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Determination of Soil-Related Factors Controlling Initial Nipa (*Nypa fruticans* Wurmb.) Growth in an Abandoned Shrimp Pond

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Abstract

In an abandoned shrimp pond, the spatial variability of the height of nipa (*Nypa fruticans* Wurmb.) plants 5 years after their planting was evaluated to elucidate the determining factors for height. Soil properties were evaluated in 20 points in an area of 0.48 ha. Physical (e.g., hardness, water content) and chemical (e.g., pH and EC) properties were determined using surface soil samples collected at each point. Nipa height was moderately variable, showing a CV value of 31.2%. Soil conditions were considered to affect nipa height; therefore, principal component analysis (PCA) was conducted to elucidate the relationships among soil properties. As a result, three factors were extracted. PC1 correlated positively with relative ground level and Eh, and negatively with moisture. Because these properties were closely related to topography, PC1 was referred to as the topography factor. PC3 showed the second important contribution, a high K content contributed to a large nipa height. Multivariate analysis was also performed to examine the spatial property of nipa height (H), and as a result, the following equation was obtained: H = 423.94 - 0.39 x PC1 - 0.57 x PC3 (r^2=0.53). Results of this study indicate that 53% of nipa height variation was explained by soil properties, which is larger than the nipa height variation explained solely by topography (23%). Site-specific management to regulate soil properties could be a practical strategy for nipa plantation.

Keywords: nipa, soil properties, abandoned shrimp pond, principle component analysis, geostatistics

1. Introduction

Nypa fruticans (Wurmb.) is one of major mangrove species, whose habitat is distributed in tropical and subtropical coastal regions. It provides important commodity materials to inhabitants from thatching materials, medicinal products (Hamilton & Murphy 1988) to food sources and bioethanol feedstock (Matsui et al., 2011). One notable characteristic of nipa farming is its long-term operation (Matsui et al., 2014). Sap has been continuously collected in nipa farming for more than 100 years without replanting and fertilization. This outstanding longevity enables sustainable land use in tropical coastal area. However, the mangrove ecosystem including nipa has been converted and degraded owing to commercial exploitations. A major threat to mangrove is its conversion to aquaculture. After the development of intensive shrimp farming techniques in Taiwan in the 1970s, there was a sudden rush into modern shrimp farming in Southeast Asia; for example, 2,000 km^2 of mangrove forests was destroyed between 1961 and 1996 in Thailand (Chauppat et al., 1997). The Royal Forest Department of the Thai government conducted the first mangrove plantation in 1986 and has so far taken several measures, such as enacting protective laws for mangrove. Consequently, a number of mangrove rehabilitation projects were conducted either by the government or by the private sector, resulting in the completion of an approximately 29 km^2 mangrove plantation in 1999. However, nipa planting had not been conducted until 2010 when a royal project was initiated in Nakhon Sri Thammarat.

Soil condition has been recognized as an important factor for mangrove plantation in Thailand. Soil texture and topography have been the basis of species selection. For example, *Rhizophora spp.* are chosen for muddy areas and *Sonneratia spp.* for sandy texture. For mangrove growth, topography is considered to be the single most important factor (Komiyama et al., 1996; Kitaya et al., 2002) and recognized to be important for the distribution of mangrove species (Bunt and Stieglitz, 1999). Topography is closely related to soil properties, and in turn soil properties are closely related to plant growth. Therefore, mangrove growth can better be explained when soil properties are taken into consideration with topography (Matsui et al., 2008).

The objectives of this study were 1) to determine the significance of soil factors in the initial nipa growth in an abandoned shrimp pond and 2) to clarify the possible relationship between soil properties and nipa height. Findings of this study may contribute to the understanding of the way to reutilize degraded wetlands in coastal areas by nipa plantation.

2. Method

2.1 Study Area

The experimental site was located in the Pak Phanang region, Nakhon Sri Thammarat province, Thailand (8° 12' N, 100° 14'E) (Figure 1). A small-scale nipa plantation with an area of about 0.48 ha was established in October 2001 (Figure 2). The total number of nipa seedlings was about 100, planted at a spacing of 6 m. This site was formerly a shrimp aquaculture pond, which degraded in the 90s, leading to its abandonment without practical use, until the start of this nipa plantation.

