Journal of Tropical Forest Research 3 (2) : 17-28 (2019)

Original article

Environmental Factors Related to the Site Index of Siamese Rosewood Plantations in Thailand

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Received: Nov 1, 2019 Revised: Dec 18, 2019 Accepted: Dec 20, 2019

ABSTRACT

Environment plays an important role in the growth of a tree. In this study, we focused on searching for appropriate soil properties and climatic factors related to the site index equation and growth rate of Siamese rosewood (*Dalbergia cochinchinensis* Pierre) in plantation around Thailand, using a stepwise multiple regression analysis. The results indicated that four types of soil textures exist which are sandy loam, loamy sand, sandy clay loam, and sand. However, the dominant soil textures were sandy loam and loamy sand. The site index was found to be correlated with the pH of both the topsoil and subsoil, at depths of 0-10 and 10-30 cm, while the mean temperature was the only climatic factor found to be correlated with the site index. The soil factor related to the absolute growth rate (AGR) was pH at both the topsoil and subsoil depths. However, the AGR at subsoil was also related to sodium while the relative growth rate (RGR) was not related to any soil variable at the topsoil level but related with porosity at the subsoil level. The temperature, humidity, and the number of rainy days were found to be related to AGR while only the temperature was related to RGR. A combination of soil and climatic factors was found to be related to pH, temperature and humidity with AGR of topsoil and subsoil. AGR at topsoil level was related to exchangeable potassium while only the temperature was related to RGR at both the soil depths.

Keywords: Environmental factors, Climatic factors, Soil properties, Site index, *Dalbergia cochinchinensis* Pierre

INTRODUCTION

Thailand is located in a *tropical* zone and enjoys a vast tree diversity in its rainforest. Several tree species have been promoted to be planted as commercial species by the Royal Forest Department (RFD) depending on their growth rate, rotation period, and the economic value of wood. These include *Eucalyptus camaldulensis*. Dehn., *Dipterocarpus alatus* Roxb. ex G.Don, *Tectona grandis* L.f., *Dalbergia cochinchinensis* Pierre (Siamese rosewood) etc. Siamese rosewood has a slow growth rate, long rotation period but has a high economic value (Forestry Research Center, 1996). The oldest plantation recorded by RFD is almost 60 years old and continues to be promoted and propagated around Thailand. The general distribution of Siamese rosewood found in the north, the east, and the northeastern part of Thailand and some parts of Cambodia, Laos, and Vietnam are at elevations between 100 to 775 meters above sea level (a.s.l.), in dry evergreen and mixed deciduous forests (Eiadthong and Tangmitcharoen, 2015). However, illegal logging has caused a gradual reduction in their numbers and resulted in The International Union for Conservation of Nature (IUCN) placing this species in the red list, i.e., a threatened species in the vulnerable category (*International Union for Conservation of Nature* [IUCN], 2008). Thus, both increasing the number of forest plantations and developing methods to improve the number of Siamese rosewood is essential. Currently, several researches have sought to explain and understand the characteristics of Siamese rosewood. A research done by Pukittayacamee and Bhodthipuks (2002) indicated that a low temperature and storage in a sealed container resulted in a longer preservation time of its seed. Furthermore, a soil: rice husk ratio if 1:2 was reported as a viable growing media compared with a combination of soil: burnt rice husk in the same ratio (Sermvongtrakul, 2000). In addition, coconut husk and the mixture of coconut husk with other media led to an increase in the germination rate (Chujit, 2001). During the planting stage, it was shown that stump seeding can be used instead of potted seeding as the growing rates were similar after two years (Tiyanon, 1997). Furthermore, the most appropriate ratio of chemical fertilizers to be applied on one-year seedlings was 15:15:15 (N:P:K) (Sirisawang, 1997). The total estimated biomass of 15 year old trees in Sakaeraj district, Nakhon Ratchasima province, Thailand was 132.82 tons per ha (Vacharangkura, 2003), while Kuasakun (2017) reported that the hardwood percentage of Siamese rosewood in the plantation varied between 31- 68%. A lot of research is still needed about Siamese rosewood, especially focusing on its growing environment as this is a key factor affecting the growth of and yield from the species. In addition, the factors affecting site index are climate, soil characteristics, and vegetation of the local area (Yadav, 2014). Thus, the present research reports on the relationship between tree growth and environmental factors in terms of the most appropriate soil properties and climatic factors. This study will be useful in in increasing our understanding about the species and in making informed future decisions.

