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Soil fertility improvement from commercial monospecific mangrove forests *(Rhizophora apiculata)* at Yeesarn Village, Samut Songkram Province, Thailand

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Abstract: In Thailand, local inhabitants use charcoal production from commercial *Rhizophora apiculata* plantation forests for renewable energy and income sources. In this study we investigated soil quality development in commercial, monospecific mangrove forests at different ages (0–5, 5–10 and 10–15 years). Soil samples were randomly taken from each mangrove forest site in 2015 at two different depths (0–30 and 30–60 cm). The results revealed that generally in top soil (0–30 cm), the soil texture was clay with pH values ranging between 5.4 and 6.5. ECe and the organic matter contents ranged between 59.9–67.93 dS m^{-1} and 0.43–1.19%, respectively. In deeper soil, the pH values ranged between 4.6 and 5.2 and the ECe values were around 56.58 to 61.93 dS m^{-1}. The organic matter contents varied from 0.37 to 1.68%. Overall, soil properties were comparable and similar to a tidal mangrove environment (acidic and saline conditions). When comparing soil properties among different ages of forest, in older forest sites (10–15 years), organic matter and the total N and P contents in the top soil tended to exhibit higher values than in younger forest stands (0–5 years). In contrast, gradual reductions in the organic matter and the total N and P contents were detected in deeper soil layers. In intermediate mangrove forest (5–10 years), soil properties were similar to those found in a semi-natural mangrove site since both areas were of similar age. Therefore, this study suggests that commercial, monospecific mangrove forests have important ecological roles in soil fertility and improvement through time.

Key words: Estuary, mangrove plantation, nitrogen, organic matter, phosphorus, soil properties, tropical zone.

Introduction

Thailand is a tropical country with abundant mangrove forest. Recent estimation of mangrove forests by LANDSAT 8 satellite in 2014 showed that mangrove forests covered an area of approximately 256,000 hectares, which was a slight increase from the past years. Expansion of mangrove forest is probably due to the government's policy of promoting sustainable mangrove forest management and conservation as well as mangrove forest plantation with high economic value. In particular, commercial, monospecific mangrove forests not only help generate income for the local community but may also be beneficial to the environment and ecosystems.

In Thailand, a well-known site for mangrove-based charcoal production from plantation is in the

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Yee San sub-district, Amphawa district of Samut Songkram province, lower central Thailand. The local community there has operated and used traditional charcoal-making processes and techniques since 1937 (Kridiborworn *et al.* 2012; Sunthoncheewawut 2003). Charcoal products are still used nowadays for cooking by many Thais and exported to many countries such as Japan, Korea and Taiwan (Winterwerp *et al.* 2005). The most common variety of mangrove plantation that local people use for charcoal production is *Rhizophora apiculata*. In recent years, the mangrove areas in Samut Songkram province have slightly expanded partly because of private mangrove plantation as a source of income after the failure of shrimp farming due to disease outbreaks (Kridiborworn *et al.* 2012). It is estimated that commercial mangrove plantation covers around 1,315 hectares within this province alone (Hassan 2006).

Mangrove preservation and plantation increases the value of ecosystem services particularly in relation to the soil environment since both natural and commercial mangrove forests have specific ecological roles and functions in muddy coastal zones. For example, the root network system of fringe mangrove forests helps to protect the coastline from erosion (Ewel *et al.* 2008). Intact mangrove stands also trap sediment and stabilise sediment deposits (Winterwerp *et al.* 2005). Other common features of mangroves include high primary productivity, efficient biological nutrient recycling and high rates of organic matter accumulation which provide benefits not only within the mangrove ecosystem but also to adjacent areas and marine food webs (Jennerjahn & Ittekkot 2002). In addition, carbon and nutrient concentrations in the soils of mangrove forests increase during mangrove succession (Lovelock *et al.* 2010).

Most research has so far focused on the roles of natural mangrove forests on soil characteristics. In this study, we aimed particularly to document and determine the roles of private, monospecific mangrove plantations (*Rhizophora apiculata*) in soil fertility and soil quality improvement through time. We studied the soil properties of tropical commercial mangrove sites at different ages as well as investigating the quality of soil in semi natural mangrove forest. The ultimate goal of this research was to gain insight into the goods and services that commercial mangrove forests may provide to the ecosystem in terms of nutrient enrichment and the development of soil quality with forest planting age.

