SOIL PROPERTIES AND TREE COMPOSITION IN A 27-YEAR OLD *Acacia mangium* Willd. PLANTATION ON ABANDONED MINING AREA AT PHANGNGA FORESTRY RESEARCH STATION**

JETSADA WONGPROM[1*], ROONGREANG POOLSIRI[2], SAPIT DILOKSUMPUN[2]
AND CHATCHAI NGERNSAENGSARUAY[3]

[1]*Faculty of Forestry, Kasetsart University, Bangkok 10900, Thailand*
[2]*Department of Silviclture, Faculty of Forestry, Kasetsart University, Bangkok 10900, Thailand*
[3]*Department of Botany, Faculty of Science, Kasetsart University, Bangkok 10900, Thailand*
*Corresponding author, e-mail: fforjdw@ku.ac.th

Received 19 December 2018 / Accepted 04 April 2019

ABSTRACT

In order to validate the important role of *Acacia mangium* plantation in mining rehabilitation, a study was conducted on the soil properties and tree composition in a 27-year-old *A. mangium* plantation growing on sandy (S27) and clay (C27) soil types, as well as a mixed plantation (MP) growing on clay soil type. The results were compared with those grown on an abandoned mining area (AB), a secondary forest (SF) and a primary forest (PF), at the Phangnga Forestry Research Station, Thailand. Three 40 x 40 m permanent plots were established and soil samples were randomly collected from depths of 0-10, 10-20, 20-30, and 30-50 cm, in each of the S27, C27, MP, AB, SF, and PF. The bulk density values in the S27, C27, and MP were lower than that in AB and was similar to those in SF and PF, particularly, the top soil. Total nitrogen, available phosphorus, organic matter, exchangeable potassium, and magnesium contents in the S27, C27, and MP were higher than that in AB, but were lower than those in SF and PF, indicating that the soil development in the S27, C27, and MP was slower than in the SF and PF. This lower bulk density values and higher soil nutrient contents were positively contributed by the *A. mangium* plantation. The Shannon-Wiener index obtained for S27 (1.43), C27 (2.51), and MP (2.77) were lower than that for the SF (3.86). The similarity indices of the tree species found in S27, C27, MP, and PF were low, ranging from 5.83 - 8.00, indicating that the development of the forest community was slow compared to SF (31.03). Enrichment planting with poorly dispersed shade tolerant trees has increased the diversity and improved the forest structure in the mined out areas and other similarly degraded lands.

Keywords: *Acacia mangium,* mining area, soil properties, tree composition

INTRODUCTION

Ever since mining has been widely operational all over Thailand, the local environment and ecosystem conditions have been severely impacted by the mining activities (Macdonald *et al.* 2015). Vegetations were destroyed and soil properties were changed from the originally rich to currently poor soil. Soil textures have become unsuitable for planting (Oktavia *et al.* 2015). In some areas, the soil has turned extremely acidic and the soil moisture went very low during the dry season (Tripathi *et al.* 2016). As a result, soil improvement and forest restoration in mining areas has taken a long time. Invariably, changes in such important factors as soil properties like soil texture, organic matter, pH, nitrogen, phosphorus and potassium have negatively affected the development of a forest community in

*Corresponding author, e-mail: fforjdw@ku.ac.th
**This paper was presented at the 3rd International Conference on Tropical Biology 2018, 20-21 September 2018, Bogor, West Java, Indonesia

previously mined areas (Zhao *et al.* 2013; Lei *et al.* 2015). Oftentimes, nitrogen limits the growth and reestablishment of forest seedlings. As such, natural regeneration using native trees was applied to accelerate plantation establishment. However, restoration of several mined out areas is costly and is usually a long term process (Oktavia *et al.* 2015).

The popularly known nitrogen fixing tree, *Acacia mangium* is a multipurpose fast-growing tree which plays an important role in restoring the soil quality of degraded lands. This species has been widely introduced in Southeast Asia (Nambiar & Harwood 2014). Its survival, growth rate and the aboveground biomass it produces are relatively high compared to other fast growing and native tree species found in abandoned mining areas (Martpalakorn 1990). *A. mangium* plantation has been established in degraded lands for wood production, forest restoration, as well as soil improvement (Wang *et al.* 2010). Degraded land restoration using plantation is one approach for catalyzing the natural succession process and increasing the tree species diversity (Tripathi *et al.* 2016). Since native tree species have been introduced into plantations, resulting in an increased tree species richness and increased forest structure complexity, the restoration of previously mined areas using nitrogen fixing trees has been focused on soil improvement (Bohre & Chaubey 2014). Generally, after plantation establishment, the soil physical and chemical properties will improve (Zhao *et al.* 2013; Bohre & Chaubey 2014), simultaneously with the ecosystem services such as litter supply, nutrient cycling, and biodiversity (Parrotta 1999; Celentano 2011).

