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SOIL PROPERTIES BELOW EXOTIC TREE PLANTATIONS AT THE SAITHONG SILVICULTURAL RESEARCH STATION IN PRACHUAP KHIRI KHAN PROVINCE, THAILAND**

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ABSTRACT

Often, exotic trees grow very fast in their new environments and sometimes even faster than the indigenous ones. These exotics seem to be tougher and live through harsher conditions. They may be drought resistant, and they can survive long periods with little to no rainfall. These trees are fast growing and are resistant to pests and diseases which tend to damage the locally growing trees. Moreover, these trees can help improve soil physical and chemical properties. Hence, the objective of this study was to compare the physical and chemical properties of soil under different tree plantations, namely *Eucalyptus urophylla, Acacia crassicarpa* and *Acacia aulacocarpa* at the Saithong Silvicultural Research Station. Three soil composite samples were collected from soil depths of 0 - 10, 10 - 30, and 30 - 50 cm, in the three stands aged 27-year old and planted at a spacing of 2 x 2 m. Soil type in these stands was sandy loam. Soil moisture percentage (12.85%) was significantly the highest in the *E. urophylla* plantation. Phosphorus (18.2 mg/kg DW), magnesium (6.98 $cmol_c$/kg DW), and potassium (6.98 $cmol_c$/kg DW) contents were also the greatest in the *E. urophylla* plantation. Organic matter content was the highest in the *A. crassicarpa* plantation (7.59%), while nitrogen (0.04%) and calcium (36.17$cmol_c$/kg DW) contents were the highest in the *A. aulacocarpa* plantation. Significant differences were also observed in the soil bulk density and porosity attributable to structure, tillage, cropping practices, soil depth and compaction. Characterization of soil pore system is equally important in understanding soil physical and parent material composition, which has a direct impact on soil chemistry and fertility. Parent material rich in soluble ions (calcium, magnesium, potassium and sodium) is desirable, as these chemicals are easily dissolved in water and readily available for plants. For soils with poor nutrient content found in warm and humid tropical climates with low water supply, *E. urophylla, A. crassicarpa* and *A. aulacocarpa* have the potential to enhance the aboveground stand production. Undoubtedly, when planted, they can help restore the soil nutrients faster and therefore, can be used in forest plantations or in agroforestry farms.

Keywords: exotic tree plantation, Saithong Silvicultural Research Station, soil properties

INTRODUCTION

Soil properties are important tree growth factors and as such, maintaining soil quality is paramount for tree health. Soil degradation, on the other hand, involves the destruction of soil structure through loss of organic matter, due to factors related to topography, climate, and poor soil management (Özdemir 1993; Haynes 2000) Often, exotic tree species possess more useful attributes than the native species, such as, a faster growth rate, fewer pests and reduced competition, all leading to a higher economic value (Kalinganire 1996; Tavares *et al*. 1999; Lott *et al*. 2000; Takaoka 2008; Anglaaere *et al*. 2011; Tefera *et al*. 2014). *Acacia aulacocarpa* and *Acacia crassicarpa* not only have shown potential for reclaiming deforested areas, but also for shelterbelts, coastal sand dunes fixation, soil improvement and land rehabilitation on a wide range of degraded sites, as a result of their rapid growth, ability to suppress weeds and abundant *Rhizobium* nodulation (Doran & Gunn 1987).

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Eucalyptus is also one of the most commonly used species for reforestation in commercial plantations, with the added benefit of being an exotic species in study site which can promote the establishment of a stable forest cover in degraded sites (Farias *et al.* 2016). *Eucalyptus* spp. and *Acacia* spp. can grow rapidly in poor soils (Yang *et al.* 2009; Chen *et al.* 2011).

Planting exotic trees in tropical countries is becoming an increasingly important forestry activity as many tropical countries that depended on wood supply from natural forests are now recognizing the need to establish plantations to augment supplies from the dwindling and unsustainable natural forests. The total area of tropical forest plantations increased from about 6.7 million ha in 1965 to 109 million in 2005. Though most species used for tropical plantations are already fast growing, their growth rate can still be improved substantially through appropriate silvicultural practices, such as site-species matching, site nutrient management, and the use of hybrid species.

