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Original Article

Growth of immature rubber trees planted in abandoned paddy field and upland areas in relation to soil properties and leaf nutrients

Jumpen Onthong[1*], Khwunta Khawmee[1], and Chutharmard Keawmano[1]

Department of Earth Science, Faculty of Natural Resources, Prince of Songkla University, Hat Yai, Songkhla, 90112 Thailand

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Abstract

Although lowland area is not suitable for rubber production, rubber trees are currently extended into abandoned paddy fields. This study investigated rubber growth, soil properties and leaf nutrients of immature rubber trees planted in lowland and upland plantations. Nine soils (0-30 cm depth) in both poor and good productive lowland and upland plots from three districts in Songkhla province were sampled for some physical and chemical analysis and leaf samples were also performed for nutrient analysis. Growth of rubber trees was recorded. Results showed that soil in the lowland had finer texture compared with the upland soil, resulting in tendency of higher organic matter, total N and CEC. In addition, high DTPA Mn and soil mottles are generally found in a profile of the lowland soil. However, immature rubber trees planted in the good productive lowland plot grew as similar as in the upland soil. Whereas, in the poor productive plot, rubber growth was limited and concentrations of leaf N, P and K tended to be lower than those in the upland soil, in contrast to leaf Mn. These findings revealed that soil mottles within 0-30 cm are markedly indicator of limitation of the lowland for rubber cultivation.

Keywords: growth of immature rubber, lowland and upland, abandoned paddy field, leaf nutrient, soil properties

1. Introduction

Thailand is an important rubber producing country and most rubber plantations are in the south (Rubber Research Institute, 2012). Total rubber growing area in Thailand in 2011 was 3,001,721 ha with about 1,921,457 ha located in the south (Office of Agricultural Economics [OAE], 2012). Since the suitable rubber plantation area in the south becomes limited, new plantations have been developed in eastern and northern Thailand in the past decade (Kungpisadan, 2009), including in unsuitable areas like abandoned paddy fields (lowland). In general, suitable area for rubber production should be loamy texture soil with a minimum depth of 1 m, well drained and soil pH lies in the range of 4.0-6.5 (Karthikakuttyamma, Joseph, & Nair, 2000). However, areas of rubber plantation in the lowland have increased substantially in all rubber growing provinces as well as in Songkhla province (254,036 ha), the second most rubber growing area next to Surat Thani province (OAE, 2012). Growth and yield of rubber plants in lowland are always found very poor owing to poor physical properties and waterlogged condition. The texture, depth and drainage of soil are very important in terms of affecting rubber growth and yield. These physical properties are much more important as they are not easily amendable, while most of chemical properties can be corrected by application of fertilizers and soil amendments (Karthikakuttyamma *et al.*, 2000).

It was reported that latex yield of rubber trees in the lowlands was lower than that in the uplands and most of soils in the lowland had finer texture compared to the upland (Nualkaew, Poonpakdee, Kaewmano, & Onthong, 2013). Analysis of 46 soil samples in the lowland and 44 soil samples in the upland collected from rubber plantations (0-30 cm depth) in Songkhla revealed that percentage of clay in the

* Corresponding author.
Email address: jumpen.o@psu.ac.th

lowland and upland soils ranged 22-31 and 18-24, respectively (Poonpakdee, Onthong, Khawmee, & Duangthong, 2013). It was also noted that growth of rubber trees grown in the lowland was inferior to the upland while latex yield was not clearly different (Chiarawipa & Yeedum, 2010).

Although growing rubber in lowland is not supported by Office of Rubber Replanting Aid Fund, expanding of rubber cultivation into lowlands including abandoned paddy field has been continuously performed. Abandoned paddy field areas occupy about 17,825 ha in Songkhla province (Office of Soil Survey and Land Use Planning, 2014). Most of them are general used for rubber cultivation. Some lowlands can result in good productivity but some give the poor productivity. Therefore, the objectives of this current study were to compare (i) growth of immature rubber trees planted in upland and abandoned paddy fields which are classified as good and poor productive plots, and (ii) leaf nutrients and soil properties of upland and lowland rubber growing areas. This investigation will provide criteria of soil properties that limit rubber cultivation and useful information for soil improvement in the lowlands.