The objectives of this study were, firstly; to evaluate the soil properties, tree composition, and diversity of a 27-year-old *A. mangium* plantation located in Phangnga Forestry Research Station, Thailand and compare these with an abandoned mining area (AB), secondary forest (SF) and primary forest (PF) and secondly, to recommend trees, like *A. mangium,* that are suitable for this site restoration programs and for other mined out areas.

MATERIALS AND METHODS

Study Area

The experiment was conducted on an abandoned tin mine at Phangnga Forestry Research Station, Takuapa District, Phangnga Province, Thailand. The area also includes a 27-year-old *A. mangium* plantation grown on sandy (S27) and, clay (C27) soil types, as well as mixed plantation (MP) of *Eucalyptus camaldulensis*, *A. mangium,* and *Diptercapus alatus* grown on a clay soil type. Phangnga Forestry Research Station is approximately 3 km away from a primary forest (PF) and is surrounded with rubber and oil palm plantations. The area receives a mean annual rainfall of 3,668.80 mm, with rainy season occurring from April to November and dry season from December to March. Its relative humidity is around 83% and its mean annual temperature is at 27.1 °C (Wongprom *et al.* 2013). In addition, secondary forest (SF), primary forest (PF), and abandoned mining area (AB) were established as reference sites. The SF plot is approximately a 30-year-old protected forest, a tropical rainforest that was disturbed in the past by shifting cultivation.

Soil Properties

Soil samples were collected from the S27, C27, MP, AB, SF and PF sites at four soil depth series, 0 - 10, 10 - 20, 20 - 30 and 30 - 50 cm. Three soil pits were randomly established, while soil samples were collected from each plot using a split tube sampler for the soil physical and chemical analyses. For the chemical properties, the samples within each plot were mixed thoroughly to form a soil composite. Soil bulk density was analyzed by the core method, while the soil texture was analyzed by the hydrometer method. Soil pH was examined by a pH meter with 1:1 soil: water ratio. Total nitrogen (N) was measured using the Dumas method (Jackson 1965) by CHNS analyzer. Organic matter content (OM) was analyzed by the Walkley and Black rapid titration method. Available phosphorus (P) was extracted using the Bray II method and was analyzed using a spectrometer. The exchangeable potassium (K), calcium (Ca) and magnesium (Mg) were extracted with ammonium acetate (NH_4OAc) 1 N pH 7.0 and analyzed by an atomic absorption spectrometer (Estefan *et al.* 2013).

Tree Composition

Three permanent plots of 40 x 40 m were established in each of the S27, C27, MP, SF, and PF sites. Each sample plot was divided into sixteen subplots of size 10 x 10 m plot. At the permanent plots, all tree species with diameter at breast height (DBH) ≥ 4.5 cm were identified and recorded. The DBH and total height of a tree was measured using a diameter tape and Haga altimeter, respectively. Plant specimens were collected and identified, and the unidentified species were compared with the herbarium specimens deposited at the Forest Herbarium, Natural Parks, Wildlife and Plant Conservation Department.

Data Analyses

Soil physical and chemical properties, including bulk density, porosity, soil pH, total N, available P, OM, exchangeable K, Ca, and Mg were analyzed using a one-way analysis of variance (ANOVA) and the means were compared using Tukey's test at 5% probability level. The importance value index (IVI), tree density, and basal area were also calculated. The IVI value was obtained as a relative density (RD), relative frequency (RF), and relative dominance (RDo) of a given tree species.The tree species diversity for each site was calculated using the Shannon-Wiener index (Shannon & Weaver 1949) using the formula:

$$H' = -\sum_{n=1}^{n} (pi*\ln pi)$$

where, H' is the Shannon-Wiener index, Pi is the proportion of each species in the sample, ln Pi is the natural logarithm of this proportion.

Species evenness (E) was calculated as follows (Pielou 1966):

$$E = H' / \ln S$$

where, H' is the Shannon-Wiener index and S is total number of species in the sample.

The similarity of plant composition was calculated using the Sørensen similarity index (Sørensen 1948) by the formula:

$$S = 2c / (a + b) \times 100$$

where, S is the Sørensen similarity index, a is the number of species found in site A, b is the number of species in site B, and c is the number of species shared by the two sites. Shannon-Wiener index and the Sørensen similarity index are the most widely used tools to evaluate plant community (Barrantes & Sandoval 2009; Martínez-Ruiz & Fernández-Santos 2005; Zhang *et al.* 2014).

