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Study on Growth and Productivity of Six Tropical Exotic Pine Species in the Taung Lay Lone Reserved Forest

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တောင်လေးလုံးကြိုးဝိုင်း သစ်တောသုတေသနစခန်းရှိ ဒေသမျိုးစုံမှ အပူပိုင်းထင်းရှူး သစ်မျိုးများ၏ ရှင်သန်ကြီးထွားမှုကိုလေ့လာခြင်း

ဒေါက်တာချောချောစိန်၊ ဦးစီးအရာရှိ
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စာတမ်းအကျဉ်း

ရှမ်းဒေသကြီးသည် မြန်မာနိုင်ငံတွင် သဘာဝထင်းရှူးတောများ ပေါက်ရောက်ရာ ဒေသကြီး တစ်ခုဖြစ်ပါသည်။ တောအလွန်အကျွံ ခုတ်ယူသုံးစွဲခြင်း၊ တောမီးလောင်ကျွမ်းခြင်းနှင့် တိရိစ္ဆာန်အစာ အတွက် စားကျက်ချခြင်းတို့ကြောင့် မြေဆီလွှာဆုတ်ယုတ်ပျက်စီးကာ မြေတိုက်စားခြင်းများ ဖြစ်ပေါ်လျက် ရှိပေသည်။ သို့ဖြစ်ရာ ဒေသမျိုးရင်းဖြစ်သော *Pinus kesiya* ဖြင့် ထင်းရှူးစိုက်ခင်း များကို ၁၉၈၀ခုနှစ်မှ စတင်တည်ထောင်ခဲ့ကြပါသည်။ သို့သော် ကြီးထွားမှုနှေးကွေးခြင်းကြောင့် ၁၉၈၁ ခုနှစ်မှစတင်၍ နိုင်ငံရပ်ခြား အပူပိုင်း ထင်းရှူးမျိုးများဖြင့် စိုက်ခင်းများစမ်းသပ် တည်ထောင်ခဲ့ကြ ပါသည်။ ယခုစာတမ်းတွင် သစ်တောသုတေသန တောင်လေးလုံးကြိုးဝိုင်းအတွင်းရှိ နိုင်ငံရပ်ခြား အပူပိုင်း ထင်းရှူးမျိုးများ(၆)မျိုး *Pinus caribaea, Pinus kesiya, Pinus maximinoi, Pinus oocarpa, Pinus patula and Pinus pesudotropus* တို့၏ရှင်သန်ကြီးထွားမှုကိုလေ့လာဖော်ထုတ် ထားပါသည်။လေ့လာတွေ့ရှိချက်များအရ *Pinus maximinoiand* နှင့် *Pinus pseudotropus* တို့သည် ရှင်သန်ကြီးထွားမှု အကောင်းဆုံးဖြစ်ကြောင်း လေ့လာ တွေ့ရှိ ရပါသည်။

Study on Growth and Productivity of Six Tropical Exotic Pine Species in the Taung Lay Lone Reserved Forest

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Abstract

Shan State is one of the natural pine regions in Myanmar. Due to over cutting, forest fires and grazing, some forests of these hill regions became deteriorated and some area became denudated and resulting in erosion and degradation of soil. Pine plantations have been established on a large scale in the Shan State since 1980, using indigenous species *Pinus kesiya*. Due to the slow growth and poor form of the indigenous species, six exotic tropical pine species *Pinus caribaea, Pinus kesiya*, *Pinus maximinoi, Pinus oocarpa, Pinus patula and Pinus pesudotropus* were introduced from Central American region since 1981. The six temporary sample plots were selected and and further divided into subplots of 20 m x 20 m. The diameters at breast height (dbh) - 1.3 m above ground and heights of all the standing trees were measured. Growth and site condition such as relationship between stand height and diameter, estimated stand basal area, volume production and mean annual increment of six tropical exotic pine species were assessed. It was observed that *Pinus maximinoiand Pinus pseudotropus* were the best in growth and productivity than other four species.

Key words: Estimated Stand Basal Area, MAI, Exotic Tropical Pine, Growth and Productivity

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Study on Growth and Productivity of Six Tropical Exotic Pine Species in the Taung Lay Lone Reserved Forest

1. Introduction

Shan State is one of the natural pine regions in Myanmar. Due to over cutting, forest fires and grazing, some forests of these hill regions became deteriorated and some area became denudated and resulting in erosion and degradation of soil. Thus in these regions erosion control and soil conservation were urgently needed. To curb those adverse affects, plantation establishment was necessary. Due to experiences gained from plantation establishment, pine plantation establishment is found to be more suitable for this region. Pine plantations have been established on a large scale in the Shan State since 1980, using indigenous species *Pinus kesiya*. Due to the slow growth and poor form of the indigenous species, tropical pines from Central America have been introduced and planted extensively in the tropical and sub-tropical countries (Baconand Hawkins, 1980; Hawkinsetal., 1978; Lamb,1973; Whitmore and Liezel,1980) with great success due to their good growth and versatility of Timber, the Forest Research Institute has initiated trials on exotic pines in 1981, in the Shan State. The following six tropical exotic pine species were also planted in the Taung Lay Lone Research Station in 1986.