MATERIALS AND METHODS

Study area

The study area was a Siamese rosewood plantation under RFD and the Forest Industry Organization (FIO). The location of the plantations and their respective codes are listed in Figure 1 and table 1. The study site covers all the regions of Thailand which are located between 5° 37” N and 20° 27” N latitude and 97°22” E and 105°37” E longitude. Meteorological data indicated that the mean annual temperature is around 27° C, the annual rainfall ranges between 1,200 to 1600 mm, and the mean annual rainfall is 1,587 mm (Thai Meteorological Department, 2014).

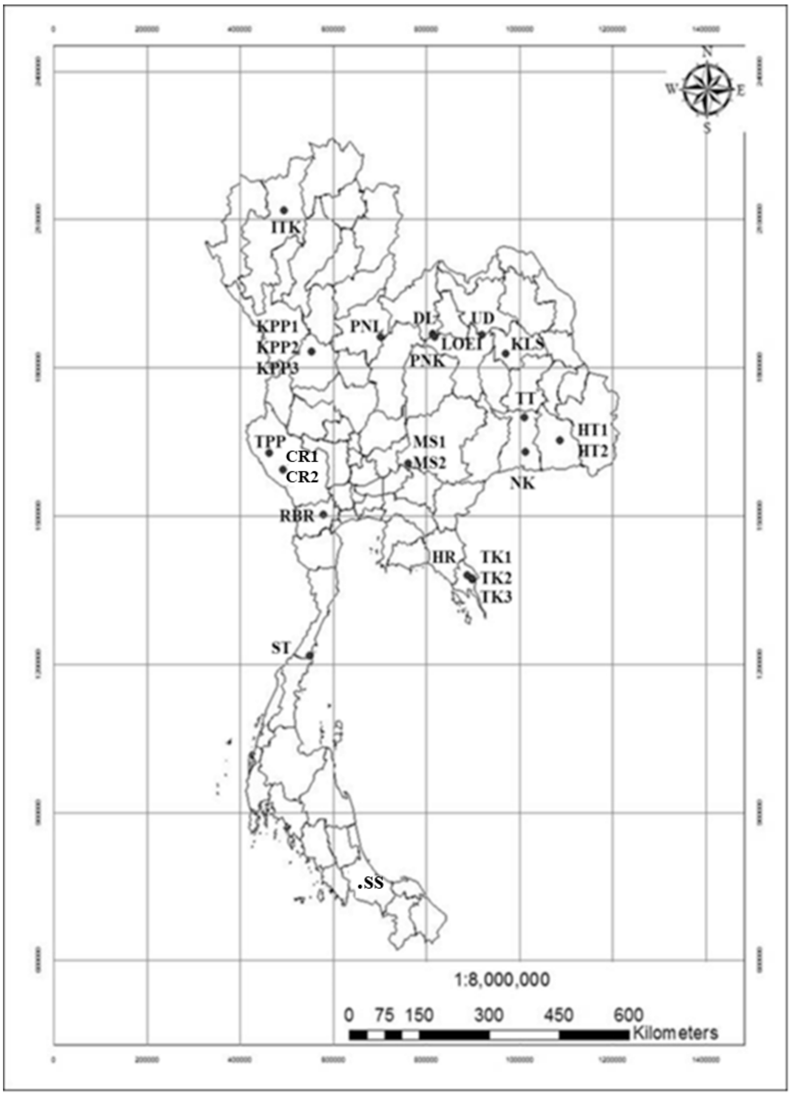

Figure 1 Map indicating the locations of Siamese rosewood study sites in Thailand.