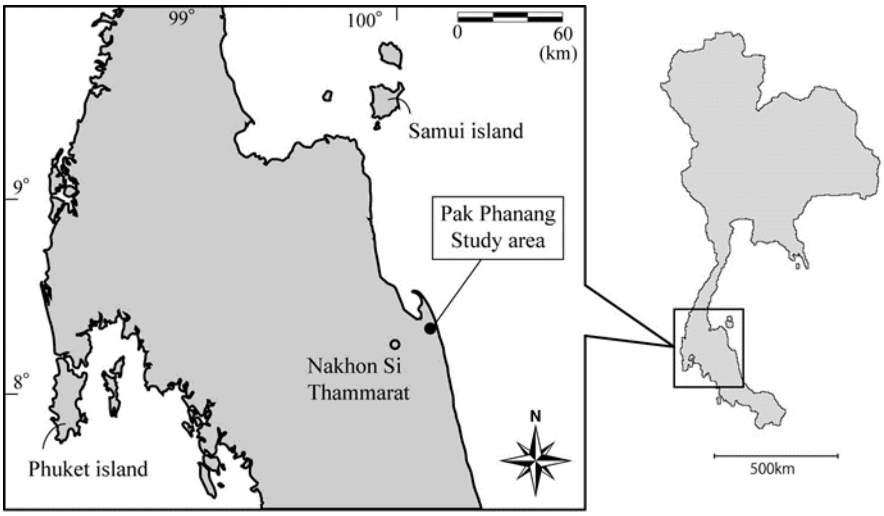

Figure 1. Location of the nipa plantation site

Figure 2. Picture showing the study site where 5-year-old nipa plants are growing

2.2 Ground Level Survey

Owing to the pond construction, the former ground condition drastically changed. Ground level is considered to be the principal factor for deciding a site for mangrove plantation by the local forestry staff working in mangrove rehabilitation. Therefore, relative ground level was measured using the Real-time Kinematic Global Positioning

System (RTK-GPS) (Trimple 5700) in the study site. The precision level was set at 2 cm in the determination of both the vertical and horizontal positions. Allocating the ground level at the lowest point as a reference level, the relative ground levels of other sampling points were measured. Accordingly, it was found that relative ground levels ranged from 14 cm to 107 cm (Figure 3). The central part of the site where the pond was formerly located showed a lower elevation than the surrounding area.

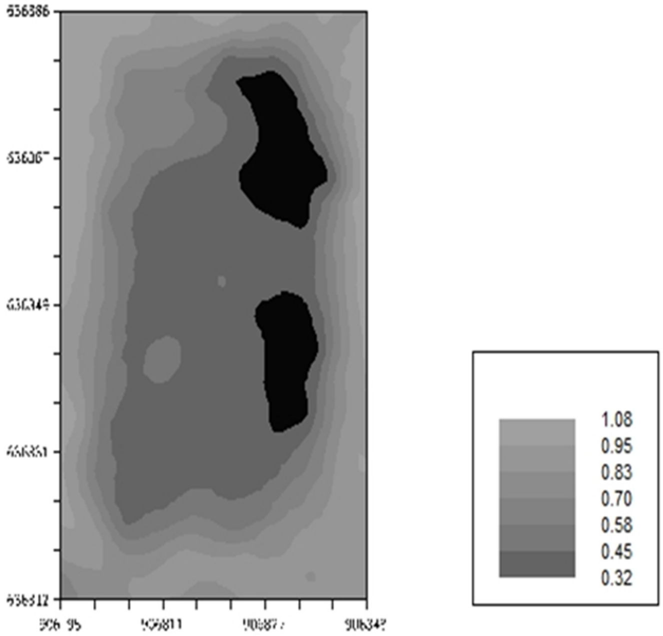

Figure 3. Ground level map of the study site, showing different ground levels within the site

2.3 Soil Sampling and Analysis

In February 2006, we measured the height of 20 nipa plants to examine their growth 5 years after their planting. Soil samples were collected after measuring soil hardness and redox potential (Eh) in situ at 20 points. Moisture content was measured by heating a soil sample in a 100 cc volumetric cylinder at 105℃ for 48 h. Soil for moisture content measurement was sampled within 30 min after water receded from the site. pH and electrical conductivity (EC) were measured after shaking fresh soil samples in water for 1 h at a soil-to-water ratio of 1:10 using a BeckmanΦ72 and a CyberScan Con300, respectively. Fresh soil samples were prepared by shaking them with 1 N ammonia acetate, and then measured for exchangeable Ca, Mg, Na, and K by the atomic absorption method (Shimadzu A-6000, Kyoto, Japan).