Species	Provenance
Pinus caribaea	Puerto cabezas, Nicaragua
Pinus kesiya	Bodana population, Madagascar
Pinus maximinoi	Dantali, Nicaragua
Pinus oocarpa	Fince la Lagunilla,Guatemala
Pinus patula	Jitotil Mexico
Pinus pseudostrobus	Tecpan, Guatemala

The objectives of the study are as follows

(a) To assess the growth and productivity of six exotic tropical pine species in the Taung Lay Lone reserved forest.

(b) To recommend the most suitable exotic pine species for the Shan state.

2. Literature Review

General Description of six tropical pine species

Pinus caribaea

Pinus caribaea is a medium-growing tree that reaches 45 m in height and more than 1 m d.b.h. The shafts are generally straight and free of branches. The bark is thick with wide fissures and is reddish brown to ashy brown. This variety has fascicles of three, and in the young trees these fascicles have four to six acicular leaves. The acicular leaves are 15 to 25 cm long and 1.5 mm wide; they are stiff and finely serrated, dark green to yellowish green, and covered with white stripes of stomata. The tree has a pivot root in deep soils, and super ficial roots in slightly deep soils. It adapts very well to a wide variety of environments, including degraded, poor, lixiviated, rather low soils with good drainage. The species grows well in acid sandy soils (pH 4.3 to 6.5) and, to a lesser degree, sandy-clayey soils. Generally, moisture in the soil determines development more than the availability of nutrients. The tree grows well in oxisol soils that are not very deep, are saturated with water during the rainy season, and are very dry in the rainless season. In wet climates of the Tropics the species tends to form foxtail. It can tolerate drought for up to 6 months and sporadic floods. However, drought can also cause large losses in young stands (Lamprecht 1990). *Pinus caribaea* grows well where temperatures range from 20 to 27 °C and annual precipitation is between 1000 and 1800 mm. Some trees grow where precipitation is 600 to 3900 mm. In its native region the tree grows from sea level to 850 m; it is occasionally found at 1000 m.

The hard wood of *P. caribaea* is appropriate for floors and all types of construction. Treated with a preservative, the wood is used in mines, pilings, and railroad ties. Primarily used in construction and carpentry, the wood is also dried and turned (Centro Agronómico Tropical de Investigación Enseñza 1994, SEFORVEN 1993). In Villanueva, Casanare, Colombia, wood obtained by precommercial thinning at 8 to 10 years is used in tongue and groove boards and cabinetmaking (portable crates, doors, windows, desks, and bookcases).

Pinus kesiya

Range of distribution covers large area of SE Asia including Thailand, Burma, Laos, S. China and Vietnam to the Philippines. Normally confi ned to altitudes 700 -1200 m.a.s.l., in east India however, reported up to 3000 m. Often forming pure stands. When growing in the same area as *P. merkusii* the two species may be co-dominant in an overlapping altitude with *P. merkusii* being more frequent at lower altitudes and *P. kesiya* at higher. At higher altitudes, they are occasionally co-dominant with Keteleeria. Most are very adaptable to different ecological conditions. It can usually occur where rainfall is about 700 mm per year with distinct dry and rainy season. Most provenances are frost tolerant and quite fire resistant. It occurs on a variety of soil types from sandy to clay, but seemingly with preference for poor well-drained soil. In the Philippines, they also found on limestone soil. Widely planted outside its natural distribution e.g. in southern Africa.

Tree grow to a large size of 30 (-40) m height, straight round bole albeit often with basal sweep. The barks are brownish, splitting or fl aking in old trees. Needles are dark green, soft, usually with 3 needles in a fasicle at the tip of short twigs. Needles are 15-20 cm long, ocrea 1.2-1.5 cm long, persistent. Male strobili are 4-5 cm long, cylindrical, female conelets greenish purple. Old empty cones remain attached to the tree for a long time after seed dispersal. General purpose of softwood timber is to be used for e.g. construction, pulp and furniture. Also used for resin although it is less productive than *P. merkusii. Pinus kesiya* are widely grown as an industrial plantation species.

Pinus maximinoi

Pinus maximinoi is a fast-growing pine, reaching 20 to 40 m in height and 40 to 100 cm d.b.h. The trunk is usually straight and clear of branches (Carbajal and McVaugh 1992,Perry 1991). This pine grows at elevations of 600 to 2400 m. However, in relation to growth and phenotypic quality, the best stands are found at 800 to 1500 m, on seaward-facing slopes, with deep and fertile well-drained soils. Topsoil pH values typically range from 4.2 to 6.5, while subsoils may reach pH 8.0. Textures are normally sandy clay loams to clays for surface soil horizons and clays for subsoil horizons (Dvorak and Donahue 1988). The species grows in climates varying from temperate-warmer to subtropical humid (Carbajal and McVaugh 1992); annual rainfall on these sites ranges from approximately 1000 to 2100 mm (Dvorak and Donahue 1988). Mean annual temperatures vary from 17 to 22 °C. Maximum temperatures reach 40 °C, and minimum temperatures drop to -1 °C (Eguiluz-Piedra 1978).

Pinus maximinoi does not appear to tolerate freezing temperatures (Dvorak and Donahue 1988). The wood of *P. maximinoi* is soft and light; the sapwood is pale yellowish white, and the heartwood is slightly darker (Perry 1991). Specific gravity density in trials in Colombia varied from 0.32 to 0.51 and in South Africa from 0.49 to 0.50 (Wright and Baylis 1993, Wright and Osorio 1993, Wright and Wessels 1992). Its potential uses include paper, firewood, resin extracts, and hewn timbers for roof supports and doorways (Eguiluz-Piedra 1978, Perry 1991, Wright and Wessels 1992).