Material and Methods

Study area

Commercial mangrove forests are situated in Yeesarn sub-district (13°18'14.3"N 99°54'07.2"E), Amphawa district, Samut Songkram province, Thailand where three different-aged, planted mangrove sites (0–5, 5–10 and 10–15 years old) were selected for sampling. The soil properties were also determined from a semi natural mangrove forest nearby. Sampling took place in April 2014.

Soil sampling and soil property determination

At each mangrove plantation site, soil samples (each weighing approximately 1 kg) were taken from six random stations across the site at two different depths (0–30 and 30–60 cm below soil surface) using a soil auger. There were 48 soil samples in total. Soil samples were brought back for physical and chemical analysis at the Department of Environmental Technology and Management, Faculty of Environment, and Department of Soil Science, Faculty of Agriculture at Kamphaeng Saen, Kamphaeng Saen Campus, Kasetsart University, Thailand.

For soil preparation, plant particles such as leaf litter, sticks and roots were removed from each soil sample and then soil samples were air dried and ground prior to analysis. Subsequently, soil samples were sieved through 2 and 0.5 cm diameter mesh sieves and each sample was mixed well. Soil properties were measured for soil texture using the hydrometer method and the organic matter content was determined using method of Walkley and Black (1934). We measured the soil pH in a 1:1 ratio of soil and water using a pH meter. An electrical conductivity meter was used to study electrical conductivity (EC_e). Total nitrogen (N) was studied in a digestion mixture (H_2SO_4–Na_2SO_4–Se mixture) and then was distilled in an N–determination apparatus. For phosphorus, we used the Bray II (0.1 N HCl+0.03N NH_4F) method to quantify the available P and measured concentrations using a spectrophotometer at a wavelength setting of 882 nm. Exchangeable K, Ca, Mg, Na were extracted from soil samples using 1N NH_4 CH_3COO and then analysed with atomic absorption spectrophotometry. Total S was determined using the Turbidimetric method and then the absorbance was measured using spectrophotometry (420 nm wavelength). All samples were analysed in triplicate.

Data were recorded throughout as mean± standard deviation. Student's *t* test was applied to evaluate the differences of soil properties among

Table 1. Selected soil properties of top soil (0–30 cm) of mangrove sites (n=6).

Property	Age of mangrove site			
	0–5 years	5–10 years	10–15 years	Semi–natural
pH (1:1)	$6.04 \pm 0.42^{a,b}$	6.20 ± 0.41^{a}	5.40 ± 0.45^{b}	6.54 ± 0.36^{a}
EC_e (dS m^{-1})	67.45 ± 2.88^{a}	59.80 ± 12.40^{a}	65.80 ± 5.81^{a}	67.93 ± 5.09^{a}
Exchangeable K (mg kg^{-1})	12.06 ± 8.19^{a}	11.94 ± 9.22^{a}	21.72 ± 13.71^{a}	12.92 ± 7.71^{a}
Exchangeable Ca (mg kg^{-1})	18.53 ± 22.19^{a}	12.51 ± 8.25^{a}	39.42 ± 47.05^{a}	15.74 ± 6.95^{a}
Exchangeable Mg (mg kg^{-1})	2.87 ± 1.72^{a}	4.63 ± 5.75^{a}	7.89 ± 6.07^{a}	5.22 ± 5.60^{a}
Extractable S (mg kg^{-1})	2175 ± 456^{a}	2154 ± 6381^{a}	3093 ± 629^{b}	2184 ± 483^{a}
Exchangeable Na (mg kg^{-1})	1791 ± 180^{a}	1752 ± 285^{a}	1962 ± 233^{a}	1857 ± 67^{a}
Sand (%)	12.7 ± 1.2^{a}	12.7 ± 1.4^{a}	$11.1 \pm 2.2^{a,b}$	9.8 ± 1.7^{b}
Silt (%)	24.4 ± 1.2^{a}	$25.9 \pm 0.7^{a,b}$	$30.6 \pm 3.1^{b,c}$	30.8 ± 1.5^{c}
Clay (%)	62.9 ± 1.8^{a}	$61.4 \pm 1.5^{a,b}$	58.3 ± 4.1^{b}	$59.4 \pm 2.9^{a,b}$

The same superscript letters indicate non-significance among sites and the different superscript letters show significant differences at the 95% confidence level.

sampled sites and soil layers (surface and deeper soil layers). Data analyses were performed using Microsoft Excel 2013.