Sandy soil types are well aerated, thereby, allowing suitable seeds to germinate easily and the roots to penetrate properly. However, such soil types have an inherent disadvantage of being nutrient hungry as nutrients are easily leached away due to excellent soil drainage. Plants that are grown on a sandy loam soil need frequent irrigation and fertilization to maintain a healthy growth. The best way to improve a sandy loam soil is to mix organic matter into the soil. Applying a 2- to 4-inch thick layer of compost or peat moss over the area can significantly improve the ability of a sandy loam soil to hold nutrients. Many eucalyptus plantations are grown on usually nutrient deficit sandy soil types. Hence, attempts were made to plant eucalyptus in semi-arid regions on sandy soil types. In this study, leguminous trees can be planted to improve the soil nitrogen content, this can change the litter quality and soil biology. For a sustained fast-growing exotic tree plantation, it is important to manage sandy soil types in order to increase the soil organic matter content. Silvicultural practices, which help increase the organic matter content in *Eucalyptus* spp. and *Acacia* spp. plantations on sandy soil types, are also essential for their sustainability. Moreover, one of the major interests in *Acacia* is the compounds present in the plant parts that can be used as natural herbicides. Evidence of the role of allelopathy in weed control has been cited in many publications (Chou 1995; Rice 1995; Rizvi & Rizvi 1992; Waller 1987).

The introduction of exotic plants may alter the nutrient cycle of the system either directly, by modifying the quality and quantity of litter entering the soils beneath, or indirectly, by altering the physico-chemical site properties below their canopy. Moreover, the planting of native species on degraded land are highly inappropriate and of high risk due to drought, insect pests and low soil fertility. As such, exotic species are planted to improve the poor soil condition in such an area. Hence, the objective of this study is to compare the soil physical and chemical properties of three plantations of *Eucalyptus urophylla, Acacia crassicarpa* and *Acacia aulacocarpa* on a site with sandy soil types and rain all year round to be an idea for soil develops in the future., to help increase the productivity of exotic tree plantations planted on sandy soil types, as was present in the study area.

MATERIALS AND METHODS

The study was conducted at the Saithong Silvicultural Research Station, Prachuap Khiri Khan District, Thailand located at 11°17'04" N latitude and 98°50'25" E longitude (Fig. 1).

The area receives a mean annual rainfall of 1,175.9 mm, with temperatures ranging from a minimum of 16.3 °C in February to a maximum of 42.9 °C in July, with an annual mean of 28.4 °C. Its soil is primarily of the dark brown to brown (7.5YR4/4) loam to sandy loam (Sadao series) which has moderately fine to medium texture and very strongly acid (field pH 4.5).

Using a completely randomized design, three soil samples were collected from soil depths of 0 - 10, 10 - 30, 30 - 50 cm at the *E. urophylla*, *A. crassicarpa* and *A. aulacocarpa* stands, aged 27-year old and planted at a spacing of 2 x 2 m. The soil physical and chemical properties were determined as follows; the bulk density using the core method (Jalota *et al.* 1998), particle density by the pycnometer method (Jalota *et al.* 1998) using an air comparison pycnometer, soil texture by the hydrometer method, pH in 1:1 soil: water suspension by a pH meter, organic matter using the Walkley and Black's rapid titration method

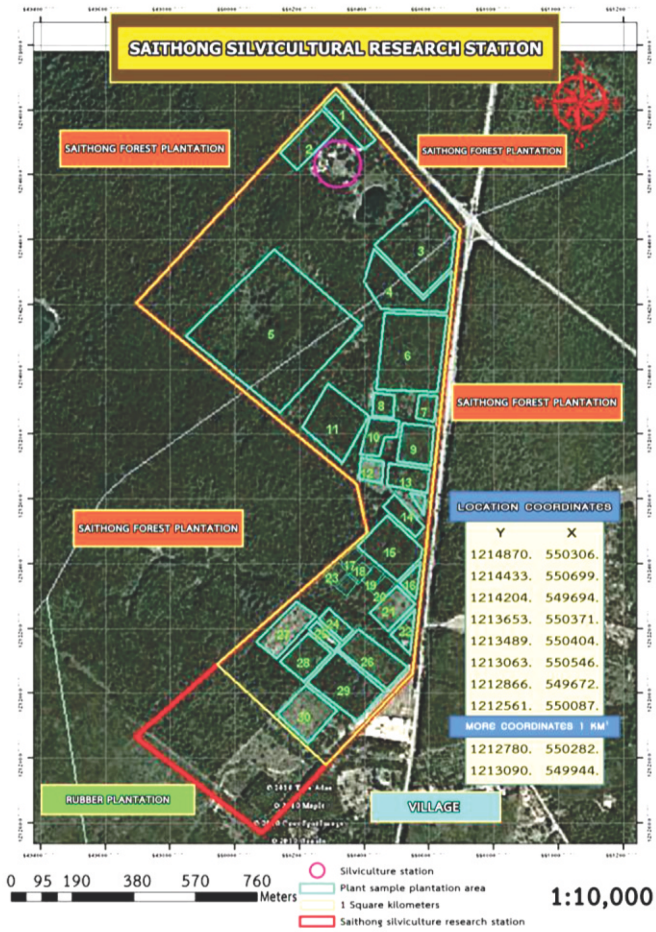

Figure 1 Saithong Silviculture Research Station, Prachuap Khiri Khan Province, Thailand