RESULTS AND DISCUSSION

Soil Physical Properties

At the top soil (0 - 10 cm), the soil bulk density and soil particles were significantly different among the sites but not for porosity (Table 1). However, at soil depths of 10 - 20, 20 - 30 and 30 - 50 cm the bulk density, soil particles, and porosity of the subsoil significantly differed among the different sites. The bulk density was the highest (1.31 g/m^3) in AB, while bulk densities of S27, C27 and MP were similar to SF and PF. The bulk density can be relatively lower in mining areas having a forest plantation (Bohre & Chaubey 2014).

Soil development at AB was slow compared to those at S27, C27 and MP. Plantations have been known to markedly improve the physical properties of soil, vegetation cover and natural regeneration in post mining sites (Zhao *et al.* 2013; Lei *et al.* 2015). The variations in soil bulk density, specific gravity, porosity, water holding capacity and soil aggregation in a reclaimed mine are mainly caused by variations in organic matter. As such, soil physical properties are largely related to the organic matter content (Charman & Roper 2000; Zhao *et al.* 2013).

Table 1 Soil physical properties on abandoned mining in the Phangnga Forestry Research Station and the reference sites

Depth (cm)	Site	Soil particle (%)			Soil texture	Bulk density (g/m^3)	Porosity (%)
		Sand	Silt	Clay			
0-10	AB	91.23^a	3.99^c	4.77^c	Sandy	1.31^a	56.99
	S27	89.33^a	2.24^c	8.42^{bc}	Loamy sand	1.04^{ab}	59.67
	C27	17.70^c	33.31^a	48.99^a	Clay	0.94^b	59.43
	MP	20.15^c	33.47^a	46.38^a	Clay	0.90^b	60.40
	SF	31.45^c	25.35^{ab}	43.20^a	Clay	0.96^{ab}	60.38
	PF	67.73^b	8.71^{bc}	23.56^b	Sandy clay loam	0.92^b	65.93
F-value		110.16*	16.72*	29.38*		4.08*	1.24^{ns}
10-20	AB	91.14^a	3.33^c	5.56^b	Sandy	1.78^a	32.86^b
	S27	87.97^{ab}	2.77^c	7.76^b	Loamy sand	1.48^b	44.92^a
	C27	22.56^c	26.93^b	50.51^a	Clay	1.21^c	53.46^a
	MP	9.03^c	38.95^a	52.01^a	Clay	1.11^c	49.08^a
	SF	18.09^c	21.26^b	60.65^a	Clay	1.09^c	55.69^a
	PF	67.11^b	7.24^c	25.65^b	Sandy clay loam	1.22^c	54.55^a
F-value		64.30*	64.89*	30.72*		45.57*	13.91*
20-30	AB	90.06^a	3.37^b	6.56^c	Sandy	1.71^a	30.28^c
	S27	84.33^a	6.93^b	10.07^{bc}	Loamy sand	1.69^a	35.62^{bc}
	C27	28.37^{bc}	27.98^a	43.65^{ab}	Clay	1.30^b	46.12^{ab}
	MP	17.70^c	26.05^a	56.25^a	Clay	1.17^b	49.87^a
	SF	26.37^{bc}	19.19^{ab}	54.44^a	Clay	1.21^b	46.97^{ab}
	PF	63.85^{ab}	5.38^b	30.77^{ab}	Sandy clay loam	1.33^b	43.78^{ab}
F-value		13.13*	8.37*	10.29*		22.56*	7.97*
30-50	AB	90.57^a	3.21^c	6.22^d	Sandy	1.58^a	38.14^b
	S27	81.71^{ab}	4.86^c	13.43^{cd}	Loamy sand	1.55^{ab}	41.45^{ab}
	C27	31.23^{cd}	26.12^{ab}	42.65^{ab}	Clay	1.12^c	53.63^a
	MP	8.44^d	33.52^a	58.04^{ab}	Clay	1.05^c	52.14^a
	SF	18.42^d	18.93^b	62.65^a	Clay	1.12^c	52.78^a
	PF	55.89^{bc}	9.12^c	34.98^{bc}	Sandy clay loam	1.30^{bc}	42.92^{ab}
F-value		31.88*	53.83*	19.99*		17.34*	6.51*

Note: * = Different superscripts along the same column indicate significant differences at $p < 0.05$.

Comparison between the rehabilitated sites, S27, C27 and MP, and the reference sites, SF and PF, indicate that the bulk density and porosity were not significantly different, especially at the top soil. Invariably, the forest plantation had a significant role in improving the bulk density. However, the restoration of soil texture at these sites to that of the levels of PF, and in particular the sandy area with a poor soil quality, can take a long time (Oktavia *et al.* 2015). While soil bulk density and porosity in SF were similar to that in PF, degradation of the soil structure due to shifting cultivation in SF may be lesser in extent compared to that in the mined out area.

