Pak. J. Bot., 49(1): 33-39, 2017.

EFFECTS OF WATER PROPERTIES AND SOIL TEXTURE ON THE GROWTH OF A MANGROVE PALM; *NYPA FRUTICANS* ON CAREY ISLAND, MALAYSIA

ROZAINAH MOHAMAD ZAKARIA[1,2*], NASRIN ASLEZAEIM[1] AND AHMAD BAKRIN SOFAWI[1]

[1]*Institute of Biological Sciences, University of Malaya, 50603, Kuala Lumpur, Malaysia.*
[2]*Institute of Ocean and Earth Sciences, University of Malaya, 50603, Kuala Lumpur, Malaysia.*
[*]*Corresponding author's email: rozainah@um.edu.my, Tel: ++0060379676794, Fax: ++0060379674178*

Abstract

Nypa fructicans is a major species of mangrove palm on Carey Island, Malaysia. The main objective of this study is to determine the effects of water properties on the growth of *Nypa fruticans.* Plant growth measurements and water analyses were carried out in six plots for 16 months. The life stages of *Nypa fruticans* were divided into seedlings, juveniles, adults and matures, based on the number of leaves. Leaf production of juvenile and mature trees showed negative correlation with salinity. Leaf production of seedlings was affected negatively only by heavy metal of Arsenic (As). Calcium (Ca) in the water had a strong positive effect on the new leaf production of juveniles and on the spear elongation of matures, and Iron (Fe) had a negative effect on the leaf elongation of adults. Similarly, spear elongation of juvenile trees was positively correlated to nitrate (NO_3^-). Silty clay texture provides the best condition for the growth of *Nypa fruticans*. The growth of *Nypa fruticans* was most significantly affected by water parameters in the early life stages.

Key words: Heavy metals, Anions, Macronutrients, Mangrove, Nipah.

Introduction

Nipah or *Nypa fruticans* Wurmb is a mangrove palm that grows well in calm estuaries and coastal regions. It is commonly found on the landward side of a mangrove forest subjected to low water salinity. The species can exist in a simple channel or complex tributaries, bays, tidal flat surfaces and creeks, as long as there is a tide and a freshwater input (Chau Sum *et al*., 2013). This tree species lacks an upright stem, and the leaves appear at the apex of a horizontal stem. Like many palms, *N. fruticans* exhibits a uniform growth pattern with constantly successive leaf production and height increments throughout the year.

N. fruticans is one of the most common palms in the mangrove forests of Malaysia, and is considered to be one of the most useful. Many products obtained from the leaves, inflorescences and fruits of *N. fruticans* are economically valuable, especially for the local communities. Several studies have focused on the ecology, distribution, and growth of *N. fruticans* (Teo *et al*., 2010; Rozainah & Aslezaeim, 2010), but there is limited knowledge on the growth response of the species to environmental parameters. Although the effects of light, soil, salinity and disturbances on the growth of many palms have been studied (Tripler *et al*., 2007), no such study is available for *N. fruticans* specifically. Such a study is highly important in light of the discovery by Irawan *et al*. (2011) that the seedling growth of the sago palm (*Metroxylon sagu*) is a significantly sensitive to N and P deficiency.

The location of the mangroves, between fresh water and the ocean, is a key site for the deposit of nutrients and other materials. Several published works deal with growth responses of mangroves to salinity and nutrients (Alongi, 2010 & 2011; Biber, 2006; Lovelock *et al*., 2007; Naidoo, 2009 & Yates *et al*., 2002), in addition to a study on the influence of nutrients in sediment with the composition of the mangrove flora (Clarke & Kerrigan, 2000). The current study focuses on the effects of environmental parameters on the growth of a mangrove palm, *N. fruticans*: mainly water qualities, and also soil texture. This investigation improves our understanding about the effective stimulus for the growth and regeneration of *N. fruticans*. A high water quality with sufficient nutrient availability and salinity enables the species to maintain continuous growth and a healthy population. However, there has been a significant increase in the natural levels of heavy metals in the aquatic ecosystems because of industrial activities and urban development (Marcovecchio *et al*., 2007). At certain levels, any chemical elements in water can be dangerous to hydrophytes plants like *N. fruticans*. Therefore, a study on water properties is needed to detect the levels of heavy metals, major metals, trace elements and nutrients in water, and determine their effects, since this species is constantly inundated. In addition, soil texture is also expected to influence the growth rates of this species.

The main objectives of the research are; 1) to find the correlation of water properties and soil texture with the growth of *N. fruticans* and 2) to determine the main parameters noticeably affecting *N. fruticans* during different life stages.

Materials and Methods

This study was carried out on Carey Island, located about 70 km to the south west of Kuala Lumpur, the Malaysian capital. Carey Island is the biggest island of the Klang Isles Mangrove Forest, in the west coast of the Peninsular Malaysia. Oil palm plantation has taken up most of the island for the past 100 years, and currently only the edge of the island is covered with mangrove forest. The study area has a humid tropical climate with high temperature from 23 to 33°C, humidity as high as 80 to 90% and a total annual precipitation of 2000-2500 mm. The study site has coordinates N 02°53'26.1"and E 101° 20'48.4" (Fig. 1). In this study, three 400 m^2 plots and three 100 m^2 plots were established where *N. fruticans* was mono-dominant and was not mixed with other mangrove tree species.