2.4 Statistical Analysis

As descriptive statistics, the mean, maximum, and minimum values and the coefficient of variation of each property were calculated. Correlation analysis was also conducted for all datasets. Principal component analysis (PCA) of soil properties was conducted to summarize data and investigate the relationships among the properties (Kosaki and Juo, 1989). The original data of ground level were geostatistically analyzed. A semivariogram of ground level was used to evaluate the spatial variability of the properties (Webster and Oliver 2001; Yanai et al. 2001; Yanai et al. 2005). Q value, which is an index explaining the degree of development of spatial dependence at the sampling scale, and the range of spatial dependence were measured. Statistical and geostatistical analyses were conducted using software JMP 8.0.2 version for Windows (SAS Inc. 2009) and GS+ Version 5.3 for Windows (Gamma Design Software), respectively.

3. Results

3.1 Descriptive Statistics of Nipa Height and Soil Properties

Table 1 shows the descriptive statistics on nipa height and measured soil properties. The average nipa height was 436.4 cm, and the coefficient of variance of nipa height was 31.2%. The coefficient of variance suggests that Eh showed a higher variability than other soil properties, whereas pH and EC showed low variabilities. The average pH and EC were 4.4, 157.4 mS m^{-1}, respectively.

Table 1. Descriptive statistics of frond heights and measured soil properties

	Valid N	Mean	Minimum	Maximum	Std. Dev	CV
Height (cm)	20	436.4	211.0	686.0	136.0	31.2
Relative ground level	20	60.2	21.4	100.8	26.9	44.7
Moisture (%)	20	54.2	15.1	69.5	17.4	32.0
EC (mS m^{-1})	20	157.4	112.0	224.0	26.6	16.9
Eh (mV)	20	-6.9	-364.0	310.0	213.0	-3086.3
Hardness	20	15.4	1.0	35.0	9.9	64.6
pH	18	4.4	3.8	6.4	0.6	13.0
Ex. Ca (cmolc kg^{-1})	18	13.2	4.7	24.7	6.5	49.1
Ex. Mg (cmolc kg^{-1})	18	7.0	3.1	9.8	1.7	24.2
Ex. Na (cmolc kg^{-1})	18	0.4	0.1	0.8	0.1	36.2
Ex. K (cmolc kg^{-1})	18	0.1	0.0	0.2	0.1	66.7

Ex. – Exchangeable.

Table 2 shows the correlation matrix of measured soil properties. Nipa growth condition was largely controlled by ground level. Relative ground level showed a statistically significant relationship with soil properties, such as moisture, EC, Eh, and hardness, but not with pH and exchangeable cations. Moisture content showed a positive relationship with EC ($p < 0.05$), but a negative one with Eh ($p < 0.01$) and hardness ($p < 0.05$).

A statistically significant relationship was found between nipa height and relative ground level. As indicated by $r^2 = 0.23$, the variance of nipa height by 23% was explained by relative ground level. The equation for nipa height predicted by relative ground level is expressed by the following equation:

$$\textit{Nipa height (H)} = 583.77 - 2.45 \times \textit{Relative ground level} \ (r^2 = 0.23) \tag{1}$$

Table 2. Correlation matrix of measured soil properties (N=16)

	Height	[a]R_G_L	Moisture	[b]EC	Eh	Hardness	pH	[c]Ca	[d]Mg	[e]Na
Relative ground level	-0.57**									
Moisture	0.53**	-0.84*								
EC	0.08	-0.50*	0.50**							
Eh	-0.49	0.83*	-0.62*	-0.57**						
Hardness	-0.30	0.64*	-0.54**	-0.30	0.61**					
pH	0.70*	-0.42	0.47	-0.17	-0.20	-0.23				
Exchangeable Ca	0.22	0.13	0.12	-0.02	0.29	0.21	0.27			
Exchangeable Mg	0.42	0.04	0.13	-0.08	0.13	0.09	0.46	0.63*		
Exchangeable Na	0.46	-0.45	0.42	-0.12	-0.36	-0.44	0.61**	-0.03	0.37	
Exchangeable K	0.45	-0.21	0.12	0.03	-0.19	-0.26	0.49	-0.16	0.18	0.60**