Pinus oocarpa

Pinus oocarpa is a closed-cone pine native to Mexico and Central America (Perry 1991). It has a geographic range of 3000 km from Sinaloa, Mexico (28°20'N latitude) to central Nicaragua (12°40'N latitude) and is the most common pine in the southern half of Mexico and Central America. It constitutes approximately 45 percent of the pine forests of Chiapas (Zamora 1981), 50 percent of Guatemala, 66 percent of Honduras (Wolffsohn 1984), 90 percent of Nicaragua (Greaves, 1979), and 60 percent of El Salvador. It is also found in several locations in the interior highlands of Belize.

Pinus oocarpa is phenotypically an extremely variable species in its native environment because it has evolved under diverse climatic and edaphic patterns over its 3000-km geographic distribution. It occurs from 350 to 2500 m elevation in Mexico and Central America but reaches its best development between 1200 to 1800 m. Along the northwest coast of Mexico it occurs in areas with as little as 600 to 800 mm of annual rainfall (Pérez de la Rosa 1998). In southern and eastern Mexico and most of Central America it generally occurs in areas of 1000 to 1500 mm of annual precipitation with dry seasons of up to 5 months. In some locations where *P. oocarpa* is found, like Ocotal Chico,Veracruz, Mexico, annual rainfall amounts exceed 2250 mm. *Pinus oocarpa* is most often found on shallow, sandy clay soils of moderate soil acidity (pH 4.0 to 6.5) that are well drained. The species distribution appears to be very dependent on the existence of frequently occurring fires. Trees of *P. oocarpa* can be recognized in their native habitats by their irregular crowns, thick, gray, platy bark, ovoid-shaped cones with a large, thick peduncle, and needles in fascicles of five. On deep, well-drained soils and with good rainfall regimes, *P. oocarpa* is a medium-to-large tree about 20 to 35 m in height and 45 to 80 cm d.b.h. The species reaches its best development in eastern Guatemala, Honduras, and northern Nicaragua where soils are deep and annual rainfalls are above 1200 mm. The growth rates of *P. oocarpa* in natural stands in these regions are approximately 3 to 4 m3 per ha per year. In northern Mexico, where the climate is drier than in most parts of Central America, trees reach only 10 to 15 m height and are generally poorly formed. Trees are also often less than 10 to 12 m height where they grow on shallow, eroded soil on ridge tops, or at elevations below 800 to 900 m (Zamora 1981). The growth rate of P. oocarpa in these dry regions is approximately 1 m^3 per ha per year. *Pinus oocarpa* crosses naturally with both *P. caribaea* var. hondurensis (Sénécl) Barr. & Golf. and P. tecunumanii Eguiluz& J. P. Perry, and a number of hybrid swarms exist in Central America (Furman and others 1996, Squillace and Perry 1992). Artificial crosses among all three pine species have been successfully made for years in Queensland, Australia (Nikles 1989). The wood of *P. oocarpa* is whitish yellow. Wood density is moderate and provenance averages range from 0.450 to 0.550 g per cm3 for trees 30 to 60 years of age throughout Mexico and Central America. Local industries and farmers have used the wood for plywood, construction lumber, packing boxes, soft drink boxes, broomstick handles, Popsicle sticks, railroad ties, and posts (Zamora 1981). However, its greatest use in the region is for fuel wood and kindling (ocote) as well as for resin production.

Pinus patula

Pinus patula var. *patula* occurs primarily in the Sierra Madre Oriental in the eastern part of Mexico between 18° and 24°N latitude. A closely related variety, *P.patula* var. longipeduculata Loock ex Martínez, is found primarily in the Sierra Madre del Sur in southern and western Mexico between 16°N and 17°N latitude. Because the seeds of both varieties can be handled in a similar fashion, they are referred to here as simply *P. patula*. When important differences occur between the two varieties, the varietal names will be used. Pinus patula grows in both pure and mixed stands in association with Abies sp., Carya sp., Juniperus sp., Liquidambar styraciflua L., Quercus spp., P. ayacahuite Ehrenb., P. douglasiana Mart., P. leiophylla Schiede ex Schlectendal & Chamisso, P . montezumae Lamb., *P . pseudostrobus* Lindl., P. rudis Endl., P. teocote Schiede ex Schlectendal & Chamisso, and Taxus sp. *Pinus patula,* a closed-cone pine with straight stem form, reddish flaky bark, and pale-green, pendent foliage, can reach a height of 35 m and 80 cm d.b.h. It grows on fertile, well- drained soils on mountain ridges and slopes in cloud forest environments at elevations between 1490 and 3100 m (Dvorak and Donahue 1992) but is most common between 2100 and 2800 m (Perry 1991). It generally occupies sites that receive between 1000 and 2000 mm of annual precipitation with distinct dry seasons of up to 4 months. Growth rates of trees of *P. patula* in natural stands may be as high as 8 m3 per ha per year on the best sites. *Pinus patula* var. *patula* and sources of var. longipeduculata from northern Oaxaca are cold tolerant and can withstand hard freezes. However, sources of *P . patula* var. longipedunculata Loock in Martínez from southern and western Oaxaca are more susceptible to cold weather and suffered freeze damage when planted in field trials in South Africa. (Dvorak and others 1995).