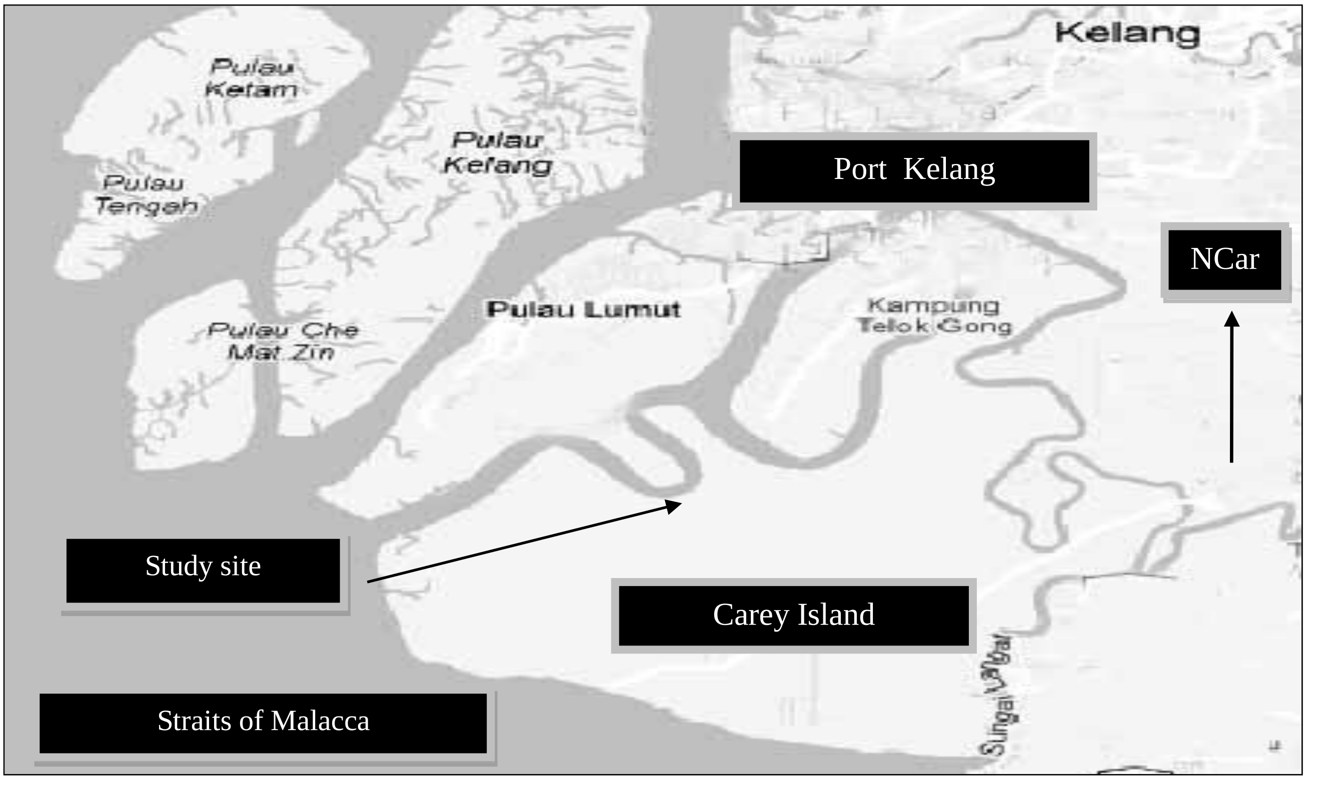

Fig. 1. Location of the study site at Carey Island, Malaysia (Rozainah & Aslezaeim, 2010).

The classification of life stages each individual was based on leaf numbers as stated in Rozainah & Aslezaeim (2010). Four developmental stages were identified:

1. Seedlings - from small individuals with one intact leaf to plants with three leaves.
2. Juveniles – individuals with four to seven larger leaves.
3. Adults - individuals with eight to fourteen leaves, with or without reproductive organs.
4. Mature - individuals with fifteen and more leaves, with or without reproductive organs.

The growth measurement of *N. fruticans* was calculated based on leaf production rate and spear elongation over a period of time, as has been reported in Rozainah & Aslezaeim (2010). A total of 84 individuals, representing all stages, were selected randomly, across the six plots, and were observed for a period of 16 months for their spear elongation and leaf production. New spear leaf productions, and development of each spear leaf until it was fully expanded, were recorded for each individual every month. Subsequently, leaf production was expressed as the number of leaves presented over a period of time.

Water quality: At each plot, three water samples were collected from the surface of riverbanks and puddles, at low tide, every two months for 16 months. The samples were transferred to the laboratory for physical and chemical analysis. Samples collected in full plastic bottles were filtered through a 0.45 µm membrane filter. Water pH, temperature, salinity, TDS and conductivity were measured using a multi-parameter probe (Professional Plus, YSI incorporated, Ohio, USA), and dissolved oxygen (DO) was recorded at site in each plot from waterways using a DO meter (Pro20, YSI incorporated, Ohio, USA). Metal concentrations including heavy metals (Pb, Cu, Zn, As), major metals (Fe, Mn), macronutrients (Ca, Mg) and a trace element (Al) were detected by the inductively coupled plasma optical emission spectrophotometer (ICP-OES) (Perkin-Elmer, Optima 5300 DV, USA). Anions (Cl^-, SO_4^{2-} and NO_3^-) were determined by *using Ion Chromatography* (IC) (*Metrohm,* 861).