Data collection

Seventy-eight temporary sample plots were selected from twenty-six Siamese rosewood plantations spread across Thailand. In each plot, growth characteristics were measured which indicated that the mean age was 28 years (13 - 55 years), mean diameter at breast height (DBH) was 20.03 cm (7.99 - 33.80 cm), mean total height was 16.48 m (6.18-23.20 m), and the mean dominant height was 20.79 m (7.32 - 24.82 m). The dominant tree in each plot was measured to input into the contracted site index equation following Phunchaisri *et al.* (2018) as SI = $\exp(ln H_{do} - 12.476(A^{-1} - A_b^{-1}))$ where SI is the site index, e is the natural exponent, *ln* is the natural logarithm, H_{do} is the dominant height, A is the stand age, and A_b is the base age at 30 years. Soil samples were collected at depths of 0-10 and 10-30 cm in each plot. The soil pits were dug manually and 100 cc of the soil core and 500 grams of soil were taken in a plastic bag. Physical properties such as bulk density using the core method (Jalota *et al.,* 1998), soil texture using the hydrometer method were estimated. In addition, chemical properties such as the pH determined by a soil: KCl solution ratio of 1:2.5 using a glass electrode (Horiba, Kyoto, Japan) described by Jackson (1958). Organic matter, nitrogen using the dry combustion method of Steward *et al.* (1964) and NC analyzer (J-Science JM 1000CN). Available phosphorus using BrayII method described by Shoji *et al.* (1964). Exchangeable cation as exchangeable potassium, exchangeable calcium, exchangeable magnesium, and exchangeable sodium were extracted with a1M ammonium acetate buffered at a pH of 7.0, and the concentrations were analyzed by an atomic absorption spectrophotometer (Summer and Miller, 1996).

Table 1 Summary of the 26 Siamese Rosewood study sites in Thailand.

No	Plantation	Code	latitude	longitude
1	Kam Phaeng Phet Silvicultural Research Station	KPP1	16°33′	99° 30′
2	Kam Phaeng Phet Silvicultural Research Station	KPP2	16° 34′	99° 30′
3	Kam Phaeng Phet Silvicultural Research Station	KPP3	16° 33′	99° 30′
4	Phit Sa Nu Lok Silvicultural Research Station	PNL	16° 50′	100° 53′
5	In Tha Khin Silvicultural Research Station	ITK	19° 9′	98° 56′
6	Tha Tum Silvicultural Research Station	TT	15° 18′	103° 45′
7	Nong Khu Silvicultural Research Station	NK	14° 41′	103° 45′
8	Huai Tha Silvicultural Research Station	HT1	14° 52′	104° 26′
9	Huai Tha Silvicultural Research Station	HT2	14° 52′	104° 26′
10	Pha Nok Khao Silvicultural Research Station	PNK	16° 50′	101° 56′
11	Loei Forestry and Forest Products Research Center	LOEI	16° 52′	101° 56′
12	Udon Tha Ni Forest Nursery Center	UD	16° 50′	102° 56′
13	Mu Si Silvicultural Research Station	MS1	14° 30′	101° 25′
14	Mu Si Silvicultural Research Station	MS2	14° 30′	101° 25′
15	Ka La Sin Silvicultural Research Station	KLS	16° 28′	103° 24′
16	Dong Lan Silvicultural Research Station	DL	16° 49′	101° 59′
17	Huai Rang Silvicultural Research Plantation	HR	12° 26′	102° 33′
18	Tha Kum Noboru Umeda Plantation	TK1	12° 22′	102° 40′
19	Tha Kum Noboru Umeda Plantation	TK2	12° 23′	102° 39′
20	Tha Kum Noboru Umeda Plantation	TK3	12° 23′	102° 39′
21	Rat Cha Bu Ri Silvicultural Research Station	RBR	13° 34′	99° 44′
22	Central Silvicultural Research Center Central	CR1	14° 24′	98° 55′
23	Silvicultural Research Center	CR2	14° 24′	98° 55′
24	Thong Pha Phum Silvicultural Research Station	TPP	14° 42′	98° 39′
25	Southern Silvicultural Research Center	SS	7° 1′	100° 17′
26	Sai Thong Silvicultural Research Station	ST	10° 59′	99° 27′