2. Materials and Methods

The experiment was conducted in Khlong Hoi Khong, Na Thawi and Rattaphum districts, Songkhla province, southern Thailand. The experimental design was randomized complete block with three blocks (using districts as a block). In each district, one plantation of a 3-year-old rubber trees (RRIM 600 clone planting in 2007) grown in upland, good productive (trees with dense crown as in the upland) and poor productive (trees with fewer branches and spare crown) plots which were given the similar practical managements was sampled for this study. Field investigation of morphology was performed as described by Kheoruenromne (1999). Undisturbed soil samples at the depth of 0-30 cm were collected for bulk density by core method (Blake & Hartge, 1986). At starting experiment, composited soil (0-30 cm depth) represent for each plot was sampled as X-shape (9 cores/ plantation) for analysis of texture by hydrometer method (Gee & Bauder, 1986), soil pH (soil:water =1:5) by pH meter, organic matter by Walkley and Black method, total N by Kjeldahl method, available K, exchangeable Mg and cation exchange capacity by NH_4OAc method, and extractable Mn by DTPA method according to the manual of soil and plant analysis (Onthong & Poonpakdee, 2012). Depths of water table in the lowland plots were recorded twice a month. Trunk girths of 50 trees at 150 cm above ground and 20 cm above bud union were measured twice a year during 2011-2012. Fresh biomass (FB; kg/tree) was calculated from trunk girth (G; cm) at 20 cm above bud union ($FB = 2.3167G^{1.1972}$) (Sangsing, 2005). The first or second compound leaf of growing whorl after four months of defoliation (Kungpisadan, 2007) was sampled (9 trees/ plot) for nutrient analysis. Leaves were dried, ground and digested for chemical analysis according to the procedures described by Onthong and Poonpakdee (2012). After a Kjedhal digestion of ground leaf samples, N was determined by distillation-titration method. Whereas HNO_3-$HClO_4$ digestion was used for analysis of leaf P, K, Ca, Mg, and Mn. Determinations of P was performed by Vanadomolybdate method, K by Atomic Emission Spectrophotometry, and Ca, Mg and Mn by Atomic Absorption Spectrophotometry. Data derived from the same plot characterization in different districts were averaged and compared among the upland, good productive and poor productive plots. To evaluate the effects of plot characterization on trunk girth and fresh biomass, data were analyzed using one-way analysis of variance and Duncan's Multiple Range Test ($P = 0.05$).

3. Results

Landform and field soil characteristics: The upland rubber growing soils occurred on low terrace, foot slope and alluvial undulating plain with slope of 4-9% and 38-58 m above mean sea level (Table 1). Soils in the experimental plots were Ultisols, except the upland plot in Na Thawi district (Table 2). All lowland soils of this study were Plinthaquults. Upland soils were very strongly acid to strongly acid (pH 4.5-5.5) without any mottles (Table 2). While the good and poor productive lowland rubber growing soils occurred on low terrace with lower slope (1-2%) and an elevation of 18-31 m above mean sea level (Table 1). These soils had finer texture and were very deep with poor drainage and extremely acid to strongly acid (pH 4.0-5.0). There were commonly mottles due to water logging within the soil profiles developed in the lowland, especially in the poor productive plots even within the depth of 0-30 cm but soil mottles in the good productive plots were found deeper than those in the poor productive plot. However, slightly yellowish brown and reddish brown root mottles were generally found at depths of 0-30 cm in the good productive plots in the lowland. Appearance of soil mottles was associated with depth of water table. The water table of poor productive lowland plot was nearer soil surface than in good productive lowland plot (Figure. 2), while it was deeper than 1 meter in the upland plot during experiment period.

Selected physical and chemical properties of soils: Soils in the upland plots contained higher sand, in contrast to clay, and had coarser texture, compared with the lowland plots (Table 3). Bulk density values of upland soils tended to be higher than that in the lowland soils.