Soil sampling: The rhizomes of *N. Fruticans* creep horizontally near the surface, rarely extending deeper than 30cm, so a soil scoop was used to take homogeneous soil samples within the first 30cm. Three samples in each plot, scattered uniformly over the plots as representatives of the area, were collected every month over a period of 16 months. Soil pH and temperature were measured on site using a meter that recorded both pH and temperature (Eijkelkamp). The soil samples were placed in labelled plastic bags and brought to the laboratory for further analysis. The percentage of water content was calculated following Radojevic & Baskkin (2006) methodology. Soil particle sizes or soil textures were determined using a particle size analyzer (PSA, Coulter, model L 230). For soil classification, three main fractions according to the size of mineral particles were used; sand (50-2000 µm), silt (2-50 µm) and clay (<2 µm) on a triangular system (Ashman & Puri, 2002).

Statistical analysis of data: Analysis of variance (ANOVA) was conducted in this experiment. Data were presented by mean and standard deviation (SD), representing the distribution of data around the mean. Correlation analysis was done by Pearson Correlation and partial correlation in the SPSS program to determine the relationship of soil and water characteristics with growth rates in different stages of *N. fruticans*. Partial correlation revealed that some environmental factors have moderating effects on correlations between the growth and environment.

Results

Growth rate: The growth rates presented in Table 1 and life stage distributions of *N. fruticans* have been reported elsewhere with complete details by the same lead authors (Rozainah & Aslezaeim, 2010). The purpose of this paper is to reflect on the correlation between the environmental factors and the reported growth rates in the four life stages of this species. ANOVA showed that there were significant differences in total leaves, new leaf production and leaf elongation among all life stages ($p<0.05$). Table 1 also showed that the adult stage was most numerous in this population.

Relationship between water characteristics and growth rates: Average data of water qualities i.e. pH, salinity, temperature, TDS, EC, and DO are shown in Table 2. Average data of heavy metal, major metal, trace metal and anions are also included in Table 2. The Pearson correlation between the growth rates of each life stage and the environmental water quality is shown in Table 3. Generally, only the seedlings' growth was greatly influenced by some of these environmental factors. In seedlings, new leaf productions were positively related to As ($r = 0.85$, $p<0.05$). Conversely, Ca, Cl^- and SO_4^{2-} showed a very strong negative correlation with seedling growth ($p<0.01$), whilst physical parameters had no significant effect on this stage. The juvenile stage did not tolerate high salinity, and neither did the mature stage. However, in the juvenile stage, there was a positive relationship between NO_3^- and spear elongation ($r = 0.80$, $p<0.05$), and production of new leaves correlated well with temperature ($r = 0.36$, $p<0.01$). The growth of adults and matures seemed to be more stable and was not generally affected by these factors, although Ca has a strong positive impact on the leaf production of the mature stage ($p<0.01$).

Relationship between soil characteristics and growth rates: The soils in all six study plots were silty-clay, containing 54.19 ± 7.05% silt and 45.08 ± 6.92% clay with mean soil moisture content of 34.24 ± 6%. Soil temperature was 29.6 ± 1ºC, and soil pH was 6.4 ± 0.4, slightly acidic. Table 4 showed no relationship between the soil variables (pH, temperature and moisture content) and growth of trees in juvenile and adult stages, whilst seedlings and matures showed a weak relationship with soil temperature ($p<0.05$). The new leaf production of matures was positively related to the soil temperature ($r= 0.319$, $p<0.05$), while the new leaf production of seedlings was negatively related to soil temperature ($r = -0.798$, $p<0.05$). In addition, the correlation analysis showed that the new leaf production of seedlings was positively related to silt ($r = 0.727$, $p<0.05$) but negatively related to clay ($r = -0.903$, $p<0.01$). There was a positive relationship of juveniles' leaf production with clay ($r = 0.295$, $p<0.05$).

Discussion

The measurements of both leaf production and leaf elongation (Svenning, 2001) are considered as the growth rate for *N. fruticans*. Seedlings have the highest leaf production of up to 2.9 leaves per year, followed by the older stages, which rarely go beyond 1 leaf per year (Rozainah & Aslezaeim, 2010). This very slow growth is very common for palms, and results in a low rate of forest generation (Widyatmoko *et al*., 2005; Sampaio *et al*., 2008).