Data analysis

The correlation between SI and growth rate with the soil and climatic factors was determined using stepwise multiple regressions. The climate data used in the analysis is shown in Table 2. Relative growth rate (RGR) is an efficiency index measuring the growth rate per unit size per time and Absolute growth rate (AGR) or Mean Annual Increment (MAI) is the total increase per unit size per time. In this study, we constructed six separate equations as indicated below:

$RGR_h = (InH_2 - InH_1)/Y_2 - Y_1$,..............(1)

$RGR_{hd} = (InHd_1 - InHd_1)/ Y_{22} - Y_1$,…......(2)

$RGR_{dbh} = (DBH_2 - DBH_1)/ Y_2 - Y_1$,…..... (3)

$AGR_h = (H_2 - H_1)/ Y_2 - Y_1$,….................. (4)

$AGR_{hd} = (Hd_2 - Hd_1)/ Y_2 - Y_1$,............… (5)

$AGR_{dbh} = (DBH_2 - DBH_1)/Y_2 - Y_1$,........… (6)

where RGR_h; Relative growth rate at total height (m m^{-1}y^{-1}), RGR_{hd}; Relative growth rate at dominant height (m m^{-1}y^{-1}), RGR_{dbh}; Relative growth rate at DBH (cm cm^{-1}y^{-1}), AGR_h; Absolute growth rate at total height (m y^{-1}) AGR_{hd}; Absolute growth rate at dominant height (m y^{-1}), AGR_{dbh}; Absolute growth rate at mean DBH (cm y^{-1}). H_2; total height at Y_2 (m), H_1; total height at Y_1 (m), Hd_2; dominant height at Y_2 (m), Hd_1; dominant height at Y_1 (m), DBH_2; DBH at Y_2 (cm), DBH_1; DBH at Y_1 (cm), and Y_2-Y_1 is the time period (y).

Table 2 The climatic data obtained from meteorological stations.

No.	Station name	Temperature (°C)			Relative Humidity (%)			Rainfall (mm yr^{-1})	No. of Rainy Days (day yr^{-1})
		Max.	Min.	Mean	Max.	Min.	Mean		
1	Prachuap Khiri Khan	35.8	21.8	28.8	87.8	61.9	76.3	1056	125
2	Phitsanulok	35.9	20.4	28.1	90.1	53.3	74.2	1399	129
3	Ratchaburi	35.8	21.5	28.6	93.6	56.7	78.1	1067	135
4	Kamphaengphet	36.3	20.7	28.5	92.8	55.4	76.8	1372	136
5	Chiangmai	35.6	18.9	27.2	89.1	49.1	71.3	1158	130
6	Kanchanaburi	37.2	20.7	29.0	86.9	49.6	70.4	1104	117
7	Thong Phaphum	36.7	19.6	28.1	93.7	54.9	78.5	1827	158
8	Trat	34.0	21.9	27.9	92.4	67.4	81.4	4988	202
9	Pakchong Agromet	33.9	19.0	26.4	88.5	55.0	73.3	1206	142
10	Surin	35.8	19.7	27.7	89.1	52.6	72.4	1454	122
11	Sisaket Agromet	35.9	19.5	27.7	89.7	55.0	74.8	1420	117
12	Loei	35.8	18.0	26.9	90.6	49.9	73.2	1310	128
13	Kalasin	35.5	19.0	27.2	90.7	55.4	72.0	1340	120
14	Khon Kaen	36.2	19.2	27.7	87.2	50.9	70.4	1196	118
15	Udonthani	36.2	18.7	27.5	88.0	50.7	71.1	1338	139
16	Thatum	36.2	19.5	27.9	89.4	54.4	74.1	1313	114
17	Hatyai	34.8	21.7	28.3	92.8	59.8	79.4	1793	192