The averages of soil pH, organic matter, total N, exchangeable Mg and cation exchange capacity in the upland and lowland plots were not clearly different, whereas available P in the upland and good productive plots was higher compared with the poor productive plot (Table 4). Available K in the upland plot seemed to be the highest. On the contrary, Mn extracted by DTPA from both good and poor productive lowland plots was much higher than that in the upland plot.

Table 1. General information of experimental upland, good productive and poor productive lowland immature rubber plots in Khlong Hoi Khong, Na Thawi and Rattaphum district, Songkhla province.

Plantation characterization	District	Coordinate	Slope (%)	Elevation (m MSL)	Landform	Parent material
Upland	Khlong Hoi Khong	47 0653762 E 0757603 N	4	44	Low terrace	Old alluvium
	Na Thawi	47 0681579 E 0746722 N	9	58	Footslope	Colluvium of sandstone and quartzite rocks
	Rattaphum	47 0643963 E 0784660 N	4	38	Alluvial undulating plain	Alluvium
Good productive lowland	Khlong Hoi Khong	47 0656784 E 0762113 N	1	18	Low terrace	Alluvium
	Na Thawi	47 0685580 E 0747415 N	2	28	Low terrace	Alluvium
	Rattaphum	47 0640107 E 0787150 N	1	22	Erosional low terrace	Local alluvium over residuum derived from sandstone
Poor productive lowland	Khlong Hoi Khong	47 0656924 E 0762420 N	1	18	Low terrace	Alluvium
	Na Thawi	47 0686096 E 0747484 N	1	27	Low terrace	Alluvium
	Rattaphum	47 0640137 E 0787838 N	1	31	Low terrace	Alluvium

Climate and water table: The average rainfall and temperature in Songkhla province at time of conducting the experiment were 3,017 mm and 27.93 degrees Celsius, respectively. During October 2011 and January 2012, there was higher rainfall than other months (Figure 1) and the water table of the lowland plots during those times were closed to the soil surface and there was flooded in November 2011 both in good and poor productive lowland plots (Figure 2). Since February 2012 onward, the water tables were substantial declined associated with the monthly rainfall. A period of water saturation within 1 m of the soils in the poor productive plots was longer than the good productive plots. The average water table during conducting the experiment in good productive plot (72 cm) was deeper than that in the poor productive plot (65 cm).

Rubber growth: The growths of rubber trees in terms of trunk girth and fresh biomass grown in the upland and lowland were not significantly different at the commencement of the experiment (Figure 3). When the rubber trees reached the end of experiment (5 years old rubber tree), trunk girth at 20 cm above bud union and fresh biomass of rubber trees grown in the upland and good productive lowland were higher than those in the poor productive lowland. While trunk girth at 150 cm above the ground showed significantly different since rubber trees were 4.5 years old onward.

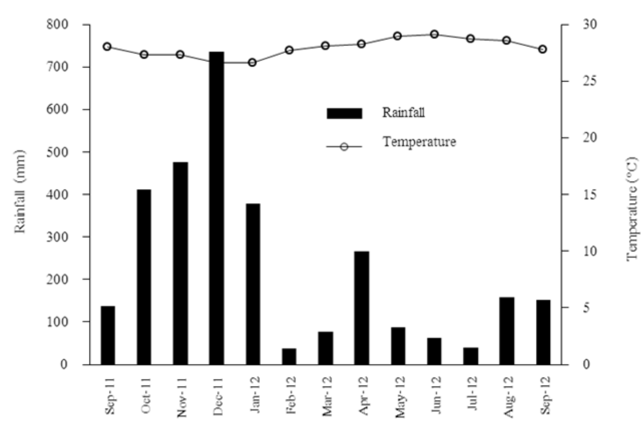

Figure 1. Rainfall and temperature in Songkhla province during September 2011 to September 2012.

However, growths of rubber in the upland and good productive lowland were not significant difference but higher compared in the lowland.

Leaf nutrients: Concentrations of N, P and K tended to be highest in the leaf of rubber trees grown in the upland soil, followed by in good and poor productive plots, excluding K (Table 5). While leaf Ca, in contrast to Mg, was found to be higher in the upland soil compared with in the lowland soil.

