Agriculture and Natural Resources 50 (2016) 321–325

Contents lists available at ScienceDirect

Agriculture and Natural Resources

journal homepage: http://www.journals.elsevier.com/agriculture-and-natural-resources/

Original Article

Manganese status in upland and lowland rubber-growing soils in Songkhla province, southern Thailand

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ARTICLE INFO

Article history:
Received 27 January 2015
Accepted 14 January 2016
Available online 8 October 2016

Keywords:
Lowland
Manganese toxicity
Rubber tree
Upland

ABSTRACT

Rubber trees, the most economic crop in southern Thailand, are generally cultivated in acid upland soils and currently have been extended into lowland areas which induce higher solubility of manganese (Mn) which may result in Mn toxicity to rubber. This study investigated soil Mn and leaf Mn levels in rubber trees grown in upland and lowland soils. Ninety soil samples from upland and lowland rubber plantations in Songkhla province were collected and analyzed for water soluble Mn, NH_4OAc Mn, diethylenetriaminepentaacetic acid test (DTPA) Mn, reducible Mn and total Mn forms. Leaf Mn analysis was also undertaken on samples of each plantation. The results revealed that the Mn concentrations of all soil Mn forms and leaf Mn in the lowland soils were higher than those of the upland samples. Comparing the optimum level reported by the Rubber Research Institute, both DTPA Mn and leaf Mn in the upland and lowland samples were high. Correlation analysis showed high and significant positive correlations of DTPA Mn and water Mn ($r = 0.715$), NH_4OAc Mn ($r = 0.975$), reducible Mn ($r = 0.953$) and total Mn ($r = 0.809$) in the lowland samples. Medium to high positive correlations among Mn forms were also found in the upland samples. The correlation of soil properties (pH, electrical conductivity, organic matter, available K, exchangeable Ca, Mg and Na and cation exchange capacity) and soil Mn were clearly defined. These results indicated that soil properties affect the release of Mn. However, a correlation between soil Mn and leaf Mn was not observed.

Introduction

Rubber trees are widely cultivated in acid upland soils and currently have been expanded into lowland areas and abandoned paddy fields (Chiarawipa and Yeedum, 2010) which are not suitable and possibly contain high Mn because of reduction of Mn oxide to soluble Mn^{2+} (McBride, 1994). Manganese is a micronutrient whose concentration is greatly increased under acidic and poor drainage conditions (Havlin et al., 2005). Therefore, a high amount of Mn will present in highly weathered acid soils, such as Ultisols and Oxisols (Tan, 2005). In Thailand, Ultisols occupy 44.81% (51.3 million ha) and Oxisols represent 0.26% (0.13 million ha) of the country (Kheoruenromne and Kesawapitak, 1989). In southern Thailand, acid soils occupy over 3.5 million ha or 68% of the total cultivated areas on which rubber trees are the main crop in this region (Kheoruenromne and Kesawapitak, 1989).

In 2010, the total rubber cultivation areas in Thailand was approximately 2.931 million ha and mainly (65.11%) in the south (Rubber Research Institute of Thailand (2012)). Chiarawipa and Yeedum (2010) noted that the growth and yield of rubber significantly decreased in abandoned paddy fields in Phattalung province. Likewise, an experiment of six varieties of wheat grown in acidic soil (Khabaz-Saberi et al., 2006) found that waterlogging increased the Mn solubility in soils and Mn uptake by the plants (Havlin et al., 2005), as the reducing oxide fraction (Mn^{3+}, Mn^{4+} and easily reducible MnO_2) affected the increasing level of mobile Mn under those conditions (Khabaz-Saberi et al., 2006; Iu et al., 1981; Stepniewska et al., 2010). The equilibrium of Mn among these forms is influenced greatly by soil pH and redox potential (Barber, 1984; Karavanova et al., 2006). In other words, soil waterlogging will reduce O_2 and lower the redox potential, which increase the concentration of soluble Mn, especially in acidic soils and Mn toxicity possibly occurs (Havlin et al., 2005).

