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Chemical properties and phosphorus fractions in profiles of acid sulfate soils of major rice growing areas in Brunei Darussalam

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ABSTRACT

Brunei Darussalam contains a wide range of potential acid sulfate soils, and its rice yield is only about 1.7 t/ha, which is significantly lower than that of other rice producing countries. A few studies have used the sequential phosphorus (P) fraction to investigate P dynamics and interactions in rice soils, which is necessary for the management of P. However, there is currently no information available regarding the fractions of P in Brunei Darussalam. Therefore, this study was conducted to assess the chemical properties and different inorganic forms of P in potential acid sulfate rice soils of Brunei Darussalam to enable better crop management. A total of 40 samples were collected at depths ranging from 0 to 100 cm and analyzed for soil chemical properties and inorganic P fractions. The major soil constraints for rice cultivation are extreme acidity, low cation exchange capacity, toxicity of Al and micronutrients and low P. Al, Fe and Mn toxicities are common in acid sulfate soils. Among the P fractions, the distribution of inorganic P forms in the soils was in the order of Fe–P > Al–P > Reductant soluble-P > loosely bound P (Saloid-P) > Ca–P. These findings indicate that soil reclamation with liming and a good fertilizer management program is essential to boosting rice production in potential acid sulfate soils.

1. Introduction

The main limitation of crop growth worldwide is acidic soil, especially in humid tropical, subtropical and temperate zones. A total of 24 million ha of acid sulfate soils exit worldwide (Sullivan, 2004). In areas containing these soils, agricultural productivity has decreased because of strong acidic conditions, which, in turn were caused by oxidation of pyritic materials and toxic metals (Van Mensvoort and Dent, 1998). Brunei Darussalam contains a wide range of acid sulfate soils, which is likely a factor in its low rice yield of about 1.7 t/ha (Galawat and Mitsuyasu, 2012). Yield limitations are due to soil acidity, water logging and sulfidic material (Grealish et al., 2008). Achieving self-sufficiency in the food supply is very important for Brunei Darussalam as it imports most of its food, including 95% of its rice (Debbie, 2014). To meet the target of increasing rice production and reduce reliance on imported food products, a suitable fertilizer management program is required.

Phosphorus availability is usually restricted in acid sulfate soils as added P is strongly absorbed (Belmehdi and Nyiri, 1990). It is very important to know about the different P fractions as these fractions replenish depleted P or fix available P (Saleque et al., 2004). As such, soil P fractions have been investigated since 1957 and were later applied to overcome the limited information provided by total P analysis (Zhou et al., 2001). Sequential chemical extractions provide a snapshot of the general strength of P adsorption to soil materials, as well as a pool of fixation (Hall, 2008). These methods are based on the selective extraction of operationally defined P fractions by using single extractants in a sequential manner (Ruiz et al., 1997).

The P chemistry of lowland rice soils is different from that of arable soils because of the wetting and drying cycles imposed during cultivation. The few studies of sequential P fractionation in rice systems have focused on how fertility management (both chemical and organic) affects the fate of P within soils (Yang et al., 2006; Zhang et al., 2006; Pheav et al., 2005; Saleque et al., 2004). However, information regarding the chemical forms of P is essential to the understanding of P dynamics and its interactions in rice soils, and therefore necessary for P management.

This study was conducted: (i) to examine rice soil-P fractions in agriculture development areas in Brunei Darussalam and (ii) to understand the relationship between soil-P fractions and other soil chemical properties to facilitate design of efficient soil fertility management systems.

2. Materials and methods

2.1. Study sites

Brunei Darussalam is divided into four districts: namely, Brunei-Muara, Tutong, Belait and Temburong. Soil samples were collected

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from four agricultural development areas, Wasan and Limau Manis (Junjungan) in the Brunei-Muara District, Selapon in the Temburong District and Labi (Lot Sengkuang) in the Belait District (Fig. 1). The climate and soil-type history of the study sites is summarized in Table 1.

2.2. Soil sampling and analysis

Soil samples were collected at depths of 0–20, 20–40, 40–60, 60–80 and 80–100 cm in two lowland rice fields at four locations (five samples per paddy field) using a soil auger (2.5 in. in diameter). All soil samples were analyzed in triplicate.

Soil samples were dried for 5 days at 40 °C, then powdered using a mortar and pestle, after which they were passed through a 2 mm-sieve. To estimate the organic carbon (OC), a small quantity of the 2 mm-sieved material was passed through a 0.2 mm-sieve, after which it was finely ground with a mortar and pestle. The pH and electrical conductivity were determined in a 1:2.5 soil water (weight to volume) suspension. OC was measured using Walkley and Black's wet oxidation method with potassium dichromate, sulfuric acid and orthophosphoric acid (Van Reeuwijk, 2002). The exchangeable bases (Ca, Mg, Na, and K) were extracted with 1 M NH_4OAc solution in a 1:10 (soil-solution) ratio, while micronutrients (Fe, Cu, Mn and Zn) were extracted with 0.005 M diethylene triamine pentaacetic acid (DTPA) solution using a 1:2 soil-solution ratio and determined by inductively coupled plasma optical emission spectroscopy (ICP-OES). Cation exchange capacity (CEC) was measured by summation of the exchangeable Ca, Mg, Na and K (Watson and Brown, 2014). Exchangeable aluminum was extracted with 1 M KCl solution in a 1:20 ratio and titrated with a 0.1 N HCl solution using a phenolphthalein indicator (McLean, 1965). Available P was determined using the Bray-I method and total P was determined by the nitric acid digestion method. To obtain Bray-I P, 2 g of soil was extracted with 14 ml of extractant solution (0.03 M NH_4F and 0.025 M HCl-1:1.7 ml), after which the mixture was shaken for 5 min at 180 rpm. The contents were then filtered through a Whatman No. 2 filter paper (Van Reeuwijk, 2002). Total P was obtained by digesting 2 g of soil with 30 mL of nitric acid (65%). After the mixture cooled, 20-mL of distilled water was added and the contents were filtered through a Whatman No. 1 filter paper. The inorganic P fractions which included Saloid-P, Al–P, Fe–P, reductant soluble-P and Ca–P, were measured by the (Kuo, 1996) fractionation scheme as shown in Fig. 2 (Pierzynski, 2000). The fractionation procedures were based on the differential solubility of the various inorganic forms in different extracts. P analysis was conducted using ascorbic acid (Murphy and Riley, 1962) and then determined by the colorimetric method using a UV-spectrophotometer.