Pinus pseudostrobus

Pinus pseudostrobus is primarily a Mexican pine although its range reaches the high mountains in Guatemala. It is chiefly distributed along the Volcanic Axis Mountains in Central Mexico (Martínez 1948, Perry 1991). *Pinus pseudostrobus* forms pure stands or grows in association with *P. montezumae, P. douglasiana, P. michoacana, P. maximinoi, P. leiophylla, P.ayacahuite, P. patula, P. cembroides Zucc., P. rudis, P. pringlei,* Abies religiosa (Kunth) Schltr. & Cham. , Quercus sp., Arbutus sp., Juniperus sp., Buddleia sp., and Dasylirion sp. (Eguiluz- Piedra 1978, Perry 1991). *Pinus pseudostrobus* is one of Mexico's finest pines with its usually straight, branchless trunk. It is a fast-growing tree that reaches 30 to 40 m or more in height and 40 to 80 cm d.b.h. (Perry 1991, Stead and Styles 1984). The species grows at elevations from 1600 to 3250 m, but the best stands are found at 2500 m on deep volcanic soils. This tree can also be found in swallow and calcareous soils. *Pinus pseudostrobus* grows in temperate to temperate-warmer climates, where temperatures may drop to freezing during the coldest winter months. The species is found where temperatures range from 9 to 40 °C and annual rainfall from May to October is 600 to 2000 mm (Eguiluz-Piedra 1978, Martínez 1948, Perry 1991). No geographic races have been reported, but the species can naturally hybridize with *P. montezumae.* (Perry 1991). The wood is light, soft, strong, and yellow, with a specific gravity 0.32 to 0.51 and high pulp yields. It is widely used for general construction, hewn timber, decorative items, pulp, and firewood (Eguiluz-Piedra 1978, Perry 1991, Wright and Malan 1991, Wright and Wessels 1992, Zobel 1965).

3. Materials and Methods

Study Site

The study area is situated in the Southern Shan Region, Taunggyi Township, Taung Lay Lone Reserved Forest. In this research station, many indigenous and exotic pine plantations were established since 1986.

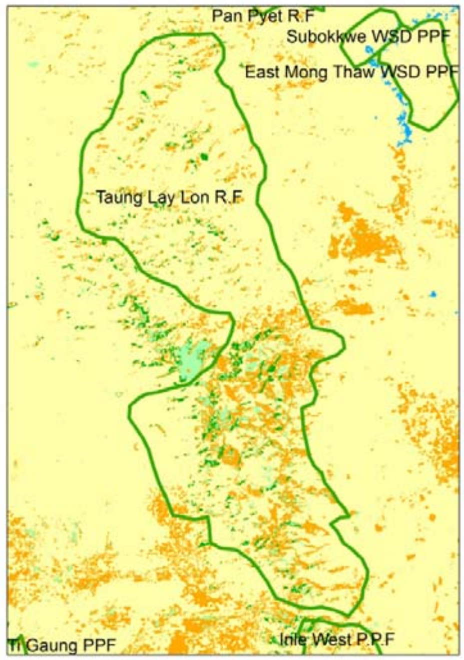

Figure (1) Study Area

Methodology

In forestry research, inventory is one of the basic steps to other forestry branches in putting the silvicultural and management plan. For large areas, sampling could provide all necessary information at much lower costs with reliable result than total enumeration (ADAM, 1989). A field survey was carried out in six tropical pine plantations with subjective sampling. The six temporary sample plots were selected only in places where stocking was full for each plantation. The sample plots are all square with 60 m x 60 m in size and further divided into subplots of 20 m x 20 m. The diameters at breast height (dbh) - 1.3 m above ground and heights of all the standing trees were measured using diameter tape and clinometer respectively.