Soil Mn exists as Mn^{2+}, Mn^{3+} and Mn^{4+} which are absorbed by plant roots primarily as Mn^{2+}, since Mn^{3+} and Mn^{4+} are insoluble and unstable forms (Barber, 1984). Soil Mn is classified into various

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Peer review under responsibility of Kasetsart University.

http://dx.doi.org/10.1016/j.anres.2016.01.005

forms—exchangeable, water soluble, specifically adsorbed Mn, complexed by soil organic matter and insoluble precipitate (Gambrell, 1996) and easily reducible as MnO$_2$ (Tisdale et al., 1990; Guest et al., 2002). Total soil Mn is generally in the range 20–3000 mg/kg (Barber, 1984; Tisdale et al., 1990; Havlin et al., 2005; Troeh and Thompson, 2005). Commonly, the Mn concentration for optimum growth should be 2–3 mg/kg, 0.2–5 mg/kg and 25–65 mg/kg for the water soluble, exchangeable and easily reducible forms, respectively (Havlin et al., 2005; Tisdale et al., 1990). However, the optimum Mn concentration for rubber should be 2–4 mg/kg (based on the diethylenetriaminepentaacetic acid test; DTPA) in the soil and 45–150 mg/kg in leaves (Kungpisadan, 2009). The current study aimed to determine and compare leaf Mn of rubber trees and soil Mn forms in upland and lowland areas and to analyze the correlation among soil Mn forms, leaf Mn and soil properties.

Materials and methods

Soil sampling and analysis

Ninety soils were sampled during July 2011 using a cross-shaped layout (9 cores/plantation) at a depth of 0–30 cm from upland and lowland rubber plantation areas, consisting of 47 farms with immature rubber (aged 4 yr) and 43 farms with mature rubber (aged 8 yr) in Rattaphum, Na Thawi, and Khlong Hoi Kong districts, Songkhla province, southern Thailand. The soils consisted of 45 upland soils (Typic Kandiudults; Kohong and Lithic Udorthents/Typic Hapludults; Ranong associated with the Phato series) and 45 lowland soils (Typic Paleaquults; Bang Nara, Typic Plinthaquults; Visai and Typic Plinthaquults; Nam Krachai associated with the Sathon series). The upland soils showed no mottling throughout the soil profiles whereas lowland soils had mottling in the soil profiles. The soil samples were air dried and passed through a 2 mm screen sieve. The soil samples were determined for Mn forms—water soluble Mn (soil:water; 1:10), exchangeable Mn (soil:1 M NH$_4$OAc; 1:10) and DTPA Mn (soil:DTPA; 1:2), reducible Mn (soil:1 M NH$_4$OAc-hydroquinone; 1:10) and total Mn in soil (H$_2$O$_2$, H$_2$SO$_4$, HNO$_3$, HClO$_4$ and HF) according to Gambrell (1996). Manganese in each extractant was analyzed using atomic absorption spectrophotometry (AAS). Some basic soil properties—pH, total N, available P and K, exchangeable Ca, Mg and Na, cation exchange capacity (CEC), organic matter (OM) and electrical conductivity (EC)—were also analyzed (Onthong and Poonpakdee, 2012).

Leaf sampling and analysis

Mature (aged 100–150 d) first or second compound leaves of the growing whorl of rubber branches were sampled (Kungpisadan, 2009) from 9 trees/plantation using a cross-shaped design. The leaves were dried at 70 °C and ground through a 20 mesh screen of a hammer mill. Then, the leaf Mn concentration was analyzed by digesting with mixed acid (HNO$_3$:HClO$_4$; 3:1) and determined using AAS (Onthong and Poonpakdee, 2012).

Statistics and data analysis

The mean and interval estimation of soil and leaf Mn values were calculated and Mn values in the upland and lowland areas were compared using an independent Student's t test (significant at $p \leq 0.05$ and highly significant at $p \leq 0.01$). The correlation between Mn in the soil and Mn in leaves, as well as soil Mn and soil properties were computed.