RESULTS AND DISCUSSION

The physical and chemical soil properties in the Siamese rosewood plantations, as determined from 26 sites, are presented in table 3. Four types of soil texture were found in the various plantations and were classified as sandy loam, loamy sand, sandy clay loam, and sand. However, the dominant soil texture found in study sites is sandy loam and loamy sand as indicated in table 4. The various multiple regression models are shown in table 5. At both the soil depths, i.e., between 0-10 and 10 – 30 cm, a large number of factors were related to the pH. The best fit regression had a coefficient of determination (R^2) = 0.302 (significance of 0.004) and 0.352 (significance of 0.001), respectively. A large number of climatic factors were related to Tmean. The best fit regression had a coefficient of determination (R^2) = 0.161 and a significance of 0.042. Among the combined factors, SI was related with pH and Tmean at soil depth of 0-10 cm and only pH at a soil depth of 10-30 cm. The regression had a coefficient of determination (R^2) = 0.441 (significance of 0.004) and 0.352 (significance of 0.001), respectively.

Table 3 Summary of the soil properties in 26 Siamese rosewood study sites and climatic factors obtained from 17 meteorological stations.

Factor	Soil depth between 0–10 cm			Soil depth between 10–30 cm			Climatic factor		
	Mean	**SD**	**SE**	**Mean**	**SD**	**SE**	**Mean**	**SD**	**SE**
Db(g/cm^3)	1.26	0.20	0.04	1.33	0.14	0.03	-	-	-
Pr (%)	51.57	8.91	1.75	45.73	8.05	1.58	-	-	-
Sand (%)	74.88	14.07	2.76	76.08	7.88	1.54	-	-	-
Silt (%)	10.09	2.83	0.55	9.37	3.41	0.67	-	-	-
Clay (%)	12.40	6.72	1.32	14.56	7.26	1.42	-	-	-
pH	5.22	0.41	0.08	5.14	0.39	0.08	-	-	-
OM (%)	2.42	1.73	0.34	1.53	1.34	0.26	-	-	-
N (%)	0.14	0.08	0.01	1.11	0.61	0.12	-	-	-
P (mg kg^{-1})	11.07	39.38	7.72	0.11	0.06	0.01	-	-	-
K (mg kg^{-1})	71.54	60.29	11.82	37.82	33.55	6.58	-	-	-
Ca (mg kg-1)	330.16	442.16	86.71	271.02	363.32	71.25	-	-	-
Mg (mg kg^{-1})	117.05	168.62	33.07	78.72	102.09	20.02	-	-	-
Na (mg kg^{-1})	16.12	11.11	2.18	16.81	14.84	2.91	-	-	-
Tmax (C^o)	-	-	-	-	-	-	35.49	1.08	0.21
Tmin (C^o)	-	-	-	-	-	-	20.12	1.29	0.25
Tmean (C^o)	-	-	-	-	-	-	27.81	0.76	0.15
Hmax (%)	-	-	-	-	-	-	90.42	2.20	0.43
Hmin (%)	-	-	-	-	-	-	56.10	5.85	1.15
Hmean (%)	-	-	-	-	-	-	75.32	3.63	0.71
Rf (mm yr^{-1})	-	-	-	-	-	-	1883.70	1362.49	267.21
Nr (day yr^{-1})	-	-	-	-	-	-	142.00	30.00	6.00

Remarks: Db; bulk density. Pr; porosity. OM; organic matter. N; nitrogen. P; available phosphorus. K; exchangeable potassium. Ca; exchangeable calcium. Mg; exchangeable magnesium. Na; exchangeable sodium. Tmax; maximum temperature. Tmin; minimum temperature.Tmean; mean temperature. Hmax; maximum relative humidity. Hmin; minimum relative humidity. Hmean; mean relative humidity. Rf; rainfall. Nr; number of the rainy days.