Table 2. Classification and general field characteristics of soils in the experimental upland, good productive lowland and poor productive lowland immature rubber plots in Khlong Hoi Khong, Na Thawi and Rattaphum district, Songkhla province.

Plantation characterization	District	*Soil classification	Field soil characteristics
Upland	Khlong Hoi Khong	Fine-clayey, kaolinitic, isohyperthermic AquicKandiudults	Deep (> 100 cm), brown sandy clay loam with good drainage soil and extremely acid to very strongly acid (pH 4.5-5.0).
	Na Thawi	Loamy-skeletal, mixed, semiactive, acid, isohyperthermic Lithic Udorthents	Shallow (40 cm), yellowish brown clay loam soil containing gravels, good drainage and very strongly acid (pH 4.5).
	Rattaphum	Loamy-skeletal, mixed, semiactive, isohyperthermic Typic Hapludults	Very deep (>150 cm), grayish brown or brownish gray clay in surface and orange and brown mottles found in subsoil (> 25 cm), very strongly acid to strongly acid (pH 4.5-5.5).
Good productive lowland	Khlong Hoi Khong	Fine-loamy, mixed, semiactive, isohyperthermic Typic Plinthaquults	Very deep, yellowish red and grayish brown clay soil with poor drainage, very strongly acid (pH 4.5-5.0), slightly yellowish brown and reddish brown root mottles found within 0-32 cm from surface, commonly reddish brown mottles found below 32 cm.
	Na Thawi	Coarse-loamy, mixed, semiactive, isohyperthermic Typic Plinthaquults	Very deep, brownish gray clay loam with poor drainage, extremely acid to very strongly acid (pH 4.0-5.0), slightly reddish brown root mottles found within 0-32 cm, many reddish yellow mottles found below 32 cm, nodules and concretions of iron and manganese oxides found below 110 cm.
	Rattaphum	Fine-loamy, mixed, semiactive, isohyperthermic Typic Plinthaquults	Very deep, grayish brown sandy loam soil with poor drainage, very strongly acid (pH 4.5-5.0), gray sandy clay loam of subsoil, yellowish brown and yellowish orange mottles found below 35 cm.
Poor productive lowland	Khlong Hoi Khong	Fine-loamy, mixed, semiactive, isohyperthermic Typic Plinthaquults	Very deep, brownish gray silty clay soil with poor drainage, extremely acid (pH 4.5), commonly brown mottles found within 0-32 cm, yellowish gray subsoil and many yellowish brown mottles found below 32 cm.
	Na Thawi	Fine-loamy, mixed, semiactive, isohyperthermic Typic Plinthaquults	Very deep, reddish yellow and brownish gray clay loam soil with poor drainage, extremely acid to very strongly acid (pH 4.0-5.0), commonly reddish brown and reddish yellow mottles found within 0-30 cm, gray with many reddish brown and reddish yellow mottles in subsoil below 30 cm .
	Rattaphum	Fine-loamy, mixed, semiactive, isohyperthermic Typic Plinthaquults	Very deep, brownish gray clay soil with poor drainage, extremely acid to strongly acid (pH 4.5-5.0), many brown and common reddish brown found within 30 cm, gray silty clay with many yellowish and reddish brown mottles in subsoil.

* Soil name is based on USDA Soil Taxonomy and given by Office of Soil Survey and Land Use Planning (2014)

Table 3. Selected physical properties of soils (0-30 cm) in upland, good productive and poor productive immature rubber plots in different districts.

Plantation characterization	District	Soil particle (%)			Soil texture	Bulk density ($g\ cm^{-3}$)
		Sand	Silt	Clay		
Upland	Khlong Hoi Khong	72	18	10	Sandy Loam	1.64
	Na Thawi	38	35	27	Clay Loam	1.70
	Rattaphum	39	32	29	Clay Loam	1.68
	Average ± SD	**50±19**	**28±9**	**22±10**	**Sandy Clay Loam**	**1.67±0.03**
Good productive lowland	Khlong Hoi Khong	24	38	38	Clay Loam	1.45
	Na Thawi	43	30	27	Clay Loam	1.62
	Rattaphum	73	21	6	Sandy Loam	1.65
	Average ± SD	**47±25**	**30±9**	**23±16**	**Loam**	**1.57±0.11**
Poor productive lowland	Khlong Hoi Khong	26	39	35	Clay Loam	1.55
	Na Thawi	23	40	37	Clay Loam	1.56
	Rattaphum	33	42	25	Loam	1.61
	Average ± SD	**27±5**	**40±2**	**33±7**	**Clay Loam**	**1.57±0.03**