(Walkley & Black 1934), total nitrogen using the Dumas or dry combustion method (Jackson 1965) using a CHNS analyzer PerkinElmer series 2400 Series II CHNS/O Elemental Analyzer, the available phosphorus (P) by Bray II method (Bray & Kurtz 1945) using a spectrometer, and the exchangeable potassium (K), calcium (Ca) and magnesium (Mg) in ammonium acetate (NH_4OAc) 1 N pH 7.0 by using an atomic absorption spectrometer. Variance analyses of the experimental data were done using the SPSS statistic program at a significance level of $p < 0.05$.

To monitor soil changes induced by tree growth, the soil properties, organic matter accumulation and decomposition, as well as nutrient cycling are measured on several sample plots over the full rotation of a plantation (Lundgren 1978). In this study, soil sampling was carried out in the *E. urophylla*, *A. crassicarpa* and *A. aulacocarpa* plantations aged 27-year old located near each other on the same soil type.

RESULTS AND DISCUSSION

Soil Physical Properties

The three stands were of a sandy loam type and experienced rain all year round. Soil moisture percentage was the highest in *E. urophylla* plantation (12.85%) (Table 1). The potassium (18.2 mg/kg), Mg (6.98 $cmol_c$/kg DW) and P (6.98 $cmol_c$/kg DW) contents were the highest in the *E. urophylla* plantation. (Table 2). The organic matter content was the highest in *A. crassicarpa* plantation (7.59%). Calcium (36.17$cmol_c$/kg DW) content was the greatest in *A. aulacocarpa* plantation (Table 2). These results revealed that leguminous species are instrumental in increasing soil organic matter content, invariably with the presence of the nitrogen-fixing bacteria (Turnbull 1984; Bernhard-Reversat 1993; Bernhard-Reversat *et al.* 1993; Higa & Higa 2000). However, the leguminous species can also cause soil acidification (Binkley 1992; Yamashita *et al.* 2008;

Table 1 Soil physical properties in the 27-year old *E. urophylla*, *A. crassicarpa* and *A. aulacocarpa* plantations at the Saithong Silvicultural Research Station, Prachuap Khiri Khan Province, Thailand

Soil parameters	Depth (cm)	*E. urophylla*	*A. crassicarpa*	*A. aulacocarpa*	F-value
Particle density (g/cm^3)	0-10	2.55	2.53	2.58	0.49^{ns}
	10-30	2.58	2.53	2.71	2.47^{ns}
	30-50	2.66	2.61	2.59	0.48^{ns}
	Mean	2.60	2.56	2.63	
Bulk density (g/cm^3)	0-10	0.89^{b}	0.91^{ab}	0.92^{a}	7.36*
	10-30	0.89^{b}	0.91^{a}	0.90^{ab}	5.75*
	30-50	0.88^{b}	0.91^{a}	0.90^{a}	16.88*
	Mean	0.89	0.91	0.91	
Porosity (%)	0-10	33.84	34.82	34.70	0.70 ^{ns}
	10-30	33.52	34.93	32.49	2.30 ^{ns}
	30-50	32.05	33.80	33.90	1.84 ^{ns}
	Mean	33.14	34.52	33.70	
Soil moisture (%)	0-10	12.76^{a}	10.28^{ab}	8.63^{b}	7.36*
	10-30	12.16^{a}	9.96^{b}	10.52^{b}	5.81*
	30-50	13.63^{a}	10.25^{b}	10.83^{b}	17.26*
	Mean	12.85	10.16	9.99	
Sand (%)	0-10	74.89	76.35	74.65	0.10^{ns}
	10-30	73.68	76.35	75.68	0.35^{ns}
	30-50	74.23	74.77	74.35	0.01^{ns}
	Mean	74.27	75.82	74.89	
Silt (%)	0-10	13.45	10.67	11.33	0.28^{ns}
	10-30	12.00	9.33	10.00	0.27^{ns}
	30-50	6.79	6.67	8.67	2.50^{ns}
	Mean	10.74	8.89	10.00	
Clay (%)	0-10	11.65	12.99	14.03	3.05^{ns}
	10-30	14.32	14.32	14.32	0.00^{ns}
	30-50	18.99	18.56	16.99	0.19^{ns}
	Mean	14.99	15.29	15.11	

Notes: * = significant difference at $p < 0.05$;
Superscripts a and b in the same row indicate significant differences at $p < 0.05$ using Duncan's Multiple Range Test;
ns = not significant.