Table 1. The growth rates of all life stages (mean ± sd) and density of *Nypa fruticans* on Carey Island. (Rozainah & Aslezaeim, 2010)

Growth rates	Seedling	Juvenile	Adult	Mature
Tlf ($year^{-1}plant^{-1}$)	4.3 ± 2.6^c	7.7 ± 1.6^c	12.3 ± 2.2^b	17.7 ± 2.1^a
Spear elongation (cm/month)	n.a.	55.5 ± 23.2^b	81.0 ± 13.5^a	91.0 ± 13.7^a
Nlf ($year^{1}plant^{-1}$)	2.9 ± 0.9^a	1.0 ± 0.8^b	1.0 ± 0.7^b	1.0 ± 0.9^b
Percentage in population (%)	2.2	13.7	67.9	16.2

Tlf = Total leaves, Nlf = New leaves, similar letter in the same row denotes no significant difference

Table 2. The mean concentration of metals, nutrients and physical characteristics of water samples.

Heavy metal (mg/L)	Major metal (mg/L)	Macronutrients (mg/L)	Trace metal (mg/L))	Anion (ppm)
Pb 0.019 ± 0.01	Mn 0.12 ± 0.12	Ca 188 ± 87.4	Al 0.25 ± 0.25	CL^- 21.74 ± 10
Cu 0.048 ± 0.04	Fe 0.61 ± 1.20	Mg 31.3 ± 153.1		SO_4^{2-} 3.96 ± 7.29
Zn 0.035 ± 0.09				NO_3^- 32.82 ± 15.43
As 0.069 ± 0.16				

pH	Salinity (ppt)	Temperature (Cº)	DO (mg/L)	TDS (ppt)	EC (ms/cm)
6.4 ± 0.4	24.5 ± 2.4	27.3 ± 0.8	7.7 ± 1.6	24.5 ± 3.0	38.3 ± 3.9

DO = Dissolved oxygen, TDS= total dissolved solid, EC= electro conductivity

Table 3. Pearson correlation coefficient between growth of *N. fruticans* and water characteristics.

Water parameter	Life stages	Seedlings (growth rate)		Juveniles (growth rate)			Adults (growth rate)			Matures (growth rate)		
		Tlf	Nlf	Tlf	SE	Nlf	Tlf	SE	Nlf	Tlf	SE	Nlf
Heavy metals	Pb	0.26	0.37	0.25	0.58	0.35	0.20	0.20	0.05	0.08	-0.16	-0.13
	Cu	-0.34	-0.37	0.14	-0.5	-0.01	0.06	0.03	0.09	0.02	-0.35	0.04
	Zn	-0.34	-0.52	-0.27	-0.10	-0.03	0.09	0.02	-0.2	-0.16	-0.08	0.28
	As	0.69	0.85	-0.02	-0.21	0.07	-0.15	0.16	0.06	0.13	-0.30	0.15
Major metals	Mn	0.18	0.08	-0.03	-0.18	-0.19	-0.09	0.03	-0.11	0.10	0.32	-0.10
	Fe	-0.46	-0.70	0.00	0.46	-0.15	0.12	-0.27*	0.14	-0.02	-0.01	-0.03
Macro nutrients	Ca	-0.68	-0.90*	0.15	0.17	-0.32*	0.16	0.20	-0.07	0.05	0.70**	0.17
	Mg	0.21	0.16	0.15	0.50	-0.04	-0.06	0.00	0.00	0.05	0.31	0.14
Trace metals	Al	-0.79*	-0.72*	0.14	0.62	-0.06	0.12	0.01	0.07	-0.07	0.13	0.07
Anions	Cl^-	-0.9**	-0.88**	0.02	0.22	0.16	0.00	0.24	-0.05	-0.01	0.16	0.03
	SO_4^{2-}	-0.9**	-0.86**	0.11	0.25	0.11	-0.03	-0.10	-0.08	-0.02	0.38	0.09
	NO_3^-	-0.37	-0.49	-0.07	-0.80*	-0.06	0.17	-0.01	0.07	-0.12	0.44	-0.13
Physical	pH	-0.44	-0.62	-0.24	-0.21	-0.27	0.09	-0.10	-0.03	0.00	-0.01	-0.10
	Salinity	0.47	0.40	-0.31*	0.47	-0.29*	0.02	0.02	0.08	0.05	0.10	-0.26
	Temp	-0.47	-0.55	0.21	-0.40	0.36**	0.02	0.18	-0.12	0.00	0.02	0.10
	TDS	0.10	0.42	-0.15	0.46	-0.10	-0.02	-0.01	-0.02	0.00	0.21	-0.24
	EC	0.14	0.39	-0.18	0.46	-0.24	0.00	0.04	0.08	0.11	0.08	-0.19
	DO	0.34	0.35	-0.09	0.51	-0.15	0.00	0.30	-0.11	0.08	0.50*	0.15

Tlf = Total leaves ($year^{-1}plant^{-1}$), Nlf= New leaves ($year^{-1}plant^{-1}$), SE = Spear elongation, *$p< 0.05$, **$p< 0.01$

Table 4. Pearson correlation coefficient between the growths of *N. fruticans* and soil characteristics.