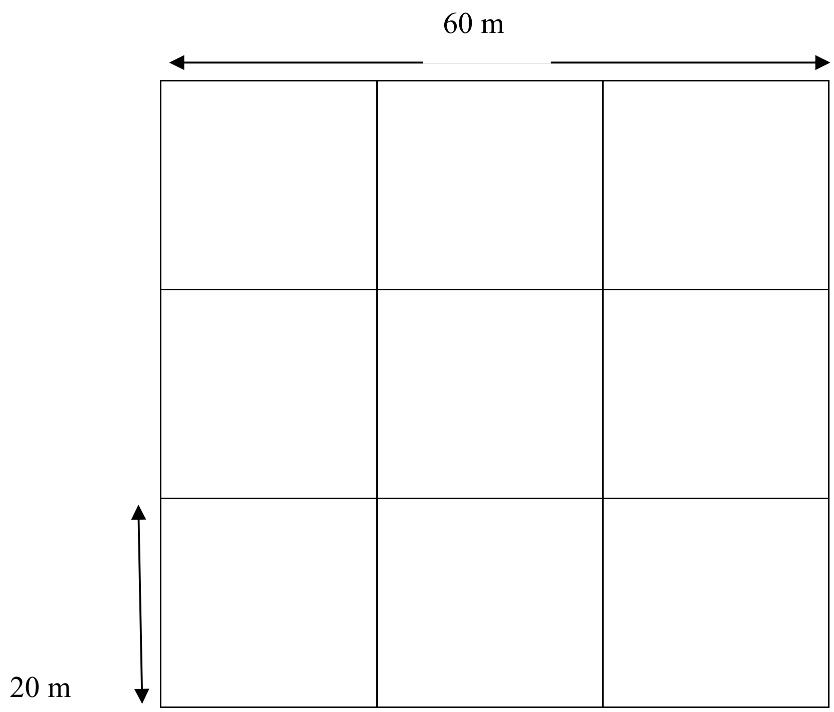

Figure (2) Layout of sample plot

4. Results and Discussions

Relationship between diameter and height

The measurement of tree height can be complicated due to the visibility of the accurate tip of the tree. Also, it is somewhat hard to observe the base of a tree in a stand with very dense under-growth, so it becomes necessary to clear out the sampling area before measurements are made. In any case, the relationship between the diameter and height of trees is vital to estimate the respective height by measuring the dbh. Stout and Shumway (1982) developed a method to estimate site quality by means of the height and diameter of dominant and co- dominant trees, while neglecting tree age. Many additional models have been applied to clarify the relationship between diameter and height. For example, Wenk et al. (1990) have utilized 30 different functions in attempt to accurately determine the relationship between diameter and height. Here, 3 different models (see table 1) were tested using the accessible diameter and height data in this study to obtain the best fit.

The Prodan model was selected as the best fits for the selected species based on the results of the coefficient of determination (r^2). The diameter-height relationship was implemented for each age class in an individual species, i.e transition curves of height, since r^2 was not suitable to construct a diameter-height relationship for all ages of an individual species. However, age should be the same for different species in order to make comparisons of diameter-height relationships. For this reason, 29-year-old stands of six tropical exotic pine species were selected. The height growth with dbh in six different pine species can be seen in figure (3-8) and the parameter values for the fitted Prodan model are shown in table 2. The smallest number of observation was found in the *Pinus oocarpa* and the highest in the *Pinus patula*. *Pinus pseudostrobus* had smallest r^2. It was not due to the number of observations, but could be due to site differences among the stands.

Table (1): Models tested for diameter-height relationship.

1. Prodan-equation:	$h = 1.3 + \dfrac{d^2}{A + B \cdot d + C \cdot d^2}$
2. Petterson-equation:	$h = 1.3 + \left(\dfrac{d}{A + B \cdot d}\right)^2$
3. Van Laar and Akca	h = 1.3+ (a*DBH + b*DBH^^{2})

Pinus maximinoi, *Pinus oocarpa* and *Pinus patula* exhibited obvious site variation in height growth over dbh. The appropriate species could be distinguished by using these diameter-height curves as guides. The performance of the fitted line for *Pinus maximinoi* was equal to that of *Pinus oocarpa* (see figure 5 and 6).

Table (2) Parameters and r^2 of diameter–height relation (Prodan fitted model, age = 29 years)

Species	N	A	B	C	r
Pinus caribaea	345	0.1005	0.7654	-9.9569	0.74
Pinus kesiya	341	0.0693	0.8785	-14.440	0.76
Pinus maximinoi	336	0.0564	0.8702	-17.7227	0.82
Pinus oocarpa	322	0.0590	1.3264	-16.9538	0.78
Pinus patula	350	0.0790	0.8101	-12.6634	0.79
Pinus pseudostrobus	329	0.1007	0.7894	-9.9365	0.72

Moreover, model fitting was also applied for each species in both provinces irrespective of age factor. All models provided comparatively similar results (r^2). However, the Prodan model provided the best fit for the diameter-height relationship. The model parameters and r^2 values for the Prodan functions for different species are shown in table 2 and the fitted curves (within the diameter range for each species) are displayed in figures 3-8.