Soil Chemical Properties

Soil pH was extremely acidic in S27, C27, MP and SF, while in PF it was strongly to moderately acidic. However, soil pH in AB was moderately to slightly acidic. These results indicate that the *A. mangium* plantation had a significant influence in reducing soil pH, an observation similar to that of Yamashita *et al.* (2008). Amounts of exchangeable K and Mg were significantly different among the sites at depths of 0 - 10, 10 - 20, 20 - 30, and 30 - 50 cm. Mining rehabilitation with *A. mangium* plantation resulted in increased K and Mg levels which were higher than those in AB. Nevertheless, K and Ca of S27, C27 and MP were lower than those in SF and PF. The levels of K, Ca and Mg were relatively high in the topsoil. Similarly, the available P, total N and OM were the highest at a depth of 0 - 10 cm, but was decreasing with the increasing soil depth.

The topsoil was rich and higher in soil nutrient content, total N, OM, the available P, K, Ca and Mg in S27, C27 and MP than those in AB. In mining restoration, the soil nutrients

Table 2 Soil chemical properties in abandoned mining in the Phangnga Forestry Research Station and the reference sites

Depth (cm)	Site	pH	Exchangeable (mg/kg)			Available P (mg/kg)	Total N (%)	OM (%)
			K	Ca	Mg			
0-10	AB	5.9^{a}	6.33^{d}	10.69	2.92^{c}	5.90^{b}	0.01^{c}	0.67^{c}
	S27	4.5^{bc}	14.38^{cd}	18.45	10.26^{bc}	12.91^{b}	0.11^{b}	1.62^{bc}
	C27	4.4^{c}	35.37^{bc}	23.98	33.56^{ab}	15.16^{b}	0.13^{ab}	2.14^{b}
	MP	4.7^{b}	38.93^{b}	27.46	35.34^{a}	9.42^{b}	0.10^{b}	1.66^{bc}
	SF	4.2^{c}	82.27^{a}	29.06	24.27^{abc}	33.32^{a}	0.17^{a}	2.42^{ab}
	PF	4.8^{b}	40.25^{b}	29.56	26.72^{abc}	50.78^{a}	0.17^{a}	3.55^{a}
F-value		68.53*	28.60*	1.40^{ns}	6.57*	70.22*	26.06*	15.38*
10-20	AB	6.0^{a}	7.46^{b}	11.17	3.21^{c}	4.34^{c}	0.01^{c}	0.33^{b}
	S27	4.7^{bc}	9.76^{b}	9.27	3.77^{bc}	7.10^{bc}	0.04^{c}	0.91^{b}
	C27	4.6^{bc}	20.42^{b}	11.81	15.91^{abc}	7.67^{bc}	0.04^{c}	0.57^{b}
	MP	4.8^{bc}	24.07^{b}	11.13	26.93^{a}	5.32^{bc}	0.04^{c}	0.86^{b}
	SF	4.4^{c}	64.34^{a}	12.83	17.38^{a}	6.25^{bc}	0.11^{b}	1.49^{ab}
	PF	4.9^{b}	29.57^{b}	12.00	16.34^{ab}	14.52^{a}	0.15^{a}	2.53^{a}
F-value		35.03*	19.40*	1.45^{ns}	11.08*	15.31*	73.57*	6.65*
20-30	AB	5.8^{a}	5.18^{c}	10.26	3.13^{b}	3.22^{b}	0.01^{c}	0.25^{b}
	S27	4.9^{b}	8.17^{c}	9.58	4.74^{b}	7.32^{ab}	0.02^{c}	0.71^{b}
	C27	4.6^{b}	9.97^{bc}	9.76	18.23^{b}	7.36^{ab}	0.03^{bc}	0.36^{b}
	MP	4.9^{b}	19.07^{abc}	9.59	35.42^{a}	4.86^{ab}	0.04^{bc}	0.47^{b}
	SF	4.6^{b}	33.14^{a}	14.21	9.87^{ab}	5.65^{ab}	0.07^{b}	1.21^{ab}
	PF	5.6^{a}	24.08^{ab}	10.59	16.45^{b}	9.15^{a}	0.13^{a}	2.29^{a}
F-value		31.28*	11.44*	1.01^{ns}	11.94*	4.81*	31.29*	6.84*
30-50	AB	6.1^{a}	5.01^{c}	9.12	2.85^{c}	3.05	0.01^{b}	0.19^{b}
	S27	5.1^{b}	6.19^{c}	7.86	2.49^{c}	5.54	0.01^{b}	0.48^{b}
	C27	4.8^{bc}	10.75^{bc}	12.41	18.53^{ab}	7.12	0.02^{ab}	0.54^{b}
	MP	4.9^{bc}	18.68^{ab}	12.50	31.51^{a}	2.62	0.02^{ab}	0.41^{b}
	SF	4.6^{c}	20.12^{ab}	9.94	5.94^{bc}	3.59	0.04^{a}	0.87^{b}
	PF	5.7^{a}	20.76^{a}	5.03	17.23^{b}	7.08	0.04^{a}	2.16^{a}
F-value		43.13*	12.70*	3.21^{ns}	15.41*	5.95^{ns}	7.37*	8.95*