Life stages	Growth	pH	Soil temperature	Moisture content
Seedlings	Tlf ($year^{-1}plant^{-1}$)	0.14	-0.29	0.02
	Nlf ($year^{-1}plant^{-1}$)	0.52	-0.79*	0.24
Juveniles	Tlf ($year^{-1}plant^{-1}$)	-0.06	0.06	0.08
	Spear elongation (cm/month)	0.00	-0.51	0.26
	Nlf ($year^{-1}plant^{-1}$)	0.15	0.09	-0.04
Adults	Tlf ($year^{-1}plant^{-1}$)	-0.18	0.05	0.04
	Spear elongation (cm/month)	0.17	0.25	-0.19
	Nlf ($year^{-1}plant^{-1}$)	0.07	-0.05	0.00
Matures	Tlf ($year^{-1}plant^{-1}$)	0.00	0.24	0.16
	Spear elongation (cm/month)	-0.04	0.44	-0.19
	Nlf ($year^{-1}plant^{-1}$)	-0.01	0.31*	-0.05

*$p< 0.05$

In the older stages, a quicker elongation of the spear leaf is apparent. This is possibly related to the strong positive effect of Ca on the leaf growth of *N. fruticans* mature stage (Mckee, 1993). According to the results of this study, although the water pH was slightly acidic, it had no negative impact on the growth rate as it was still within the optimal range (6.5-7.5) (Wakushima *et al*., 1994). Salinity and tidal inundation have been considered as important requirements for the occurrence of *N. fruticans* (Alongi, 2009). *N. fruticans* grows well in very low salinity areas (below 5 ppt) of inundation in the Sundarban (Kathiresan *et al*., 1996) as well as freshwater outflow (Fong, 1982). These previous studies agree with our predictions of the better growth in *N. fruticans* at lower level of water salinity. Therefore, *N. fruticans* seems to tolerate salinity as much as other mangroves, but its growth is more luxuriant at lower salinity which is within the natural range for tropical freshwater ecosystem. Salinity was also known as a stressor in seedlings of *Rhizophora* sp. (Biber, 2006) while *Avicennia marina* trees could extend their covering area up to 75% seawater (Manikandan *et al*., 2009) with more tolerance to high salinity than the Rhizophoraceae (Motamedi *et al*., 2014). In addition, salinity significantly reduces the growth of shoots in seedlings of *Salvadora oleoides* by decreasing water content and water potential in their leaf and stem (Hardikar *et al*., 2011). These previous studies concur with the findings of this study, in which high salinity is a limiting factor for the growth of *N. fruticans*. With higher salinity, fewer new leaves are produced in juveniles and matures. Therefore, salt tolerance within the species depend on the life stages, with young trees are potentially more sensitive to high salinity than old ones.

In this study, water pH and DO have an indirect controlling role on the growth, while water salinity has a both direct and indirect impact on the growth of young trees. Therefore pH, DO, and salinity can be controlled to moderate the negative impact of high temperature on the new leaf production of seedlings. In this study, DO was in the range of 3.52- 10.2 mg/l with the mean of 7.7 ± 1.6. This is similar to the readings at 2 rivers in the east coast of Peninsular Malaysia; mean of 7 mg/l in Sungai Kelantan (Ahmad *et al*., 2009), and between 4.64-11.43 mg/l in Setiu estuary (Kamaruzzaman *et al*., 2008). DO on occasions was very low and was not within the safe level but in totality it was a safe and healthy environment for the flora and fauna of the area.

Mangroves have been reported to grow abundantly, with high diversity, in tropical areas within countries such as Malaysia, India and Indonesia (Kathiresan & Bingham, 2001). Temperature and rainfall have the most significant influence on the composition and quality of mangrove vegetation (Gilman *et al*., 2008). In this study, the mean water temperature in the area was high. It had a weak positive effect on the growth of juveniles but a strong negative effect on seedlings (Tables 2, 3). With regards to Malaysian interim water quality standard, the area is classified into class 1 and 2 and is within safe levels as far as the DOE Interim Marine Water Quality and National Water Quality Standards (INWQS) for Malaysia (Ahmad *et al*., 2009). In this study, nitrate concentrations are higher than the standard level whilst the low levels of heavy metals are within the accepted limit. These elements are not a limiting factor for the growth of *N. fruticans* in all life stages, except for arsenic. Arsenic concentration has a strong positive effect on the new leaf production of *N. fruticans* seedlings, while As is not a necessary plant nutrient. Similarly, in a small concentration, arsenic significantly increased the growth of *Spartina alterniflora* (Carbonell *et al*., 1998), and its addition has also shown the improvement in the growth of rice (Marin *et al*., 1992).

The macronutrients; Ca and Mg, and major metals; Mn, and Fe are usually essential nutrients for plants. A strong negative effect of Al, Ca, Cl^- and SO_4^{2-}, on new leaf production of seedlings was demonstrated, and their inclusion in water resulted in the poor leaf production of *N. fruticans* seedlings. Low pH and high aluminium in soils can be toxic to the plant growth with consequences for water and nutrient uptake (Slattery *et al*., 1999).

In this study, increased Fe in water is a limiting factor, reducing the leaf elongation of *N. fruticans* adults. The reason could be related to the iron toxic effect because Fe content significantly increases in plant tissues in response to salinity (Hardikar *et al*., 2011). On the other hand, the growth of other mangrove species like *Avicennia marina* and *Ceriops tagal* was enhanced at high soluble iron supply (Alongi, 2010).

Redox potential and pH are most significant for metal solubilization with higher solubility under slightly acidic and reducing redox potential conditions (Bang & Hesterberg, 2004). In addition, Fe-Mn oxide fraction in soil decreased with the decline of pH value and redox potential (Cao *et al*., 2001). In this study, increase of Ca in water encourages intensive new leaf production of juveniles and leaf elongation of matures in *N. fruticans*.