Results

Top soil properties (0–30 cm)

The soil texture of all studied sites had clay (58-63%) as a major component. The pH values ranged from 5.4–6.5 indicating slightly acidic conditions. The EC_e values were around 59.80–67.93 dS m^{-1} implying that the soil was saline. The organic matter contents varied from 0.43–1.19%. N and P contents increased with the age of the mangrove trees. Values of pH and exchangeable S were significantly highest at the forest site aged 10–15 years compared with other sites (Table 1). In addition, extractable S and exchangeable Na were major components in the top soil layer.

Deeper soil properties (30-60 cm)

Soil texture in deeper layers was mainly clay (57–60%) which was similar to the surface soil texture. The pH values indicated acidic soil (4.6–5.1) (Table 2). EC_e ranged from 56.58–61.93 dS m^{-1}. N and P contents were comparable among mangrove plantation sites. The organic matter contents of deeper soil (0.37–1.68%) were lower than in the surface soil layers. Similar to the top soil properties, the results of exchangeable elements showed that S and Na contents were rich in deep soils compared with other elements.

Comparison of soil properties between top and deeper soil layers

We further compared soil quality between the top and deeper soil layers. It was revealed that the available P, nitrogen and organic matter contents of the top soil showed an increased tendency through time. In contrast, the values of the available P, nitrogen and organic matter in deeper soil layers decreased as the age of the mangrove trees increased (Fig. 1). For the forest site aged 10–15 years, the total N values of the top soil were significantly greater than in the deeper layer. In addition, the available P and organic matter contents of the surface soil were highest for the forest site aged 10–15 years.

Discussion

Soil properties in planted mangrove forests

The physico-chemical properties of the soil did not exhibit much variation between mangrove plots. The results of the quality analysis of the top soil in mangrove forests showed that pH values were slightly acidic at all sites as a result of oxidation of S in the soil (Hart 1959). This was consistent with the elemental content of Sulfur that was relatively abundant in the forest soil as Sulfur can be found naturally in various forms such as hydrogen sulfide (H_2S), sulfide (S^{2-}) and sulfate (SO_4^{2-}). The EC_e values of the top soil were greater than 16 dS m^{-1} indicating high salinity which is normal for a coastal environment. Overall, the results of this study were comparable with the soil properties in

Table 2. Selected soil properties from deeper soil (30–60 cm) among mangrove sites (n=6).

Property	Age of mangrove site			
	0–5 years	5–10 years	10–15 years	Semi–natural
pH (1:1)	4.57 ± 0.87[a]	5.10 ± 0.83[a]	5.09 ± 0.52[a]	5.15 ± 0.70[a]
ECE (dS/m)	58.28 ± 9.24[a]	60.67 ± 12.15[a]	56.58 ± 7.38[a]	61.93 ± 7.18[a]
Exchangeable K (mg kg^{-1})	22.51 ± 12.01[a]	14.79 ± 10.09[a]	12.37 ± 8.21[a]	19.93 ± 15.36[a]
Exchangeable Ca (mg kg^{-1})	39.37 ± 47.15[a]	22.34 ± 21.50[a]	17.28 ± 23.04[a]	35.54 ± 49.65[a]
Exchangeable Mg (mg kg^{-1})	7.59 ± 5.68[a]	4.63 ± 5.26[a]	2.87 ± 1.64[a]	6.96 ± 6.15[a]
Extractable S (mg kg^{-1})	4523 ± 1169[a]	3638 ± 1080[a]	4095 ± 363[a]	3826 ± 669[a]
Exchangeable Na (mg kg^{-1})	1628 ± 212[a]	1740 ± 461[a]	1694 ± 75[a]	1811 ± 200[a]
Sand (%)	13.8 ± 1.3[a]	13.0 ± 2.0[a]	9.7 ± 1.5[a]	8.8 ± 1.9[a]
Silt (%)	27.3 ± 2.3[a]	27.1 ± 1.6[a,b]	33.17 ± 1.8[b,c]	33.6 ± 2.3[c]
Clay (%)	58.9 ± 3.1[a]	60.0 ± 2.5[a,b]	57.2 ± 2.7[b,c]	57.6 ± 3.3[c]

The same superscript letters indicate non-significance among sites and the different superscript letters show significant differences at the 95% confidence level.

other mangrove forest areas in the tropical zone (Dinesh *et al.* 2004; Ren *et al.* 2008).