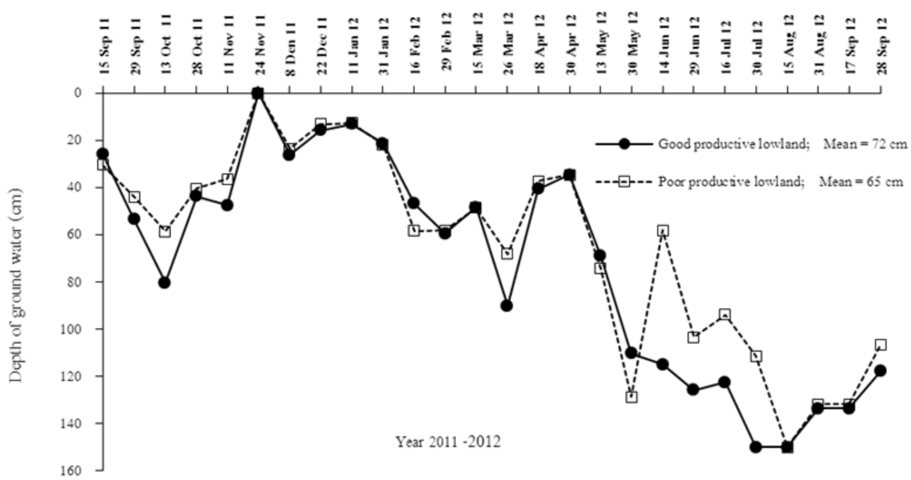

Figure 2. Depth of ground water table in good productive and poor productive immature rubber tree.

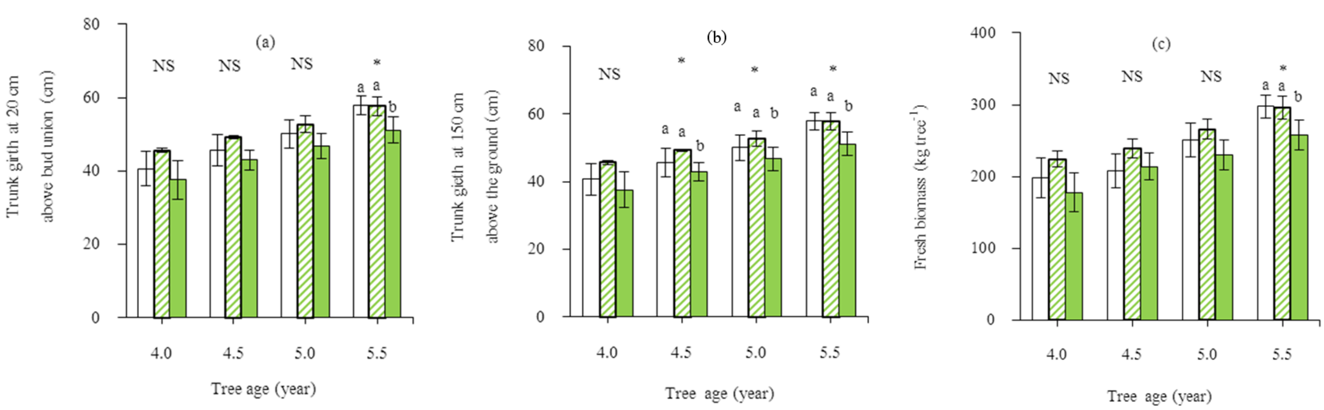

Figure 3. Trunk girth at 20 cm above bud union (a) and 150 cm above the ground (b) and fresh biomass of immature rubber tree (c) grown in upland ( ) good productive lowland ( ) and poor productive lowland ( ).
Remark: Different letters indicate significant difference at P≤0.05. NS = Not significant difference at P>0.05. I = Standard error.