Notes: * = significant difference; ns = non-significant difference; and a – c = different superscripts along a column indicate significant differences at $p < 0.05$.

and organic matter contents usually increased with the age of the stand (Zhao *et al.* 2013; Bohre & Chaubey 2014). Soil nutrients rapidly increased in plantations using a nitrogen fixing tree while natural succession increased gradually (Oktavia *et al.* 2015). However, soil nutrients such as exchangeable K, available P, total N and OM levels at S27, C27 and MP were lower than those in both SF and PF at a depth of 0 - 10 cm. Overall, the soil properties in SF particularly, available P, total N and OM contents were improved faster than those in S27, C27 and MP. Although *A. mangium* was dominant in S27, C27 and MP, the level of total N was relatively low, particularly in the sandy area. These results indicate that mining activities highly impacted the soil properties and the restoration may take a longer time.

Tree Composition and Ecological Characteristics

There were 21, 34, 40, 81 and 94 tree species, 19, 29, 31, 62 and 68 genera, and 14, 26, 25, 33 and 38 families in the S27, C27, MP, SF and PF, respectively. The basal area, density and species diversity index in PF (3.91) was the highest, in contrast with those in S27 (1.43), which had the lowest density and species diversity index (Table 3). Soil characteristics showed a significant influence on the density, species diversity index, and natural regeneration (Lei *et al.* 2015), especially in the S27. Soil texture in the area being sandy, has a low water holding capacity, and thus, has resulted in insufficient water supply during the dry season, a phenomenon causing high seedling mortality in the tropical rain forests (Li *et al.* 2011). Soil properties play important roles on revegetation

Table 3 Ecological characteristics of the rehabilitated sites, S27, C27 and MP in the Phangnga Forestry Research Station, Thailand and the reference sites, SF and PF

Ecological characteristics	Sites				
	S27	C27	MP	SF	PF
Number of species	21.00	34.00	40.00	81.00	94.00
Basal area (m^2/ha)	35.49	20.91	23.09	22.20	41.27
Density (stems/ha)	1,010.42	1,229.17	1,393.75	1,200.00	1,497.92
Shannon - Wiener index (*H'*)	1.43	2.51	2.77	3.86	3.91
Evenness of species	0.46	0.71	0.74	0.88	0.86

of native trees and forest community (Zhao *et al.* 2013; Lei *et al.* 2015).

The number of species, tree diversity and density was significantly lower in S27 and C27, than those in MP, which consisted of *A. mangium*, *E. camaldulensis* and *D. alatus*. A mixed plantation of many tree species can facilitate a successful seedling establishment in the understory and native trees were also found more abundantly than in pure plantations, resulting in a high tree diversity (Wang *et al.* 2019). However, the rehabilitated sites in S27, C27 and MP had a low tree diversity compared to SF. The number of native tree species found in S27, C27 and MP were relatively less than that in SF, resulting in a low recovery of original tree species, forest structure, and forest function. In addition, species richness and evenness in SF was larger than those in S27, C27 and MP, resulting in high tree diversity. Tree diversity is related with species richness and evenness (Strong 2016). According to the Shannon-Wiener index of the old teak (*Tectona grandis*) plantation was higher when the evenness value of the plot was high (Koonkhunthod *et al.* 2007). In addition, the Shannon-Wiener index in S27 (1.43), C27 (2.51) and MP (2.77) was lower than that in a 34-year-old *A. mangium* plantation (3.22) (Marod *et al.* 2013). *A. mangium* plantation can be highly effective to introduce native trees species (Van *et al.* 2005). In this study, the native species were mostly shade intolerant trees. Therefore, accelerating the natural succession by enrichment planting with poorly dispersed shade tolerant trees, such as *Swintonia floribunda, Dipterocarpus kerrii, Canarium patentinervium, Xanthophyllum virens, Mesua ferrea, Hopea griffithii* and *Gluta elegans,* may be considered in S27, C27 and MP for improving the forest structure and increasing the tree diversity.