Soil properties among different ages of planted mangrove forest stands

It was apparent that the monoculture mangrove plantation for charcoal production gradually improved the quality of soil properties through time as reported by Ren *et al.* (2008). The organic matter contents in top soil markedly increased with forest age. It is likely that older-aged forests might have higher accumulation rates compared with that of younger forests where there was a lower input of leaf litter or other materials from the forest stand. In addition, due to greater age, the older mangrove forests might have a higher organic material deposition brought about by inter-tidal waves than occurred in younger mangrove forests. This is partly because the extensive root system of old mangroves can enhance the trapping process (Scoffin 1970). Twilley *et al.* (1986) stated that seasonal changes in surface leaf litter corresponded with higher leaf decomposition rates when the tidal inundation frequency increased. Hence, increased organic matter contents improved the physical properties of the forest soil.

In general, top soils in mangrove forests are relatively more fertile than the soil in deeper layers. The organic matter contents in deeper soil layers decreased gradually with mangrove forest age. This is not surprising, since the organic matter in the deeper soil layers was probably removed through time via decomposition processes or through accumulation in mangrove plants (Alongi 1996). The study of Chen and Twilley (1999) supported our results that mineralization rates decreased in deeper soil layers, which corresponded with a reduction in organic matter. Higher organic matter contents in the deeper soil layer in younger forest plantation stands could be explained by the accumulation of old organic material from previous land use.

Concentrations of total N and P showed similar patterns to the organic matter contents as reported by Tam and Wong (1998) and increased with the age of the mangrove forests (Lovelock *et al.* 2010). This was also in consistent with Chen & Twilley (1999) who showed that the total N and P concentrations are closely related to patterns of forest development. Sources of N in mangrove forests may come from similar origins of organic matter such as litter production as mentioned before and it was found that N increased in the leaf litter during decomposition on the forest floor (Twilley *et al.* 1986). P was still limited in the mangrove ecosystem and did not build up much through time. A lack of anthropogenic sources of P may explain the limitation of P in mangrove forests. Furthermore, the amount of other important nutrients such as exchangeable K, Ca and Mg in the mangrove forests clearly increased especially in the mangrove plantation aged 10–15 years. Allochthonous input of mineral sediments may play a crucial role as an important source of these nutrients in mangrove forests (Chen & Twilley 1999). The overall values of soil properties in the plantations aged 5–10 years were similar to those found at a semi-natural