The sensitivity of seedling growth in sago palm to the deficiency of Ca and Mg was reported by Irawan *et al*. (2011). The reason is that calcium content in plant tissues significantly decreases in response to salinity (Hardikar *et al*., 2011). Mg and Ca are rarely limiting for marine plants because of their large quantities in seawater, while nitrogen and iron are often considered as a limiting factor (Howarth & Marino, 2006 & Alongi, 2010). Mckee (1993) demonstrated that mangrove zones dominated by *Avicennia germinans* had strongly reducing soils with high sulphide (2-4 mg/L). This agreed with water Cl^- and SO_4^{2-} concentrations in this study (Table 2). High water SO_4^{2-} contents significantly reduce the leaf production of *N. fruticans* seedlings.

For the same reason, high NO_3^-levels can generally damage, reduce growth and cause high mortality in mangroves (Youssef & Saenger, 1998). Significant acidification due to high NO_3^- in rivers and lakes could be a result of the decay of plant remains, anthropogenic and industrial wastes, agricultural drainage, run-off, and rain in the area. The optimal range of NO_3^- content is from 0.9-1.0 mg/l to 5-10 mg/l as reported by Radojevic & Baskkin (2006) while a high mean concentration of 32.8 ± 15.4 mg/l NO_3^- exists in waters in the current study. This could be related to industrial activity and N fertilizers and run-off from the oil palm agriculture and mills on Carey Islands. Not only does high nitrate content not have a negative effect on Nypa growth but it also encourages leaf elongation in juveniles. Various studies have shown the positive correlation between nitrate and leaf growth in mangroves as in *Avicennia marina* with enrichments in leaf number, plant height and branching with numerous leaves (Lovelock *et al*., 2007; Naidoo, 2009; Yates *et al*., 2002).

Furthermore, Alongi (2011) reported stem growth enhancement in *Rhizophora apiculata* and *Xylocarpus granatum* to the highest rate when of N supply (50 mg/L); *Bruguiera gymnorrhiza*, *Avicennia marina* and *Xylocarpus moluccensis* stem growth levelled off by 10 mg/L, and stem growth of *Ceriops tagal* peaked at 24–26 mg/L. Similarly, positive growth responses of *Glochidion obscurum* and *Lagerstroemia speciosa* to nitrogen additions (Hashim & Hughes, 2010) and significant growth responses of seedlings to the deficiency of nitrogen fertilizers in sago palm (Irawan *et al*., 2011) were demonstrated. In addition, plant tissues tolerate environmental conditions to varying degrees at different developmental stages (Munns, 1993).

Soils were silty-clay and differed little in the amount of silt and clay. Higher fraction of silt than clay positively affected the growth of seedlings in this study. Silty clay texture of soils provides the best condition for the growth of *N. fruticans*. A high percentage of clay reduces leaf production and total number of leaves in seedlings, while the leaf production of seedlings increases with a high percentage of silt particles. A possible explanation could be pH reduction in soils with high clay fraction (Clarke &

Kerrigan, 2000). On the other hand, a high percentage of clay particles encourages the leaf elongation in adults. The explanation is the role of clay particles in absorbing water and holding plant nutrients. In addition, a positive correlation of soil elements with clay fraction in mangrove swamps has been demonstrated (Clarke & Kerrigan, 2000).

Soil moisture is important for plant growth, and varies depending on soil topography, soil disturbance, rainfall, frequency of tidal inundation and soil quality (Ashton & Macintosh, 2002). In wet conditions, soil porosity, hydraulic conductivity, vegetation canopy, shaded condition, root action and transpiration, particularly after rainfall, all effectively increase the soil moisture (Hillel, 2012). In this study, the percentage of moisture content had little variation, and depended on the time the samples were taken. The soil moisture content in the study area is not high compared with high moisture values in Sematan mangrove forests with large areas of *N. fruticans* along the riverbanks of Sungai Sematan (Ashton & Macintosh, 2002). The homogeneous soil moisture content could be related to saturated water of the upper soil layer after rainfall having the same soil porosity, water retention, and similar vegetation cover on the study area.

Soil pH in the current study was slightly acidic, which agreed with the predictions of Ashton & Macintosh (2002) on soil and water pH in the Sematan mangrove forest in Sarawak. Similarly, Davies and Abowei (2009) reported 5.22 ± 0.27 pH in Okpoka Creek sediment where the most dominated species were Nypa palm and white mangrove. The low soil pH might be attributed to fauna and tree root respiration, to oxidation and vegetation, to the higher topographical level of mud lobster mounds with good drainage, and also to less frequent tidal inundations (MacNae, 1969). Mangrove vegetation is significantly correlated with soil moisture content (Ashton & Macintosh, 2002) and soil pH, because of their significant role in mobilizing both beneficial and toxic elements to plants (Weis & Weis, 2004).