Table 4. Selected chemical properties of soils (0-30 cm) in upland, good productive and poor productive immature rubber plots in different districts.

Plantation characterization	District	pH soil: water (1:5)	O.M. (g kg^{-1})	Total N (g kg^{-1})	Avai. P (mg kg^{-1})	Avai. K (mg kg^{-1})	Exch. Mg (cmol$_c$ kg^{-1})	CEC (cmol$_c$ kg^{-1})	DTPA-Mn (mg kg^{-1})
Upland	Khlong Hoi Khong	5.51	11.19	0.36	22.56	48.22	0.06	2.09	2.41
	Na Thawi	5.22	17.83	0.93	5.27	24.59	0.17	4.23	5.10
	Rattaphum	5.27	13.50	0.78	28.97	47.73	0.18	3.78	10.73
	Average ± $\overline{\text{SD}}$	**5.33±0.16**	**14.17±3.37**	**0.69±0.30**	**18.93±12.26**	**40.18±13.50**	**0.14±0.07**	**3.37±1.13**	**6.08±4.25**
Good productive lowland	Khlong Hoi Khong	4.60	13.31	0.85	45.65	30.13	0.12	2.42	47.60
	Na Thawi	5.08	14.34	0.68	31.80	11.73	0.16	4.15	54.54
	Rattaphum	4.80	12.51	0.81	10.97	6.32	0.05	0.69	2.08
	Average ± $\overline{\text{SD}}$	**4.83±0.24**	**13.39±0.92**	**0.78±0.09**	**29.47±17.46**	**16.06±12.48**	**0.11±0.06**	**2.42±1.73**	**34.74±28.50**
Poor productive lowland	Khlong Hoi Khong	5.46	10.33	0.68	3.89	15.29	0.24	1.69	38.86
	Na Thawi	5.82	18.94	0.91	8.24	16.59	0.28	5.64	28.38
	Rattaphum	5.51	12.44	0.90	8.37	16.79	0.11	2.90	30.54
	Average ± $\overline{\text{SD}}$	**5.60±0.20**	**13.90±4.49**	**0.83±0.13**	**6.84±2.55**	**16.22±0.81**	**0.21±0.09**	**3.41±2.02**	**32.59±5.53**

Table 5. Nutrients of leaf in upland, good productive and poor productive immature rubber plots in different districts.

Plantation characterization	District	Total N (g kg^{-1})	Total P (g kg^{-1})	Total K (g kg^{-1})	Total Ca (g kg^{-1})	Total Mg (g kg^{-1})	Total Mn (mg kg^{-1})
Upland	Khlong Hoi Khong	32.04	3.79	12.77	10.61	2.59	385.17
	Na Thawi	32.10	2.82	15.29	8.30	2.98	402.58
	Rattaphum	34.76	3.24	10.97	12.48	5.12	377.92
	Average ± $\overline{\text{SD}}$	**32.96±1.55**	**3.28±0.48**	**13.01±2.17**	**10.46±2.09**	**3.56±1.36**	**388.55±12.67**
Good productive lowland	Khlong Hoi Khong	34.08	3.56	7.41	17.39	2.45	679.83
	Na Thawi	32.97	3.07	9.43	18.25	2.77	1677.51
	Rattaphum	31.20	2.88	12.22	14.08	3.13	242.40
	Average ± $\overline{\text{SD}}$	**32.75±1.45**	**3.17±0.35**	**9.68±2.41**	**16.57±2.20**	**2.78±0.34**	**866.58±735.55**
Poor productive lowland	Khlong Hoi Khong	30.98	3.26	7.96	16.03	4.39	495.41
	Na Thawi	30.84	3.03	11.16	13.14	1.58	439.48
	Rattaphum	29.61	2.76	14.85	15.94	2.99	653.19
	Average ± $\overline{\text{SD}}$	**30.47±0.75**	**3.01±0.25**	**11.32±3.44**	**15.03±1.64**	**2.98±1.40**	**529.36±110.82**

However, rubber grown in the lowland soil gave higher concentration of leaf Mn compared with in the upland soil.