The high tree diversity and number of trees in SF could be due to various factors such as proximity to the forest fragment, rich soil nutrient content and organic matter. The vegetation composition and richness decrease with the increasing distance from the primary forest (Van *et al.* 2005; Ruiz-Jaen & Aide 2005). Therefore, the distance from a natural forest and the surrounding mining area with oil palm and rubber plantations had largely obstructed on the process of natural forest succession in the S27, C27 and MP.

This study, we showed top seven IVI in S27, C27, MP, SF and PF because they play ecological importance in ecosystem with high relative frequency, density and basal area. The dominant native trees in S27, C27 and MP included *Vitex pinnata, Aporosa planchoniana, Carallia brachiata, Melicope lunu-ankenda* and *Bridelia tomentosa* (Table 4). Most native species were identified as pioneers because of their various life forms such as very fast growth, frequent year-round flowering, production of a large number of small seeds, lighting demand for germination, and low wood density are often shade intolerant trees (Goosem & Tucker 2013; Elliott *et al.* 2013). Similarly, the dominant trees in SF were also classified as pioneers, such as *Eurya acuminata, Microcos paniculata,* and *Vitex pinnata.* These trees are mostly found in disturbed areas (Sinbumroong 2009) and old plantation (Koonkhunthod *et al.* 2007). Pioneer trees are tolerant to adverse environmental conditions; therefore, these species can be considered for restoring other degraded areas.

Twenty seven trees recorded were in both SF and PF, among which are *Barringtonia macrostachya, Diospyros wallichii*, *Canarium patentinervium*, and *Garcinia cowa*. However, these were only few small trees. Revegetation in SF was faster than in S27, C27 and MP, resulting in a complex forest structure and high tree diversity. The similarity index between PF and SF was 31.03%, PF with MP was 8.00%, PF with C27 was 6.98%, and PF with S27 was 5.83% (Table 5). The similarity index between the rehabilitated sites in the mining area and PF was low suggesting that SF may be in a mid-successional status and the rehabilitated sites at S27, C27 and MP were in early successional status, as indicated by their similarity index (Habich 2001).

Table 4 Importance Value Index (IVI), Relative Density (RD), Relative Frequency (RF) and Relative Basal Areas (RDo) of the top seven trees in S27, C27, MP, SF and PF

Site	Tree species	Family	RD	RF	RDo	IVI
S27	*Acacia mangium*	Fabaceae	63.85	35.60	95.15	194.60
	Aporosa planchoniana	Phyllanthaceae	16.45	15.15	1.21	32.81
	Carallia brachiata	Rhizophoraceae	4.33	9.85	0.54	14.72
	Bridelia tomentosa	Phyllanthaceae	3.25	7.58	0.38	11.21
	Vitex pinnata	Lamiaceae	1.95	6.06	0.74	8.75
	Litsea grandis	Lauraceae	1.52	4.55	0.22	6.29
	Morinda coreia	Rubiaceae	1.73	3.03	0.38	5.14
	Other species		6.92	18.18	1.38	26.48
C27	*Melicope lunu-ankenda*	Rutaceae	18.19	15.11	26.59	59.89
	Acacia mangium	Fabaceae	38.83	6.22	6.55	51.60
	Aporosa planchoniana	Phyllanthaceae	5.65	7.11	17.73	30.49
	Carallia brachiata	Rhizophoraceae	8.74	9.33	11.56	29.63
	Vitex pinnata	Lamiaceae	5.61	8.89	6.17	20.66
	Ilex cymosa	Aquifoliaceae	1.92	8.00	6.36	16.28
	Fagraea fragrans	Gentianaceae	2.93	11.11	1.93	15.97
	Other species		23.11	34.23	18.13	75.47
MP	*Eucalyptus camaldulensis*	Myrtaceae	10.23	9.45	47.12	66.80
	Acacia mangium	Fabaceae	15.27	8.54	20.78	44.59
	Fagraea fragrans	Gentianaceae	15.44	10.06	5.50	31.00
	Ilex cymosa	Aquifoliaceae	15.10	9.45	3.22	27.77
	Dipterocarpus alatus	Dipterocarpaceae	6.21	6.71	1.73	14.65
	Vitex pinnata	Lamiaceae	2.18	3.96	8.56	14.70
	Carallia brachiata	Rhizophoraceae	4.19	6.10	1.47	11.76
	Other species		31.38	45.73	11.62	88.73
SF	*Eurya acuminata*	Pentaphylacaceae	12.24	7.07	13.79	33.10
	Gmelina arborea	Lamiaceae	5.60	4.08	20.90	30.58
	Microcos paniculata	Malvaceae	5.39	4.62	10.21	20.22
	Barringtonia macrostachya	Lecythidaceae	5.81	6.25	1.63	13.69
	Vitex pinnata	Lamiaceae	3.11	2.99	4.86	10.96
	Diospyros wallichii	Ebenaceae	4.77	4.08	1.94	10.79
	Garcinia cowa	Clusiaceae	2.28	2.72	4.27	9.27
	Other species		60.80	68.19	42.40	171.39
PF	*Swintonia floribunda*	Anacardiaceae	5.93	4.56	19.72	30.21
	Dipterocarpus kerrii	Dipterocarpaceae	4.17	4.36	13.64	22.17
	Canarium patentinervium	Burseraceae	7.37	4.77	2.05	14.19
	Xanthophyllum virens	Polygalaceae	4.17	4.56	5.26	13.99
	Mesua ferrea	Calophyllaceae	2.04	2.70	8.17	12.91
	Hopea griffithii	Dipterocarpaceae	4.97	4.77	2.11	11.85
	Gluta elegans	Anacardiaceae	3.69	3.11	4.07	10.87
	Other species		67.66	71.17	44.98	183.81

