence will normally increase the concentration of phosphate in the soil solution, since iron and aluminium phosphates liberate...
phosphate ions as the pH rises (Larsen, 1967). The reduction of Fe(III) to Fe(II) will also cause a release into solution of adsorbed, chemically-bound and occluded phosphate. These might be the likely reasons why the phosphate concentrations in the soil solution of the submerged paddy and mangrove soils increased after decreasing initially. The initial decrease in concentration might be due to a precipitation of phosphate. The concentrations of Mn and Fe were highest during the initial stage of submergence. Therefore a proportion of the Mn and Fe released into the soil solution might form less-soluble precipitates with the phosphate.

The concentration of sulphate in the soil solution of the paddy soil increased during the initial stage of submergence and then decreased. In contrast, it decreased first and then increased for the mangrove soil. Values were also much higher for this soil, further suggesting an acid-sulphate nature for it as discussed previously for pH effects. The changes in water soluble-sulphate varies widely with soil properties (IRRI, 1965; Ponnampuruma, 1981). Reduction of sulphate to sulphide would cause a decrease in sulphate concentration of the soil solution, while release of sulphate from anion-exchange sites as pH increased would increase its concentration instead.

CONCLUSION

Submergence of dry paddy and mangrove soils changed them from an oxidized to a reduced state, as shown by their negative redox potentials. This resulted in changes in the chemical characteristics of the soil solutions. Therefore, soils under oxidized conditions have different chemical characteristics compared to soils under reduced conditions.

REFERENCES


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