Table 4 The soil texture of the 26 Siamese Rosewood study sites.

Soil texture	Study site	
	Soil depth at 0 – 10 cm	**Soil depth at 10 – 30 cm**
Sandy loam	PNK,LOEI,KPP1,MS1,MS2, TK2,TK3,PK2,PNL,DL,ITK	PNK,LOEI,UD,KPP1,MS1, MS2,TK2,PNL,DL,ITK
Loamy sand	TT,RBL,NK,HT1,HT2,UD,KLS, KPP2,PT,ST	TT,RBL,NK,HT1,HT2,KLS,KPP2, PT,ST
Sandy clay loam	HR,TK1,PK1,TPP	HR,TK1,TK3, PK2,PK1,TPP
Sand	KPP3	KPP3

The relative growth rate was not related to any variable at the topsoil level but at the subsoil level, some variables such as porosity were related with RGR_h and RGR_{hd} as indicated by an R^2 = 0.175 (significance of 0.034) and 1.183 (significance of 0.029), respectively. Tmax was the only climatic factor that affected RGR_h, RGR_{hd}, and RGR_{dbh}. However, both AGR_h and AGR_{ha} were related with only the pH of the topsoil and subsoil but AGR_{dbh} was not related with any topsoil variable but with sodium in the subsoil. In addition, AGA_{ha} was related with Tmean, Hmean, Nr, Hmax, and pH. AGR_h was related with Tmax and pH. AGR_{dbh} was related with Tmax, Tmean, and K. The results indicate that the soil factors like pH, porosity, sodium, and potassium and the climatic factors like temperature, humidity, and number of rainfall days affected the growth as every factor affected the other. Precipitation and temperature can influence the rate of growth and nutrient utilization by the plant. Porosity influences the water capacity of a soil (Davidescu, 1972). The soil pH is important for the growth of a tree for a variety of reasons including distribution of cations in the exchange complex as exchangeable potassium and exchangeable sodium (Fisher and Binkley, 2000).

Table 5 Results from the regression calculated between environmental factors and SI of the Siamese Rosewood plantations**.**