Table 5 Sørensen similarity index of tree species among S27, C27 and MP compared with SF and PF

Site	SF	PF
S27	17.48	5.83
C27	22.61	6.98
MP	23.53	8.00
SF	100.00	31.03
PF	31.03	100.00

CONCLUSION

The *A. mangium* plantation in the abandoned tin mining area played a key role in the soil improvement particularly, the top soil. The bulk density and porosity of soil under the plantation remarkably improved. The level of soil nutrients, particularly, organic matter and total N, increased as a result of the presence of *A. mangium* trees. However, these quantities were lower than those measured in the secondary and primary forests. The tree diversity and number of species were low in the sandy soil type in S27 (1.43), clay soil type in C27 (2.51), and mixed plantation in MP (2.77). Moreover, the tree similarity indices in S27, C27, and MP, as well as in primary forest PF were relatively low (5.83 - 8.00). These results showed that plant development in S27, C27, and MP was slow and the dominant trees in the rehabilitated mining sites and the SF were mostly identified as belonging to the pioneer species group, suggesting that enrichment planting with poorly dispersed shade tolerant trees should be considered in improving tree diversity and forest structure and eventually, the ecosystem processes in these areas. Nonetheless, the complexity of the forest structure and tree community in the rehabilitated area was a result of the *A. mangium* plantation, particularly the mixed plantation (MP). These results indicate the potential of *A. mangium* trees in restoring previously mined areas. Meanwhile, pioneer trees such as *Vitex pinnata*, *Carallia brachiata*, *Microcos paniculata*, and *Eurya acuminata* can also be selected for restoring other degraded lands.

ACKNOWLEDGEMENTS

The authors are grateful for the financial support provided by the Kasetsart University Research and Development Institute (KURDI), Thailand and for the field assistance of the staff at the Phangnga Forestry Research Station.

REFERENCES

Barrantes G, Sandoval L. 2009. Conceptual and statistical problems associated with the use of diversity indices in ecology. Rev Biol Trop 57:451-61.

Bohre P, Chaubey OP. 2014. Restoration of degraded lands through plantation forests. Global J Sci Frontier Res 14(1):19-27.

Celentano D, Zahawi RA, Finegan B, Ostertag R, Cole RJ, Holl KD. 2011. Litterfall dynamics under different tropical forest restoration strategies in Costa Rica. Biotropica 43:278-87.

Charman PEV, Roper MM. 2000. Soil organic matter. In: Charman PEV, Murphy BW, editors. Soil: Their Properties and Management. Melbourne (AU): Land and Water Conservation, New South Wale and Oxford University Press. p. 260-70.

Elliott S, Blakesley D, Hardwick K. 2013. Restoring tropical forest: A practical guide. Kew (UK): Royal Botanic Gardens Kew.

Estefan G, Sommer R, Ryan J. 2013. Methods of soil, plant and water analysis: A manual for the West Asia and North Africa Region. 3rd ed. Beirut (LB): ICARDA.

Goosem S, Tucker NIJ. 2013. Repairing the rainforest. Cairns (AU): Wet Tropics Management Authority and Biotropica Australia Pty. Ltd.

Habich EF. 2001. Ecological site inventory, Technical Reference 1734-7. Denver (US): Bureau of Land Management.

Jackson ML. 1965. Soil chemical analysis-advance course. Wisconsin (US): Department of Soils, University of Wisconsin.

Koonkhunthod N, Sakurai K, Tanaka S. 2007. Composition and diversity of woody regeneration in a 37-year-old teak (*Tectona grandis* L.) plantation in northern Thailand. For Ecol Manage 247:246-54.

Lei H, Peng Z, Yigang H, Yang Z. 2015. Vegetation succession and soil infiltration characteristics under different aged refuse dumps at the Heidaigou. Glob Ecol Conserv 4:255-63.