2.3. Statistical analyses

Statistical analyses were carried out using SPSS version 20 (SPSS version 20. IBM statistics, 2011). Data in tables and figures are presented as the means, the standard error. To investigate the relationships between inorganic soil P fractions and soil chemical properties, correlation analysis of the entire dataset was performed (all depths were pooled).

3. Results and discussion

3.1. Soil chemical properties

The chemical properties of the soil (0–100 cm) from the different agricultural development areas are summarized in Tables 2.1, 2.2 and 2.3. Although the soil pH of the top 20 cm did not vary much (3.4–3.9) among selected sites, a gradual increase with profile depth 0–20 (pH 3.5) to 80–100 cm (pH 4.2) was evident Fig. 3.a. These findings indicate that the soil is highly acidic in accordance with the Soil Survey Manual (Soil Survey Division Staff, 1993), which classifies a soil pH of 3.5 to 4.4 as extremely acidic. Each type of soil contains certain acidity depending on its composition and rainfall amounts. Various factors cause changes in soil pH over time; a common source of acidity is H^+ ions, which are released when high levels of Al^{3+} in the soil undergo hydrolysis (Douglas and Dwight, 2001). A slight increase in soil pH in deeper horizons indicates an accumulation of bases (Fig. 4.a). Lower pH values in the surface soils reflect the influence of organic matter in the surface. A similar trend, in which pH increases with depth of soil profile, was also observed by Kumar and Kishan (2012), Sahu et al. (2001), Deenik and Yost (2006) and Ajwa et al. (1998)). These findings could be attributed to the removal of basic cations from the surface of the soils to the lower depths (Mustapha and Loks, 2005; Voncir et al., 2008; Kolo et al., 2009; Mustapha et al., 2011), and/or the use of acid-forming fertilizers such as urea for agricultural purposes.

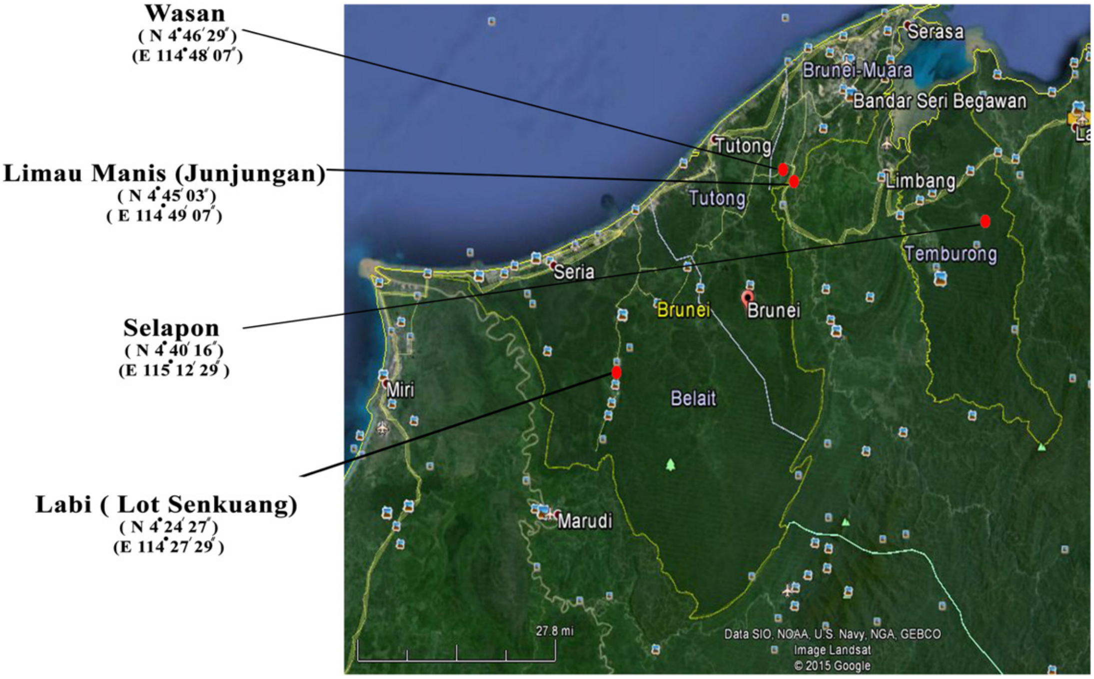

Fig. 1. Location of study areas in Brunei Darussalam.