Results

The basic soil characteristics of upland and lowland rubber-growing soils are given in Table 1. Most of the soils were acidic and the CEC, available P, OM, total N, exchangeable Ca, Mg and Na contents were higher in the lowland soils compared with the upland ones.

The concentrations of Mn forms in the upland and lowland rubber-growing soils are summarized in Table 2. The results showed that the concentrations of all Mn forms, in both immature and mature rubber plantations in the lowland were higher than those of the upland (Tables 2 and 3).

The results also showed that the highest value was for the total Mn followed by reducible Mn, DTPA Mn, NH$_4$OAc Mn and water soluble Mn, respectively. The leaf Mn in both mature and immature rubber plants showed significant differences which were also greater in the lowland (405.35 mg/kg and 380.95 mg/kg, respectively) than the upland (371.08 mg/kg and 303.16 mg/kg, respectively) as shown in Table 4.

Highly significant, medium to high positive correlations between Mn forms were observed, especially between total Mn and water soluble Mn ($r = 0.572$), NH$_4$OAc Mn ($r = 0.846$), DTPA Mn ($r = 0.809$) and reducible Mn ($r = 0.880$) in the lowland soils which were greater than in the upland soils (Table 5). The correlations between soil Mn and soil properties are presented in Table 6. In the upland, the correlation between water Mn and EC ($r = 0.728$) and available K ($r = 0.578$) showed a highly significant, positive correlation, while there was a significant correlation between total Mn and exchangeable Na ($r = 0.369$). However, NH$_4$OAc Mn ($r = -0.323$) and DTPA Mn ($r = -0.326$) had a significant, negative correlation with OM. In the lowland, pH gave close, positive correlations with NH$_4$OAc Mn ($r = 0.515$, highly significant), DTPA Mn ($r = 0.491$, significant), reducible Mn ($r = 0.533$, highly significant) and total Mn ($r = 0.448$, significant). Similar correlations between exchangeable Ca, Mg and CEC and each Mn fraction were clearly observed.

Discussion

Basic properties of soils

The soil acidic condition in rubber plantation areas (Table 1) is generally caused by high weathering and leaching which generally

Table 1
Some chemical soil properties in upland and lowland rubber-growing soils, with range values derived from interval estimation at $p \leq 0.05$.

Chemical property[a]	Top soil (0–30 cm)			
	Immature		Mature	
	Upland	Lowland	Upland	Lowland
pH (soil:water = 1:5)	5.24–5.46	5.41–5.65	5.27–5.44	4.96–5.57
EC (1:5) (dS m^{-1})	0.01–0.02	0.02–0.03	0.01–0.02	0.02–0.04
OM (g/kg)	9.86–12.41	9.94–11.34	10.17–11.99	8.93–13.10
Total N (g/kg)	0.50–0.74	0.67–0.81	0.59–0.70	0.54–0.66
Avail P (mg/kg)	4.43–8.73	3.57–9.12	4.70–7.87	5.92–7.72
Avail K (mg/kg)	4.36–16.55	3.86–12.43	5.29–10.14	13.63–20.53
Exch Ca (cmol$_c$/kg)	0.13–0.29	0.23–0.39	0.14–0.20	0.09–0.22
Exch Mg (cmol$_c$/kg)	0.03–0.05	0.05–0.12	0.03–0.04	0.03–0.06
Exch Na (cmol$_c$/kg)	0.02–0.03	0.04–0.08	0.03–0.04	0.04–0.06
CEC (cmol$_c$/kg)	1.94–2.38	1.60–3.24	1.36–1.72	0.97–1.74
Sand (%)	34–50	32–47	51–63	49–62
Silt (%)	26–36	28–39	19–25	20–26
Clay (%)	22–30	23–31	16–24	17–26

[a] EC = electrical conductivity; OM = organic matter; Avail = available; Exch = exchangeable; CEC = cation exchange capacity.