No	Constituent		Model	R^2	SEE	*P*-value	Eq.
1	Soil factors at at a depth between 0-10 cm	SI	= -6.028 + 5.452pH	0.302	3.470	0.004	1
		AGR_{hd}	= -6.001+ 0.269pH	0.246	0.197	0.010	2
		AGR_{h}	= -0.288+0.176pH	0.192	0.152	0.025	3
		AGR_{dbh}	No related variable found	-	-	-	
		RGR_{hd}	No related variable found	-	-	-	
		RGR_{h}	No related variable found	-	-	-	
		RGR_{dbh}	No related variable found	-	-	-	
2	Soil factors at a depth between 10-30 cm	SI	= -9.068 + 6.127pH	0.352	3.345	0.001	4
		AGR_{hd}	= -0.836 + 0.319pH	0.318	0.188	0.003	5
		AGR_{h}	= -0.432+0.207pH	0.243	0.147	0.010	6
		AGR_{dbh}	= 0.832-0.005Na	0.128	0.159	0.041	7
		RGR_{hd}	= 0.191-0.002Pr	0.175	0.028	0.034	8
		RGR_{h}	= 0.176-0.001Pr	0.183	0.026	0.029	
		RGR_{dbh}	= No related variable found	-	-	-	
3	Climatic factors	SI	= -37.625 + 2.159Tmean	0.161	3.805	0.042	9
		AGR_{hd}	= -0.788+0.203Tmean- 0.063Hmean+0.005Nr	0.504	0.167	0.001	10
		AGR_{h}	= -2.433+0.086Tmax	0.319	0.140	0.003	11
		AGR_{dbh}	= -2.794+0.128Tmean	0.321	0.143	0.003	12
		RGR_{hd}	= -0.369+0.014Tmax	0.234	0.027	0.012	13
		RGR_{h}	= -0.378+0.014Tmax	0.284	0.024	0.005	14
		RGR_{dbh}	= -0.342+0.013Tmax	0.224	0.026	0.015	15
4	Combination of factors at a depth between 0-10 cm	SI	= -60.890 + 5.258pH + 2.009Tmean	0.441	3.172	0.001	16
		AGR_{hd}	= -1.681+0.252pH+0.155Tmean-0.035Hmax	0.560	0.157	0.000	17
		AGR_{h}	= -2.433+0.086Tmax	0.319	0.140	0.003	18
		AGR_{dbh}	= -3.383+0.146Tmean+0.001K	0.472	0.129	0.001	19
		RGR_{hd}	= -0.369+0.014Tmax	0.234	0.027	0.012	20
		RGR_{h}	= -0.378+0.014Tmax	0.284	0.024	0.005	21
		RGR_{dbh}	= -0.342+0.013Tmax	0.224	0.026	0.015	22
5	Combination of factors at a depth between 10-30 cm	SI	= -9.068 + 6.127pH	0.352	3.345	0.001	23
		AGR_{hd}	= 0.311pH-0.046Hmax+0.121Tmean	0.612	0.148	0.000	24
		AGR_{h}	= -2.647+0.070Tmax+0.151pH	0.438	0.129	0.001	25
		AGR_{dbh}	= -2.794+0.128Tmean	0.321	0.143	0.003	26
		RGR_{hd}	= -0.369+0.014Tmax	0.234	0.027	0.012	27
		RGR_{h}	= -0.378+0.014Tmax	0.284	0.024	0.005	28
		RGR_{dbh}	= -0.342+0.013Tmax	0.224	0.026	0.015	29

Remarks: R^2; coefficient of determination. SEE; standard error of the estimate.

Not many researches exist reporting on the soil properties and environmental factors influencing the growth of Siamese Rosewood. Research is needed about other species focusing on how the pH affects the growth of a tree. Insaun *et al.,* (2009) indicated that the soil factors responsible for the growth and in increasing the yield of Eucalyptus were pH, exchangeable calcium, magnesium, and sodium. According to Jumwong (2006), who studied Acacia spp., reported that pH of the topsoil was an important factor influencing the growth. Most studies indicated that increasing pH, potassium, temperature, humidity, and the number of the rainy days led to an increased growth and SI, while sodium and porosity had a negative influence. In other words, the growth rate and SI increased with decreasing sodium and porosity.

CONCLUSION

Siamese rosewood is a native species of Thailand. We collected growth data and soil properties (at two soil depths) from 26 Siamese rosewood plantations along with the climatic data from the neighboring meteorological stations. These were used to determine the relationship between environment factors and the growth rate and SI using a stepwise multiple regression analysis. The results indicated that the growth rate was related to several environmental variables. The pH was the most frequent variable related to parameters at the two soil depths. Temperature and humidity were important to predict the growth rate and SI too. Although, the result found four types of soil texture in the study sites, a majority of plantations had a sandy loam, loamy sand, sandy clay loam, and sandy texture. Related future work related to Siamese rosewood will need long term data to determine growth rates. In addition, studies focusing on increasing productivity of Siamese rosewood plantations in areas other than the study area will be beneficial.

ACKNOWLEDGEMENTS

The author would like to express her sincerest gratitude to Professor Dr. Mamoru Kanzaki and Dr. Taiki Mori, including all the colleagues at Forest Resources and Society Laboratory and Tropical Forest Resources and Environments Laboratory, Division of Forest and Biomaterials Science, Kyoto University, Japan, who helped immensely during the exchanged program in analyzing the soil samples. The funding for this research was supported by the International Affairs Division, Kasetsart University.

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