Conclusion

In conclusion, the affect of heavy metals and nutrients on the leaf growth of *N. fruticans* depends on both the water characteristics and the life stage of the tree. Heavy metals and anions in water have the strongest effect on young trees, while major metals as well as salinity in water have significant effect on both young and older trees. Water quality and soil texture appear to be highly significant factors for the growth of *N. fruticans*, with growth determined by: Ca, Fe, Al, As, chloride, sulphate, and nitrate; salinity in water; and silt and clay fractions in soil. Recorded values in the study indicate the general water condition. The impact of time in relation to tidal inundation and meteorology has an effect on the environmental variations over the long-term study period. With the presence of enough nutrients in the area, the *Nypa* community has a good potential for continuous regeneration and growth. Consequently, maintaining the sustainable environmental conditions is suggested.

Acknowledgments

The authors wish to express their gratitude for the financial support provided by RP001M-13SUS. We are grateful to the Institute of Biological Science, Institute of Ocean and Earth Sciences and Sime Darby Plantation Berhad Carey Island during the conduct of this research.

References

Ahmad, A.K., I. Mushrifah and M.S. Othman. 2009. Water quality and heavy metal concentration sediment of Sungai Kelantan, Kelantan, Malaysia: A baseline Study. *Sains Malaysiana*, 38(4): 435-442.

Alongi, D.M. 2009. *The energetics of mangrove forests* (pp. 1-216). Dordrecht: Springer.

Alongi, D.M. 2010. Dissolved iron supply limits early growth of estuarine mangroves. *Ecology*, 91: 3229-3241.

Alongi, D.M. 2011. Early growth responses of mangroves to different rates of nitrogen and phosphorus supply. *J. Exp. Marine Biol. & Ecol.*, 397(2): 85-93.

Ashman, M.R. and G. Puri. 2002. *Essential Soil Science: A clear and concise introduction to soil science*. Oxford: Blackwell Science.

Ashton, E.C. and D.J. Macintosh. 2002. Preliminary Assessment of plant diversity and community ecology of the sematan Mangrove forest. Sarawak, Malaysia. *Forest Ecol. & Manag.*, 166(1-3): 111-129.

Bang, J. and D. Hesterberg. 2004. Dissolution of trace element contaminants from two coastal plain soils as affected by pH. *J. Environ. Quality*, 33(3): 891-901.

Biber, P.D. 2006. Measuring the effects of salinity stress in the red mangrove, *Rhizophora mangle* L. *Afr. J. Agri. Res.*, 1(1): 1-4.

Cao, X., Y. Chen, X. Wang and X. Deng. 2001. Effects of redox potential and pH value on the release of rare earth elements from soil. *Chemosphere* , 44(4): 655-61.

Carbonell, A.A., M.A. Aarabi, R.D. DeLaune, R.P. Gambrell and W.H. Jr. Patrick. 1998. Arsenic in wetland vegetation: availability, phytotoxicity, uptake and effects on plant growth and nutrition. *Sci. of Total Environ.*, 217(3): 189-199.

Chau Sum, P., E.H. Khoo and A. Azlan. 2013. Comparison of nutrient composition of ripe and unripe fruits of *Nypa fruticans*. *Fruits*, 68(6): 491-498.

Clarke, P.J. and R.A. Kerrigan. 2000. Do forest gaps influence the population structure and species composition of mangrove stands in Northern Australia? *Biotropica*, 32(4a): 642-652.

Davies, O.A. and J.F.N. Abowei. 2009. Sediment quality of lower reaches of Okpoka creek, Niger Delta, Nigeria. *Europ. J. Sci. Res.*, 26(3): 437-442.

Fong, F.W. 1982. *Nypa* swamps in Peninsular Malaysia. Proceedings of the First International Wetlands Conference. *Wetland: Ecol. Manage*., pp. 31-38.

Gilman, E.L., J. Ellison, N.C. Duke and C. Field. 2008. Threats to mangroves from climate change and adaptation options: a review. *Aquatic Bot.*, 89(2): 237-250.

Hardikar, S.A., N.S. Panchal and A.N. Pandey. 2011. Growth, water status and nutrient accumulation of seedlings of *Salvadora oleoides* (Decne.) in response to soil salinity. *Trop. Ecol.*, 52(3):253-264.

Hashim, N.R. and F.M. Hughes. 2010. The responses of secondary forest tree seedlings to soil enrichment in Peninsular Malaysia: an experimental approach. *Trop. Ecol.*, 51(2):173-182.

Hillel, D. 2012. *App. of Soil Physics*. Elsevier.

Howarth, R.W. and R. Marino. 2006. Nitrogen as the limiting nutrient for eutrophication in coastal marine ecosystems: evolving views over three decades. *Limnology and Oceanography,* 51(1): 364-376.

Irawan, A.F., Y. Yamamoto, T. Yoshida and A. Miyazaki. 2011. Comparison of early growth of sago palm (*Metroxylon sagu* Rottb.) seedlings in a culture solution with individual exclusion of macro- and micronutrients. *Trop. Agri. & Develop.,* 55(1):1-10.

Kamaruzzaman, B.Y., M.C. Ong, M.N. Azhar, S. Shahbudin and K.C.A. Jalal. 2008. Geochemistry of sediment in the major estuarine mangrove forest of Terengganu Region, Malaysia. *Amer. J. of App. Sci.,* 5(12): 1707.