4. Discussion

Soils developed in the upland and lowland differed in topographies and soil properties, resulting in the different growth of rubber trees and soil managements for rubber tree cultivation.

Landforms and soil properties in the upland and lowland plots: Soils in the upland occurred in undulating and rolling terrain on hill slope and river terrace, and soil parent materials were associated with their positions related to topography (Table 1). A higher elevation and a coarser texture compared with the lowland results in better soil drainage. Therefore, the water table of the upland soils was deeper than 1 m without any mottle in the soil profile. While the water tables in the lowland soils were found within 1 m (Figure 2) with common to many mottles (Table 2). There were two types of mottles: mottles due to waterlogging, giving the yellow or red color and root mottles that was a red long shape similar to root.

Mottles in soil profile are commonly associated with the presence of iron. Red colors come from various ironbearing minerals (Schaetzl & Anderson, 2005). In the lowland, prolonged soil-saturation (Figure 2) results in anaerobiosis leading to the formation and redistribution of ferrous ion because of migrating ground water. Subsequent drainage restores aerobic conditions, but some iron coatings on the minerals may have been entirely removed, leaving the grayish surface of the mineral grains exposed. During drainage, some areas around pores, cracks, and root channels become dry and aerated more quickly than the rest of the soil. Ferric ion precipitates in these places, forming reddish-brown spots called mottles. Finding this characteristic implies that soil water table is shallow and soil is inappropriate for rubber cultivation due to poor drainage.

Soil textures in the upland and lowland were classified as sandy loam and clay loam, respectively (Table 3) which were suitable for rubber cultivation (Karthikakuttyamma *et al.*, 2000; Rubber Research Institute, 2012). Unfortunately, water table of soils developed in the lowland was close to the soil surface that obstructed water drainage. Consequently, the soil was underwater during rainy season resulting in unsuitable condition for rubber growth, especially in poor productive lowland plot that had average water table closer to soil surface than the good productive one (Figure 2).

The chemical properties of soils (pH, organic matter, total N, CEC, Exch. Mg) in the upland and lowland plots were not markedly different (Table 3), indicating that these parameters are not the factors affecting difference in rubber growth between upland and lowland plots. Comparing the properties of these soils with the optimum level for rubber cultivation (Kungpisadan, 2011) the pH and organic matter are in the range of optimum levels. The total N is slightly lower than the optimum level. The available P and K among plots varied greatly especially in the upland plots, possibly due to residual effect of non-uniformity of chemical fertilizer application. However, the available P in the upland and good productive lowland plots is in an optimum range (11-30 mg kg^{-1}) and higher than that in the poor productive lowland plot. This may contribute to a better growth of rubber trees in the upland plot. The available K in the upland is also higher when compared to the lowland, but all of them in the lowland plots are lower than the optimum range (40-60 mg kg^{-1}). The available K in the lowland plot is lower than the upland plot although it has finer texture (Table 3) that generally has more available K (Havlin, Beaton, Tisdale, & Nelson, 2005). This could be the result of land use and management for rice production in the past. High K uptake by rice without any K application may lead to a decrease of available K. In general, only N and P fertilizer (16-20-0) is applied for rice production in fine texture soil (Department of Agriculture, 2005).

Exchangeable Mg both in the upland and the lowland soils is below an optimum level (>0.30 $cmol_c$ kg^{-1}) that is consistent with results of Suchartgul (2011). It was noted that Mg is likely to be deficient in acidic soil (Havlin *et al.*, 2005). Moreover, low exch. Mg is perhaps caused by continuous cultivation of rubber (upland) and rice (lowland) but Mg is never contained in fertilizers for rubber and rice (Department of Agriculture, 2005; Rubber Research Institute, 2012). Therefore, Mg application for rubber should be considered. However, DTPA-Mn in the upland and the lowland soils is above an optimum range (2-4 mg kg^{-1}) and Mn in the lowland is about five times higher than that in the upland. Since the pH in the upland and the lowland is not different (Table 4), higher Mn in the lowland is mainly due to water logging during rainy season that increases Mn availability (Havlin *et al.*, 2005).