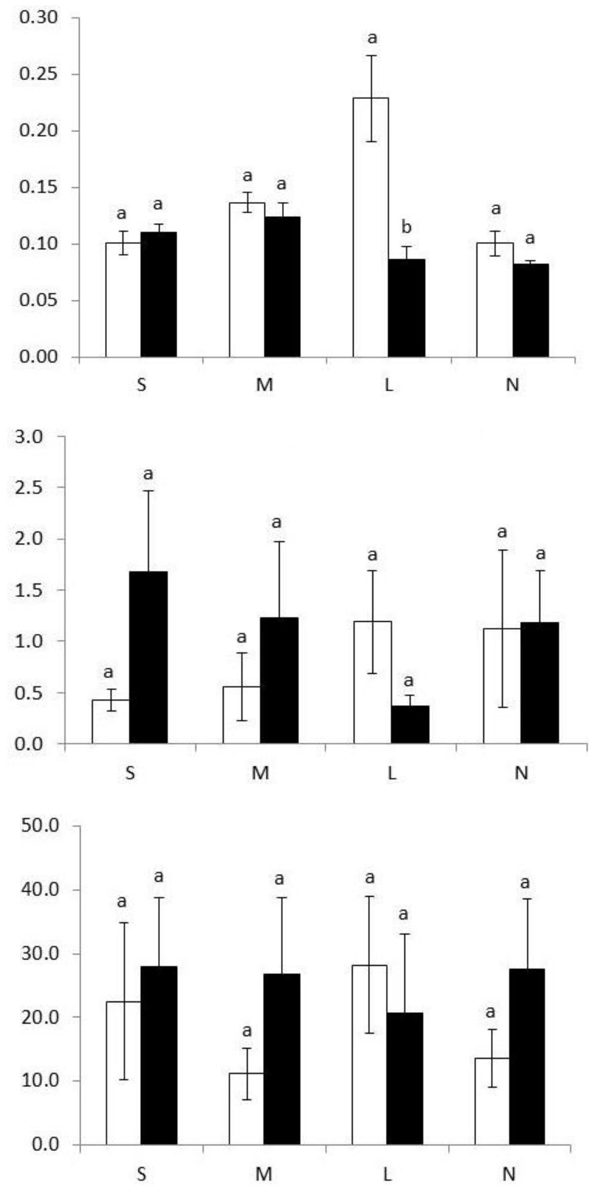

Fig. 1. Comparison of soil organic matter, N and P between top (open bar) and deeper (filled bar) soils among different ages of mangrove forest with standard error bars (S = 0–5 years, M = 5–10 years, L = 10–15 years and N = semi natural). The different letters on the bar show statistically significant differences between soil layers ($P < 0.05$).

mangrove site which could be explained by both studied plots being of a similar age.

Mechanisms that describe the variation of key nutrients in different plantations may be the result of bacterial and fungal communities and activities that differ from varying mangrove aged plantations. Especially in the surface sediments, bacteria in mangrove (0–2 cm depth) were abundant and productive (Alongi 1988), and therefore playing an important role in mineralizing and recycling material deposits in tropical aquatic systems. Furthermore, microbial community increased significantly with each stage of succession and was also associated with plant height and contents of organic matter and total nitrogen (Chen *et al.* 2016). Possible mechanisms to conserve nutrients in tropical mangrove ecosystems may include absorption and adsorption processes as well as nitrogen fixation by microbial communities (Rice 1982; Twilley & Day 1999). In addition, high litter turnover especially in mature mangrove stands aged 10–15 years may be one of the key factors that regulate the availability of nutrients. Invertebrate communities may also influence nutrient cycling and variation through benthic food webs (Alongi 1994) since there may be mechanisms of nutrient generation associated with animal assemblages. Our previous study revealed that sedimentary macro-invertebrate communities tended to increase with the age of the mangrove plantation site (Choosak *et al.* 2016). Lee (2008) suggested that macro benthic assemblages serve as important links between mangrove organic matter and estuarine production as well as exportation of organic matter through feeding excursion, organic detritus and faeces.

Another important parameter in mangrove ecosystems is carbon content that plays a major role in carbon sequestration (Alongi 2014). Even though this study did not focus on different forms of organic carbon, it can be stated that carbon content may be associated with leaf letter production and mangrove roots. Bouillon *et al.* (2003) reported that organic carbon stocks are almost of mangrove origin together with the deposition of suspended particles from intertidal adjacent environment. Accordingly, organic carbon content may build up through time as a result of accumulation of organic matter in the mangrove sediment (Fujimoto *et al.* 1999).

Conclusion

Our study suggests that mangrove monoculture plantations of *Rhizophora apiculata* for biofuels are important ecologically in terms of soil fertility and enrichment as indicated by the fact that the continuous development of soil enrichment closely corresponded with forest age. The amount of organic materials in the top soil may also serve as a food source for wildlife through benthic food webs and thus supporting biodiversity, especially communities of benthic macro-invertebrate.

Therefore, direct benefits obtained from planted mangrove forests not only go to the community as additional income from charcoal production but also for the fertility of terrestrial coastal ecosystems.

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References

Alongi, D. M. 1988. Bacterial productivity and microbial biomass in tropical mangrove sediments. *Microbial Ecology* **15:** 59–79.

Alongi, D. M. 1994. The role of bacteria in nutrient recycling in tropical mangrove and other coastal benthic ecosystems. *Hydrobiologia* **285:** 19–32.

Alongi, D. M. 1996. The dynamics of benthic nutrient pools and fluxes in tropical mangrove forests. *Journal of Marine Research* **54:** 123–148.

Alongi, D. M. 2014. Carbon cycling and storage in mangrove forests. *Annual Review of Marine Science* **6:** 195–219.

Bouillon, S., F. Dahdouh-Guebas, A. V. V. S. Rao, N. Koedam & F. Dehairs. 2003. Sources of organic carbon in mangrove sediments: variability and possible ecological implications. *Hydrobiologia* **495:** 33–39.

Chen, Q., Q. Zhao, J. Li, S. Jian & H. Ren. 2016. Mangrove succession enriches the sediment microbial community in South China. *Scientific Reports* **6:** 27468. http://doi.org/10.1038/srep27468.