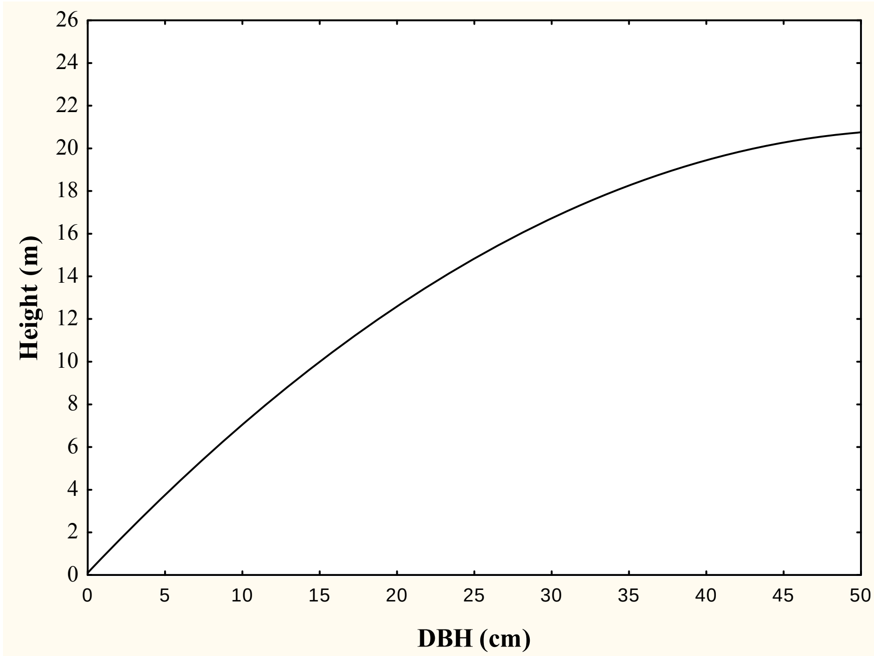

Figure: (3) Diameter-height curves of *Pinus caribaea*

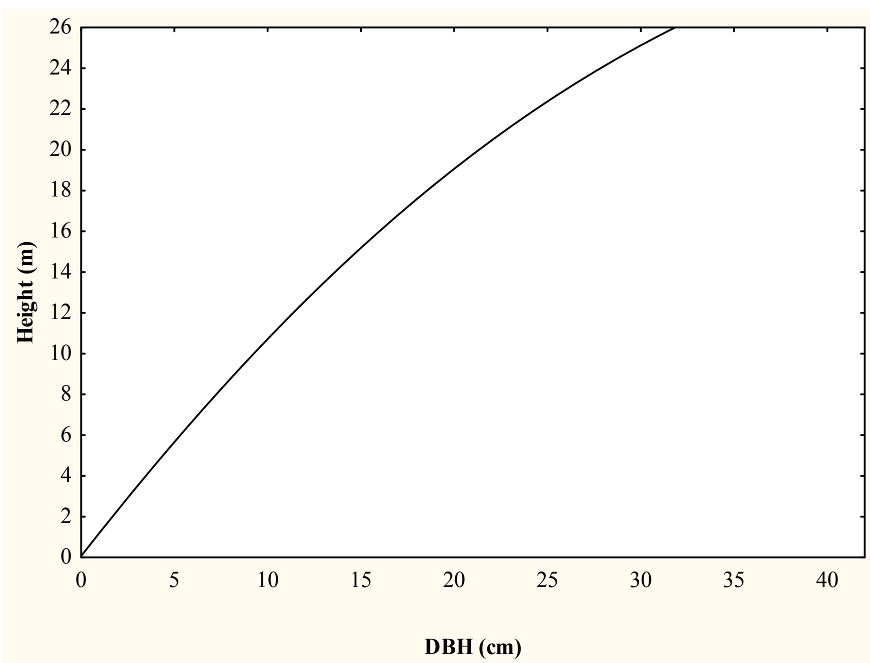

Figure: (4) Diameter-height curves of *Pinus kesiya*

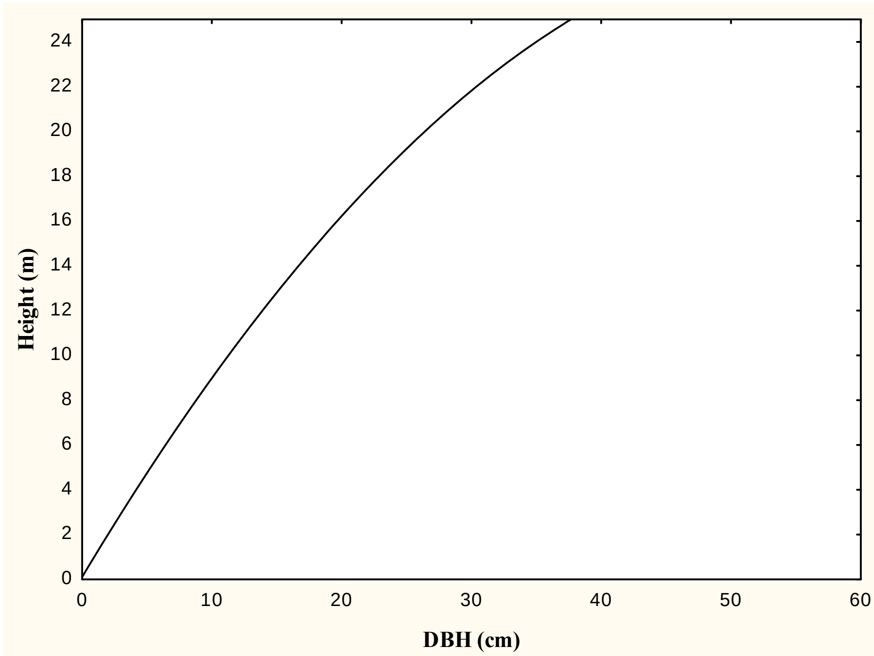

Figure: (5) Diameter-height curves of *Pinus maximinoi*

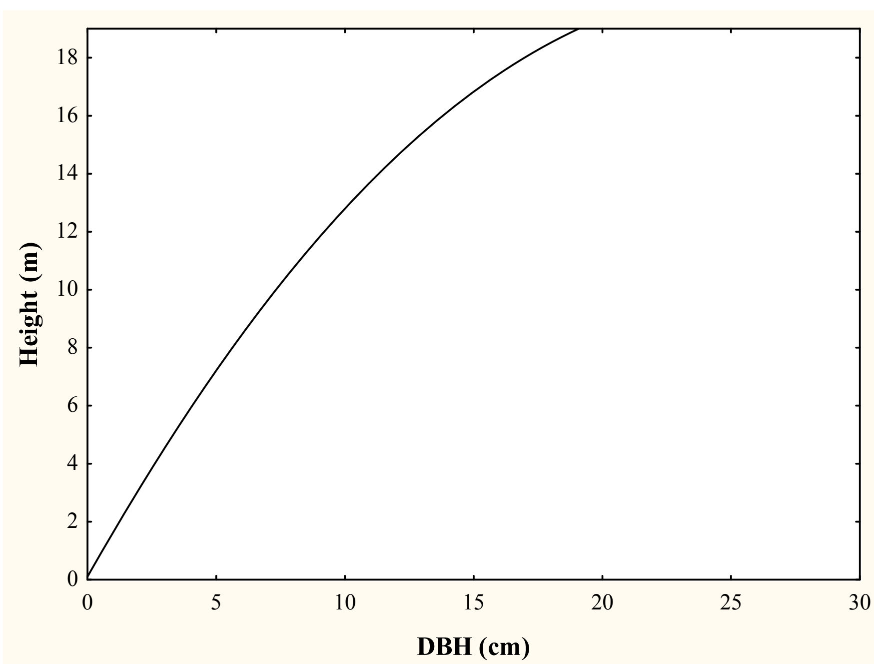

Figure: (6) Diameter-height curves of *Pinus oocarpa*

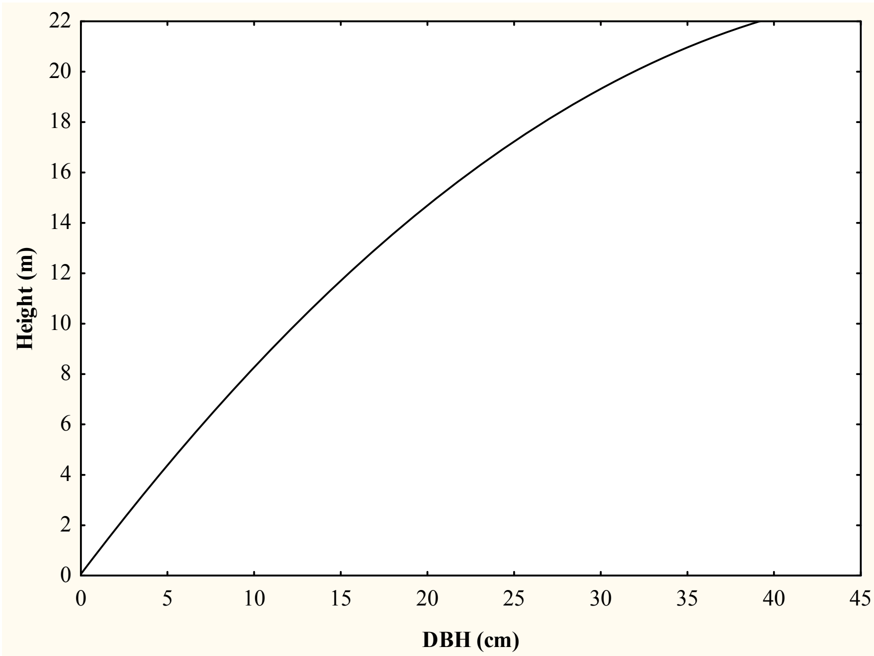

Figure: (7) Diameter-height curves of *Pinus patula*

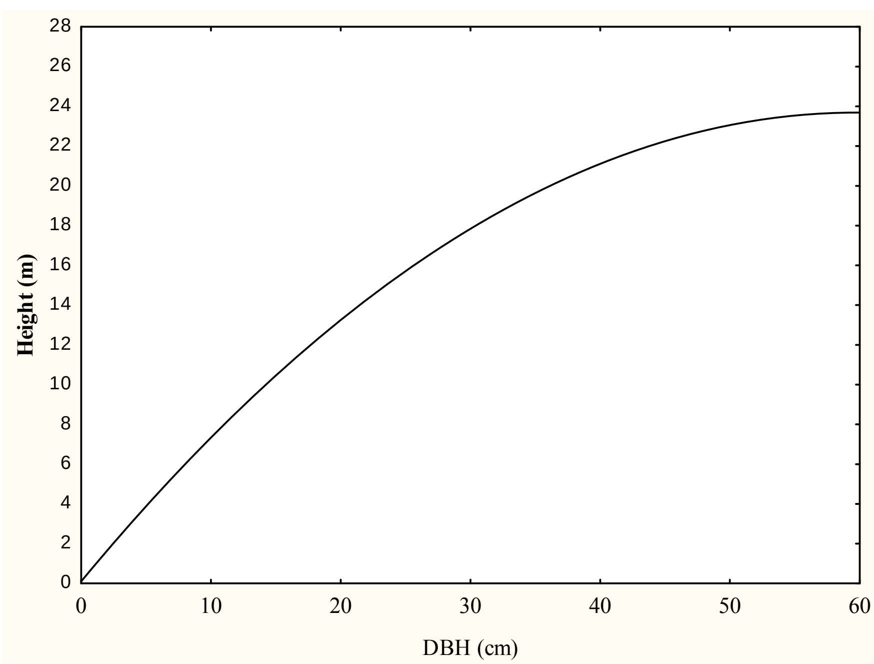

Figure: (8) Diameter-height curves of *Pinus pseudostrobus*

5. Estimated basal area of stand

Stand basal area (SBA) is simply the cross-sectional area of all trees at breast height per hectare of forest or plantation (m^2/ha). Stand basal area can be used to estimate stand volume and is a useful measure of stand density, asit is simple to measure. Stand basal area values not only depend on the number of trees, but also on the size of trees. The relationship between stand density and average tree size is important to compare different thinning regimes for industrial plantation. Von Gadow and Bredenkamp (1992) concluded that sawn timber necessitates larger diameter trees, whereas a large stand basal area is needed for pulpwood. The approximate average stand basal area in a moist evergreen forest is about 30 m2 per hectare (Weidelt, 1998). The un-thinned 67-year-oldstand of Flindersia brayleyana on basaltic soil carried a stem basal area of 78 m^2/ha (Brown et al., 2004). This is similar to the basal area recorded in the Monteverde forests of Costa Rica (Nadkarni et al., 2000), of which 70% was contributed by Flindersia brayleyana. Stand basal area may be up to 80-85 m^2/ha in a Eucalypts plantation at a productive site. The stand basal area is a 90 suitable parameter to compare un-thinned even-aged stands of a given age and site.