Rubber tree growth and leaf nutrients in the upland and lowland plots: Rubber tree growth in each treatment was not significantly different at the commencement of experiment, supporting an observation that young rubber trees grown in the lowland can grow normally. However, at the end of the experiment they showed a better growth in the upland and the good productive lowland plots, compared with the poor productive lowland plot (Figure 3). This is possibly due to roots of rubber trees in the lowland reaching to water table which restricts root growth and nutrient uptake, especially in the poor productive lowland plot where the water table was closer to the soil surface (Figure 2). The higher concentrations of almost most leaf nutrients (N, P, K, Mg) in the upland and the good productive lowland plots compared with the poor productive lowland plot (Table 5) support this phenomenon. On contrary, leaf Mn of rubber trees grown in the lowland was significantly higher than that in the upland plot (Table 5). This is associated with soil Mn (Table 3). Surprisingly, all leaf Mn of rubber trees both in the upland and the lowland plots is above an optimum level (45-150 mg kg^{-1}) (Kungpisadan, 2011). The higher Mn in the lowland soils may be another factor affecting rubber tree growth.

Limitations and managements of lowland area for rubber tree cultivation: Suitable soils for rubber cultivation should have good aeration which is essential for root penetration. Water table should be below 1 m from the soil surface (Karthikakuttyamma *et al.*, 2000; Kungpisadan, 2009). Most of rubber cultivations are widely distributed in upland soils in southern Thailand (Rubber Research Institute, 2012). Presently, it has been extended into the lowland especially in abandoned paddy fields even though they are not suitable and recommended for rubber tree cultivation. Unfortunately, there are 17,825 ha of abandoned paddy field in Songkhla province (Office of Soil Survey and Land Use Planning, 2014) and most of them are occupied by rubber trees. This study revealed that rubber trees grown in some lowland can grow as good as that in the upland (Figure 3). Our finding showed that depth of water table play an important role on rubber growth. In good productive lowland plot that gives growth as good as in the upland had water table level lower than that in the poor one. Shallow water table level obstructs water drainage and results in water logging and causes soil mottles. Therefore, depth of soil mottles represents an important indicator determining whether lowland soil is suitable or not. The deeper mottle is better for rubber tree growth. In the good productive lowland plot that soil mottles occurred below 30 cm from soil surface gave the better growth than in the poor productive lowland plot that had soil mottle widely distributing within 0-30 cm (Table 2). Mottles present near the soil surface suggest that the soil exhibits poor drainage and poor aeration. These problems decrease nutrient uptake, especially macronutrients (Table 5). Consequently, rubber trees grown in the poor productive lowland plot could not grow as good as in the good productive lowland and upland plots. Moreover, higher Mn in the lowland plots may partially limit rubber tree growth in the lowland areas. However, soil and leaf Mn in good productive lowland tend to be higher than the poor one (Table 4 and 5). Investigation of Mn toxicity and toxicity level in rubber should be elucidated.

Nowadays, most of abandoned paddy fields were replaced by rubber trees. The results from this study suggest that the shallow water table (Figure 2) causes the limited growth of rubber trees (Figure 3). Waterlogging may be the most important factor limiting rubber tree growth in the lowland. Therefore, management of water drainage in the lowland is important. It was reported that waterlogging in rubber plantation should not last longer than seven days and longer than that time digging a ditch around a planting plot or making ridges by dredging soil between rubber tree rows and placing soil onto the row of rubber trees were recommended to alleviate this problem (Nualkaew *et al.*, 2013).

5. Conclusions

Soil in the lowland has higher clay content than in the upland. Consequently, it gives the tendency of higher organic matter, total N and CEC, whereas high DTPA-Mn and mottles are generally found in a soil profile of the lowland. However, immature rubber trees planted in the good productive lowland plot can grow as good as in the upland area. In the poor productive plot which has common to many mottles within 0-30 cm from soil surface, rubber tree growth is limited. Concentrations of leaf N, P and K in this plot tend to be lower than that in the upland but leaf Mn is opposite. These findings show that soil mottles within 0-30 cm due to waterlogging is an important indicator of limitation of lowland for rubber tree cultivation. To alleviate this limitation, improving of water drainage should be conducted.

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