*[a]Relative ground level, [b]Electric conductivity, [c]exchangeable Ca, [d]exchangeable Mg, [e]exchangeable K, * and ** indicate 1% and 5% level of significance, respectively.*

3.2 Statistical and Geostatistical Analyses

PCA identified three components (PC1-3) with eigenvalues, or the variances of components, greater than 1.0. Three components accounted for 76.8% of the total variance (Table 3). On the basis of the component loadings with Varimax raw rotation, the first component showed high loadings for relative ground level, moisture, and Eh (Table 4). Because these properties were related to the topography of the site, this component was referred to as the topography factor. Similarly, the second component showed high loadings for Ca and Mg, and the third component for K. Such variations of the soil properties were categorized into three factors, which were independent of each other.

Table 3. Results of principal components analysis

	Eigenvalue	% total variance	Cumulative Eigenvalue	Cumulative %	Beta weight	*p*-level
PC1	4.13	37.6	4.1	37.6	-0.59	0.01
PC2	2.52	22.9	6.7	60.5	0.25	0.22
PC3	1.80	16.4	8.5	76.8	-0.45	0.04
PC4	0.71	6.4	9.2	83.3	0.10	0.60
PC5	0.63	5.7	9.8	89.0	-0.13	0.49

Table 4. Component loadings (Varimax raw)

	Component				
	PC1	PC2	PC3	PC4	PC5
Relative ground level	0.91*	-0.01	0.14	0.19	-0.23
Moisture	-0.90*	0.23	-0.05	-0.15	0.09
EC	-0.39	0.06	0.04	-0.90*	0.03
Eh	0.75*	0.22	0.16	0.34	-0.25
Hardness	0.53	0.06	0.16	0.09	-0.73*
pH	-0.55	0.32	-0.54	0.44	-0.20
Exchangeable Ca	0.02	0.88*	0.12	0.06	-0.25
Exchangeable Mg	0.04	0.83*	-0.36	0.09	-0.07
Exchangeable Na	-0.36	0.19	-0.67	0.30	0.41
Exchangeable K	-0.06	-0.09	-0.96*	-0.07	0.04

** indicates loading is > 0.7 or < -0.7.*

Stepwise multiple regression analysis was subsequently performed to obtain a model for predicting nipa height. In this analysis, nipa height was used as a dependent variable, and standardized scores of the three principal components described above were used as independent variables. The most appropriate model obtained with a p value of <0.04 was

$$H = 423.94 - 0.39 \times PC1 - 0.57 \times PC3 \ (r^2=0.53) \tag{2}$$

53% of nipa height variation was explained by soil properties, which is larger than the nipa height variation explained solely by topography (23% in Eq. 1). Beta weights explaining variable importance were -0.59 for PC1 and -0.45 for PC3 (Table 3), which indicated a larger contribution of PC1 on nipa height.

Considering that ground level is spatially variable, spatial analysis of ground level was performed. The semivariogram shows that the semivariance increases with increasing distance between sampling points (Figure 4). The degree of spatial dependence was relatively high, as shown by the Q value of 0.90, and a relatively wide range of spatial dependence (29 m).

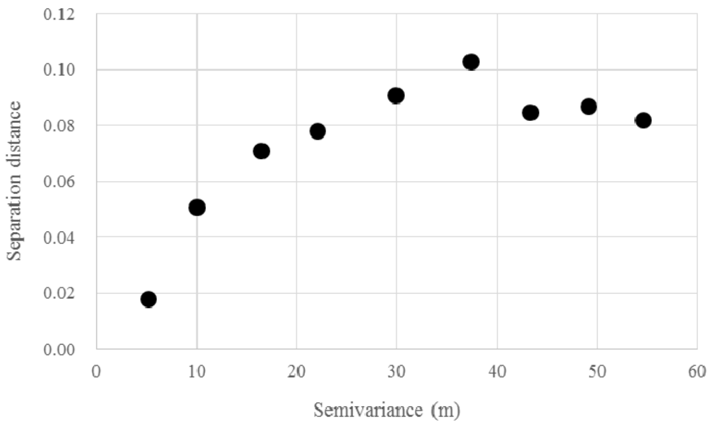

Figure 4. Semivariogram of ground level. Semivariance indicates a high degree of spatial dependence