Kasongo *et al.* 2009; Koutika *et al.* 2014). Differences in soil bulk density and porosity was caused by structure, tillage practices before and after harvest, cropping practices, soil depth and soil compaction. Heavy machinery can cause soil compaction, as well as feet stomps caused by animal passage. Characterization of soil system is important for understanding the composition of soil physical and parent materials or drift deposits, as these have a direct impact on soil chemistry and fertility. Parent materials rich in water soluble ions, such as Ca, Mg, K, and sodium (Na), are easily dissolved in water and readily available for absorption by plants.

The mean bulk density values were generally higher for *A. crassicarpa* (0.91 g/cm^3) and *A. aulacocarpa* plantations (0.91 g/cm^3) (Table 1). In the upper 0-10 cm of the soil profile, the values indicated a greater soil compaction for the *A. aulacocarpa* plantation (2.63 g/cm^3) compared to the deeper soil layers. Soil in the plantations was mainly of a sandy loam type. At the study sites, the data showed no evidence of textural change as a result of reforestation with *E. urophylla, A. crassicarpa* and *A. aulacocarpa* plantations. At the time scale involved, a comparatively stable property like soil texture is unlikely to undergo drastic changes as a result of planting the *E. urophylla, A. crassicarpa* and *A. aulacocarpa* trees.

The porosity mean was higher in the *A. crassicarpa* plantation (34.52%) and the mean of soil moisture was higher in the *E. urophylla* plantation (12.85%) (Table1). Moisture retention is an important factor governing soil fertility. However, sand is porous and has a low water retention capacity Therefore, soil types in the study sites are of poor quality as they are of the sandy texture.

Soil Chemical Properties

Table 2 Soil chemical properties in the exotic tree plantations of *E. urophylla*, *A. crassicarpa,* and *A. aulacocarpa,* at the Saithong Silvicultural Research Station, Prachuap Khiri Khan Province

Soil parameters	Depth (cm)	*E. urophylla*	*A. crassicarpa*	*A. aulacocarpa*	F-value
pH	0-10	4.20^a	3.87^b	3.89^b	10.52^*
	10-30	4.64^a	4.03^b	4.10^b	5.89^*
	30-50	4.71	4.23	4.39	0.08^{ns}
	Mean	4.52	4.04	4.13	
Organic matter (%)	0-10	0.73	1.18	2.46	1.36^{ns}
	10-30	2.01	2.52	5.83	1.60^{ns}
	30-50	6.69	3.89	6.24	0.76^{ns}
	Mean	3.14	7.59	4.84	
N (%)	0-10	0.03^b	0.04^b	0.06^a	9.80^*
	10-30	0.02	0.03	0.03	1.00^{ns}
	30-50	0.02	0.03	0.02	1.50^{ns}
	Mean	0.02	0.03	0.04	
P (mg/kg)	0-10	2.55	1.59	1.73	2.28^{ns}
	10-30	1.68	1.28	1.25	0.19^{ns}
	30-50	1.24	1.04	0.59	0.95^{ns}
	Mean	1.82	1.30	1.19	
K ($cmol_c$/kg DW)	0-10	9.05	8.28	9.03	0.25^{ns}
	10-30	5.67	4.89	5.69	1.26^{ns}
	30-50	6.21	6.16	5.94	0.27^{ns}
	Mean	6.98	6.44	6.72	
Ca (cmolc/kg DW)	0-10	31.57^b	36.45^b	54.90^a	8.04^*
	10-30	25.82	24.02	27.96	0.31^{ns}
	30-50	29.99	25.15	25.64	0.32^{ns}
	Mean	29.13	28.54	36.17	
Mg (cmolc/kg DW)	0-10	9.05	8.28	9.03	0.25^{ns}
	10-30	5.67	4.89	5.69	1.26^{ns}
	30-50	6.21	6.16	5.94	0.27^{ns}
	Mean	6.98	6.44	6.72	

Notes: superscripts a and b, across row, indicate significant differences at $p < 0.05$ using Duncan's Multiple Range Test; ns = not significant.

Soil in all three plantations was generally acid. The pH values were higher in *E. urophylla* plantation (pH 4.52) (Table 2), although the difference was not significant at a depth of 30-50 cm at any sites.