Li P, Huang ZL, Xiang YC, Ren H. 2011. Survival, growth and biomass of *Acacia auriculiformis* and *Schima superba* seedlings in different forest restoration phases in Nanao island, South China. J Trop For Sci 23(2):177-86.

Macdonald SE, Landhausser SM, Skousen J, Franklin J, Frouz J, Hall S, … Quideau S. 2015. Forest restoration following surface mining disturbance: Challenges and solutions. New Forests 46:703-32.

Marod D, Panichsuay K, Thinkamphaeng S, A-sanok L. 2013. Natural regeneration of native plant species after rehabilitation of disturbed dry evergreen forest in Sakaerat Environmental Research Station, Nakhonratchasima province. In: Thai Forest Ecology Research Network: Ecology Knowledge for Restoration. Proceedings: 2013 Jan 26-24. Bangkok (TH): Thai Forest Ecological Research Network. p. 168-79.

Martínez-Ruiz C, Fernández-Santos B. 2005. Natural revegetation on topsoiled mining-spoils according to the exposure. Acta Oecol 28:231-8.

Martpalakorn M. 1990. Tree species trials on mined spoils at Amphoe Takuapa, Changwat Phangnga [Dissertation]. Retrieved from Kasetsart University.

Nambiar EKS, Harwood CE. 2014. Productivity of acacia and eucalypt plantations in Southeast Asia 1. Bio-physical determinants of production: Opportunities and challenges. Int Forest Rev 16:225-48.

Oktavia D, Setiadi Y, Hilwan I. 2015. The comparison of soil properties in heath forest and post-tin mined land: Basic for ecosystem restoration. Procedia Environ Sci 28:124-31.

Parrotta JA. 1999. Productivity, nutrient cycling, and succession in single and mixed-species plantations of *Casuarina equisetifolia*, *Eucalyptus robusta*, and *Leucaena leucocephala* in Puerto Rico. For Ecol Manage 124:45-77.

Pielou EC. 1966. The measurement of diversity in different types of biological collections. J Theoret Biol 13:131-44.

Ruiz-Jaen M, Aide TM. 2005. Vegetation structure, species diversity, and ecosystem process as measures of restoration success. For Ecol Manage 218:159-73.

Shannon CE, Weaver W. 1949. The mathematical theory of communication. Urbana (US): University of Illinois Press.

Sinbumroong A. 2009. Structure and floristic composition of wet seasonal evergreen forest at Khao Ban Thad Wildlife Sanctuary, Trang province [Dissertation]. Retrieved from Kasetsart University.

Sørensen T. 1948. A method of establishing groups of equal amplitude in plant sociology based on similarity of species content, and its application to analyses of the vegetation on Danish commons. Biol Skr 5:1-34.

Strong WL. 2016. Biased richness and evenness relationships within Shannon-Wiener index values. Ecol Indic 67:703-13.

Tripathi N, Singh RS, Hills CD. 2016. Reclamation of mine-impacted land for ecosystem recovery. New Jersey (US): John Wiley & Sons.

Van DT, Lee DK, Van TH. 2005. Rehabilitation of native tree species in the forest plantations and denuded hills of Namlau commune in Sonla province, Vietnam. For Sci Technol 1:51-8.

Wang F, Li Z, Xia H, Zou B, Li N, Liu J, Zhu W. 2010. Effects of nitrogen-fixing and non-nitrogen-fixing tree species on soil properties and nitrogen transformation during forest restoration in southern China. Soil Sci Plant Nutr 56:297-306.

Wang X, Hua F, Wang L, Wilcove DS, Yu DW. 2019. The biodiversity benefit of native forests and mixed-species plantations over monoculture plantations. Divers Distrib 25:1721-35.

Wongprom J, Maelim S, Teejuntuk S, Sommeechai M. 2013. Effects of thinning on growth and yield of *Acacia mangium* Willd. under naturally regenerated on abandoned mining area in Phang-Nga Forestry Research Station. Thai J For 32:142-51.

Yamashita N, Ohta S, Hardjono A. 2008. Soil changes induced by *Acacia mangium* plantation establishment: comparison with secondary forest and *Imperata cylindrical* grassland soils in south Sumatra, Indonesia. For Ecol Manage 254:362-70.

Zhao Z, Shahrour I, Bai Z, Fan W, Feng L, Li H. 2013. Soil development in opencast coal mine spoils reclaimed for 1-13 years in the West-Northern Loess Plateau of China. Eur J Soil Biol 55:40-6.

Zhang Y, Yang JY, Wu HL, Shi CQ, Zhang CL, Li DX, Feng MM. 2014. Dynamic changes in soil and vegetation during varying ecological recovery conditions of abandoned mines in Beijing. Ecol Eng 73:676-83.