4. Discussion

4.1 Spatial Variance of Nipa Height and Soil Properties

Mean nipa height of 5 years old was 436.4 cm with the 686 cm maximum height. The major mangrove planting species, *Rhizophora* grew up to 300 cm in 4 years if growing condition is favorable (Matsui et al. 2012). The growth rate of nipa is comparatively high because nipa is herbaceous perennial plant whereas the other mangrove species such as *Rhizophora* are mostly arboreous.

The CV of nipa height 31.2% was almost the same as the CV of *Rhizophora* 32.4% (Matsui et al. 2008) and the degree of spatial dependence of nipa height was quite high, as shown by the Q value of 0.90. The Q value of nipa height was higher than that (0.72) of *Rhizophora* height (Matsui et al. 2008), indicating that site-specific land management would be more effective in nipa plantation.

The study site had been operated as intensive shrimp pond. At the pond construction, excavated soils were exposed to the air and became acidic. A low pH 4.4 is a consequence of this acidification. The study site is located 5 km east of seashore and tidal inundation is only few times a year. Small amounts of exchangeable Mg and Na indicate comparatively low influence of seawater. Larger amount of exchangeable Ca comparing to *Rhizophora* stand is possibly provided by fresh water flowing nearby the study site.

The mean moisture was 54.2 % and the mean EC was 157.4 mS m^{-1}, both figures are rather high comparing to those of *Rhizophora* stand indicating a presence of waterlogging. The mean Eh was -6.9 mV which also represents soils are reductive due to stagnant water in soils.

4.2 Effects of Soil Properties on Initial Nipa Growth

23% of the total variance of nipa height was explained by the relative ground level ($r^2 = 0.23$ in Eq. 1). Considering that this figure was 48% in *Rhizophora* height (Matsui et al. 2008), initial nipa growth is more affected by other factors besides the relative ground level.

As the regression coefficients in the Eq. 2 indicate the magnitude of each factor's contribution to nipa height, PC1 was found to have the most important contribution: low elevation and Eh, high water content contributed to a large nipa height. PC3 can be identified as the second important factor in this relationship. A large nipa height was thus related to a high pH and high amounts of exchangeable Na and exchangeable K, which contrasted to the fact that large *Rhizophora* height was related with a low pH and a low exchangeable K (Matsui et al. 2008). A nipa's preference for a high pH can be explained by its habitat. Nipa generally grows in a lowland as its habitat where pH is normally high due to water inundation. A high amounts of exchangeable K was related with a large nipa height, which is possibly illustrated by the fact that palm palnts such as nipa requires a large amount of K (Sim 2013).

Considering that nipa height was influenced by ground level and exchangeable K, it was assumed that nipa growth was controlled not only by moisture but also by soil fertility. As a practical interpretation, it is concluded that moisture and K variables can be good indicators of the spatial variation of nipa height, and site-specific management to regulate the moisture and K content of soil may become an effective strategy to promote nipa growth.

5. Conclusion

The heights of nipa (*N. fruticans* Wurmb.) plants 5 years after planting in an abandoned shrimp pond, were evaluated in relation to ground level and soil properties. The degree of spatial dependence of ground level was relatively high, shown by the Q value of 0.90. On the other hand, nipa height was moderately variable showing a CV value of 31.2%. Three factors were extracted from soil properties by PCA. PC1 correlated positively with relative ground level and Eh, and negatively with moisture. PC3 showed the second most importance contribution, high K contents contribute to large nipa height. Multivariate analysis was also performed to examine the spatial property of nipa height, and the following equation was obtained: H = 423.94 - 0.39 x PC1 - 0.57 x PC3 (r^2=0.53). Consequently, 53% of nipa height variation was explained by soil properties, which is larger than the nipa height variation explained solely by topography (23%). Site-specific management to regulate soil properties could be a practical strategy for nipa plantation.

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