Chen, R. & R. R. Twilley. 1999. Patterns of mangrove forest structure and nutrient dynamics along the Shark river estuary, Florida. *Estuary* **22:** 955–970.

Choosak, S., C. Thongjoo & R. Chaichana. 2016. Ecological roles of commercial mangrove plantation forests for benthic macroinvertebrate communities in Thailand. *Applied Ecology and Environmental Research* **14:** 421–432.

Dinesh, R., S. G. Chaudhuri, A. N. Ganeshamurthy & S. C. Pramanik. 2004. Biochemical properties of soils of undisturbed and disturbed mangrove forests of South Andaman (India). *Wetlands Ecology and Management* **12:** 309–320.

Ewel, K., R. Twilley & J. Ong. 2008. Different kinds of mangrove forests provide different goods and services. *Global Ecology and Biogeography Letters* **7:** 83–94.

Fujimoto, K., A. Imaya, R. Tabuchi, S. Kuramoto, H. Utsugi & T. Murofushi. 1999. Belowground carbon storage of Micronesian mangrove forests. *Ecological Research* **14:** 409–413.

Hart, M. G. R. 1959. Sulphur oxidation in tidal mangrove soils of Sierra Leone. *Plant and Soil* **11:** 215–236.

Hassan, K. 2006. *Management of Private Mangrove (*Rhizophora apiculata*) Plantation for Charcoal Production at Yeesarn Sub-District, Samut Songkram Province*. M.Sc. Thesis, Kasetsart University, Bangkok, Thailand.

Jennerjahn, T. C. & V. Ittekkot. 2002. Relevance of mangroves for the production and deposition of organic matter along tropical continental margins. *Naturwissenschaften* **89:** 23–30**.**

Kridiborworn, P., A. Chidthaisong, M. Yuttitham & S. Tripetchkul. 2012. Carbon sequestration by mangrove forest planted specifically for charcoal production in Yeesarn, Samut Songkram. *Journal of Sustainable Energy and Environment* **3**: 87-92.

Lee, S. Y. 2008. Mangrove macrobenthos: assemblages, services, and linkages. *Journal of Sea Research* **59:** 16–29.

Lovelock, C. E., B. K. Sorrell, N. Hancock, Q. Hua & A. Swales. 2010. Mangrove forest and soil development on a rapidly accreting shore in New Zealand. *Ecosystems* **13:** 437–451.

Rice, D. L. 1982. The detritus nitrogen problem: new observations and perspectives from organic geochemistry. *Marine Ecology Progress Series* **9:** 153–162.

Ren, H., S. Jian, H. Lu, Q. Zhang, W. Shen, W. Han, Z. Yin & Q. Guo. 2008. Restoration of mangrove plantations and colonisation by native species in Leizhou bay, South China. *Ecological Research* **23:** 401–407.

Scoffin, T. P. 1970. The trapping and binding of subtidal carbonate sediments by marine vegetation in Bimini Lagoon, Bahamas. *Journal of Sedimentary Petrology* **40:** 249–273.

Sunthoncheewawut, J. 2003. *Economic Sustainability Analysis of Private Mangrove Plantation (*Rhizophora apiculata*) and Charcoal Production at Tambol Yeesan, Amphoe Amphawa, Changwat Samut Songkhram*. M.Sc. Thesis. Kasetsart University, Bangkok, Thailand (in Thai).

Tam, N. F. Y. & Y. S. Wong. 1998. Variations of soil nutrient and organic matter content in a subtropical mangrove ecosystem. *Water, Air and Soil Pollution* **103:** 245–261.

Twilley, R. R. & J. W. Day, Jr. 1999. The productivity and nutrient cycling of mangrove ecosystems. pp. 127–152. *In*: A. Yáñez-Arancibia & A. L. Lara-Domínguez (eds.) *Ecosistemas de Manglar en América Tropical*. Instituto de Ecología A.C. México, UICN/ORMA, Costa Rica, NOAA/NMFS, Silver Spring, MD, USA.

Twilley, R. W., A. E. Lugo & C. Patterson-Zucca. 1986. Litter production and turnover in basin mangrove forests in Southwest Florida. *Ecology* **67:** 670–683.

Walkley, A. & I. A. Black. 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science* **37:** 29–38.

Winterwerp, J. C., W. G. Borst & M. B. de Vries. 2005. Pilot study on the erosion and rehabilitation of a mangrove mud coast. *Journal of Coastal Research* **21:** 223–230.

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