Organic matter content was the highest in the *A. crassicarpa* plantation (7.59%) and its level was lower at a depth of 0-10 cm. Total nitrogen content was the highest in the *A. aulacocarpa* plantation (0.04%) and was maximum at a depth of 0 - 10 cm. In a similar study, soil N improved significantly under the canopy of *Acacia sieberiana* trees in Songa Pastures, Rwanda (Mugunga & Mugumo 2013). *Acacia* has high rates of nitrification and high nitrogen availability for plants (Marchante *et al.* 2008). Soil nitrogen and nitrogen produced from the fallen leaves are tightly associated with ecosystem processes that support aboveground biodiversity, the living biomass above the soil including the stem, stump, branches, bark, seeds and foliage (Clark & Tilman 2008; Hautier *et al.* 2009; Dickson & Foster 2011). P level was the highest in the *E. urophylla* plantation (6.98 mg/kg) and it was maximum at a depth of 0-10 cm (Table 2).

Nutrient quantities, organic matter and exchangeable cations (Ca, Mg, and K) expressed in $cmol_c$/kg DW, were obtained from soil profiles of the *E. urophylla, A. crassicarpa,* and *A. aulacocarpa* plantations (Table 2). The nitrogen (0.04%) and Ca (17$cmol_c$/kg DW) contents were the highest in the *A. aulacocarpa* plantation (Table 2).

As indicated by the exchangeable cation analyses, K content was the greatest in the *E. urophylla* plantation (6.98$cmol_c$/kg DW) and its level was maximum at a depth of 0-10 cm. Mg content was the highest in the *E. urophylla* plantation (6.98 $cmol_c$/kg DW) and was maximum at a depth of 0-10 cm, in all the plots. Ca content (36.17 $cmol_c$/kg DW) was highest in the *A. aulacocarpa* plantation and was maximum at a depth of 0-10 cm.

Soil chemical properties were higher at the surface layer of 0 - 10 cm depth compared to those in the subsoils layers at 10 - 30 and 30 - 50 cm depths. This can be attributed to a higher concentration of organic matter in the upper soil layer, a condition that commonly occurs in most tropical soils (Obatolu & Ibiremo 1999).

Results of soil analyses on physical properties show that the soil texture remained unchanged under the three vegetation types. Most soils in Thailand, being sandy, tend to have poor mineral absorption, low acidity and low absorption. The presence of exotic tree plantations was expected to improve the sandy soil quality. The introduction of exotic plants could have altered the nutrient cycle of the system either directly, by modifying the quality and quantity of litter entering the soils beneath, or indirectly, by altering the physical-chemical site properties below their canopy. In sandy soils, the ability of a plant's root or trunks in making food is lowered, making their growth slower and inefficient.

Generally, the encroachment of exotic plant species poses a major threat to the biodiversity and ecosystem stability, however, little attention is given to the potential impacts of these invasions on soil nutrient cycling. The differences between exotic and native species do not show trends in other components of the nutrient cycles, for example, the size of soil pools of carbon and nitrogen. In some cases, a given species can have different effects on different sites, suggesting that the new composition can positively affect the invaded community and its environment such as the soil type, thereby influencing the direction and magnitude of the impact at an ecosystem-level. Exotic plants can alter the soil nutrient dynamics particularly in terms of biomass and productivity, tissue chemistry, plant morphology and phenology. As such, research may focus on these issues and integrate these in evaluating the impacts of invasive species.

Individual species have affected the various components of the carbon and nutrient cycles, including the pools of aboveground and belowground carbon, nitrogen, and other elements; the net primary productivity and plant growth rates; the chemical quality and rates of litter fall; and the nutrient and carbon mineralization rates. These evidences strongly suggest that when a community undergoes species composition changes due to the invasion and spread of exotic species, subsequent changes in the nutrient cycling processes are expected.

CONCLUSION

The adoption of exotic trees in agroforestry systems or forest tree plantations can significantly impact the soil nutrient content as a result of their rapid leaf turnover and nutrient release through decomposition leading to significant increases in soil fertility. In this study, the *E. urophylla, A. crassicarpa* and *A. aulacocarpa* trees helped improve soil fertility which most likely could enhance the herbage productivity, subsequently improving the agroforestry systems. Integrating these species in agroforestry systems and preserving these trees in arid and semi-arid areas could help maintain and enhance the sustainability of these ecosystems.

Eucalyptus spp. and *Acacia* spp. not only grow on soils with poor quality, but can also grow rapidly and survive under long periods without rainfall. The *Acacia* and *Eucalyptus* spp. in the present study played a significant role in improving the soil structure and the availability of essential nutrients.

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