Kathiresan, K. and B.L. Bingham. 2001. Biology of mangroves and mangrove ecosystems. *Adv. in Marine Biol.,* 40: 81-251.

Kathiresan, K., P. Moorthy and S. Ravikumar. 1996. A note on the influence of salinity and pH on rooting of *Rhizophora mucronata* Lamk. Seedlings. *The Ind. Forest.,* 122(8): 763-764.

Lovelock, C.E., I.C. Feller, J. Ellis, A.M. Schwarz, N. Hancock, P. Nichols and B. Sorrell. 2007. Mangrove growth in New Zealand estuaries: the role of nutrient enrichment at sites with contrasting rates of sedimentation. *Oecologia,* 153: 633-641.

MacNae, W. 1969. A general account of the fauna and flora of mangrove swamps and forests in the Indo-West-Pacific region. *Adv. in Marine Biol.,* 6: 73-270.

Manikandan, T., T. Neelakandan and G.U. Rani. 2009. Effects of salinity on the growth, photosynthesis and mineral constituents of the mangrove *Rhizophora apiculata* L. seedlings. *Recent Res. in Sci. & Technol*., 1(3): 134-141.

Marcovecchio, J.E., S.E. Botté and R.H. Freije. 2007. Heavy metals, major metals, trace elements. *Handbook of water analysis*: 275-311.

Marin, A.R., P.H. Masscheleyn and W.H. Patrick Jr. 1992. The influence of chemical form and concentration of arsenic on rice growth and tissue arsenic concentration. *Plant and Soil,* 139(2): 175-183.

Mckee, K.L. 1993. Soil physiochemical patterns and mangrove species distribution-reciprocal effects? *Journal of Ecology,* 81: 474-487.

Motamedi, S., R. Hashim, R. Zakaria, K.I. Song and B. Sofawi. 2014. Long-Term Assessment of an Innovative Mangrove Rehabilitation Project: Case Study on Carey Island, Malaysia. *The Scientific World Journal,* 12.

Munns, R. 1993. Physiological processes limiting plant growth in saline soils: some dogmas and hypotheses. *Plant Cell & Environ.,* 16: 15-24

Naidoo, G. 2009. Differential effects of nitrogen and phosphorus enrichment on growth of dwarf *Avicennia marina* mangroves. *Aquatic Bot.,* 90: 184-190.

Radojevic, M. and N.V. Baskkin. 2006. Practical Environmental analysis, 2nd Cambridge: Royal society of chemistry, pp. 135-358.

Rozainah, M.Z. and N. Aslezaeim. 2010. A demographic study of a mangrove palm, *Nypa fruticans. Sci. Res. & Essays,* 5(24): 3896-3902.

Sampaio, M.B., I.B. Schmidt and I.B. Figueiredo. 2008. Harvesting Effects and Population Ecology of the Buriti Palm (*Mauritia flexuosa* L. f., Arecaceae) in the Jalapão Region, Central Brazil. *Econ. Bot.,* 62(2): 171-181.

Slattery, W.J., M.K. Conyers and R.L. Aitken. 1999. Soil pH, aluminium, manganese and lime requirement. *Soil Analysis: An Interpretation Manual*, 103-128.

Svenning, J.C. 2001. Environmental heterogeneity, recruitment limitation and the mesoscale distribution of palms in a tropical montane rain forest (Maquipucuna, Ecuador). *J. Trop. Ecol.,* 17: 97-113.

Teo, S., A.F. Ang, S.L. Lok, B.R. Kurukulasuriya and H.T.W. Tan. 2010. The Status and distribution of the Nipah palm, *Nypa fruticans* Wurmb (Arecaceae), in Singapore. *Nature in Singapore,* 3: 45-52.

Tripler, E., A. Ben-Gal and U. Shani. 2007. Consequence of salinity and excess boron on growth, evapotranspiration and ion uptake in date palm (*Phoenix dacty*lifera L., cv. Medjool). *Plant and Soil*, 297(1-2):147-155.

Wakushima, S., S. Kuraishi and N. Sakurai. 1994. Soil salinity and pH in Japanese mangrove forests and growth of cultivated mangrove plants in different soil conditions. *J. Plant Res.,* 107(1): 39-46.

Weis, J.S. and P. Weis. 2004. Metal uptake, transport and release by wetland plants: implications for phytoremediation and restoration. *Environ. Int.,* 30(5): 685-700.

Widyatmoko, D., M.A. Burgman, E. Guhardja, J.P. Mogea, E.B. Walujo and D. Setiadi. 2005. Population status, demography and habitat preferences of the threatened lipstick palm *Cyrtostachys renda* Blume in Kerumutan Reserve, Sumatra. *Acta Oecologica,* 28(2): 107-118.

Yates, E.J., N. Ashwath and D.J. Midmore. 2002. Responses to nitrogen, phosphorus, potassium and sodium chloride by three mangrove species in pot culture. *Trees,* 16: 120-125.

Youssef, T. and P. Saenger. 1998. Photosynthetic gas exchange and accumulation of phytotoxins in mangrove seedlings in response to soil physico-chemical characteristics associated with waterlogging. *Tree Physiol.,* 18(5): 317-324.

(Received for publication 22 January 2016)