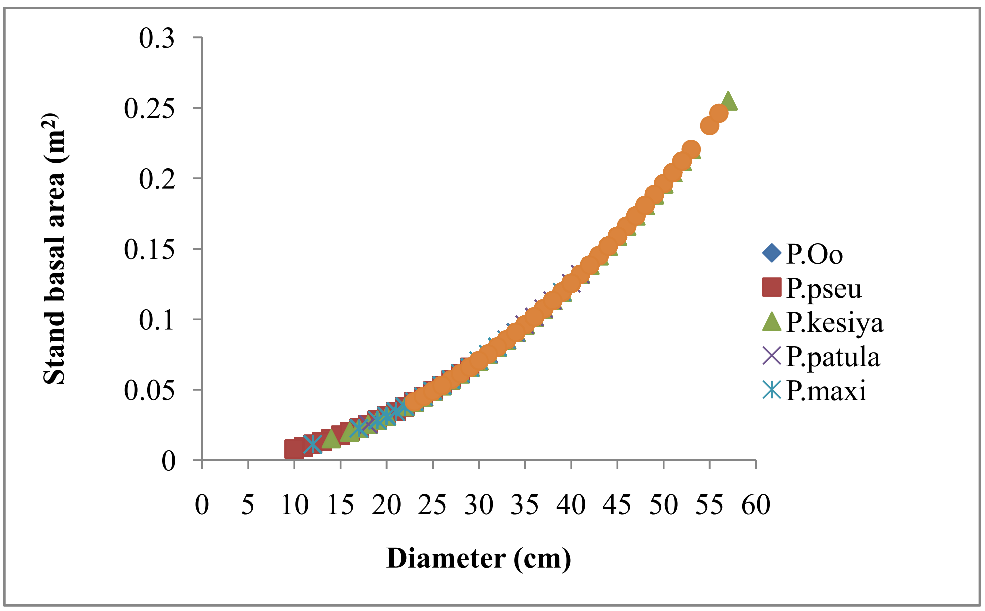

Figure (9): Mean diameter and stand basal area of selected tropical species

In this study, the minimum stand basal areas was 0.028 m^2, 0.025 m^2,0.042 m^2, 0.008 m^2, 0.0113 m^2,0.0153 m^2 and the maximum stand basal area was 0.180 m^2, 0.131 m^2, 0.246 m^2, 0.066 m^2, 0.119 m^2, 0.2550m^2 and the total basal of each stand was 25.80 m^2/ha, 22.76 m^2/ha, 40.31 m^2/ha, 10.25 m^2/ha, 18.24 m^2/ha and 36.52 m^2/ha for *Pinus caribaea, Pinus kesiya, Pinus maximinoi,Pinus oocarpa,Pinus patula, Pinus pseudostrobus.*

Figure 9 shows the basal area calculated for individual trees relative to their diameter of six tropical pine species. In most stand volume estimation models, the stand basal area plays the key role. Consequently, it is essential for the projection of potential volume to identify how one can forecast the future basal area. Hui and von Gadow (1993) developed a model that includes the stem number and top height to calculate the basal area in *Cunninghamai lanceolata* stands. A modified version of this model was applied to determine basal area in this study. This model includes the varying age and is as follows:

$$G= a^* N^{\gamma} * H_d^{\beta} * t^{\delta} \qquad \textbf{eq. (1)}$$

Where

G = Stand basal area (m2)
N = Number of stems (per ha)
H_d= Top height (m)
t = Age (years)
a, α, βandδ= Model parameters

The parameter values for equation (1) for selected species are given in table 3.

Table (3): Parameters for the estimation of the basal area of six tropical pine species

Species	A	Γ	β	Δ	r
Pinus caribaea	0.1526	-0.1026	-0.1474	0.0992	0.79
Pinus kesiya	0.0501	0.4528	-0.0789	-0.6251	0.80
Pinus maximinoi	0.2271	0.0389	-0.2889	-0.0828	0.76
Pinus oocarpa	0.1851	0.1851	-2.3741	-1.4120	0.82
Pinus patula	0.7542	0.2002	0.0721	-0.4532	0.87
Pinus pseudostrobus	0.0049	4.1601	-1.2893	-5.1613	0.89

The same model was used for different species, irrespective of site differences. Depending on the specific site or species, this model provides an estimation of the basal area of the stand. In this, *Pinus pseudostrobus* had a high r^2 of 0.89, followed by *Pinus patula* with an r^2 of 0.87 and *Pinus oocarpa* with an r^2 of 0.82. A lower r^2 value of *Pinus maximinoi* was occurred. The forest manager can easily estimate the basal area of the stands of the six tropical pine species by substituting the parameter values of table 3 in the above equation (1) if they know top height, number of stems and age of the stand.

6. Volume Production

In forestry, it is indispensable to estimate the volume of a stand based on variables measured in the field. Since volume production is usually the growth parameter of greatest interest to the forest manager, an evaluation of site productivity in terms of volume is desirable (Sammi, 1965). There are a number of practical approaches to determine stand volume. It can be calculated by means of other correlated variables such as basal area, tree height, form factor and sometimes stand age. The measurement of volume production as a guide to site productivity in plantations is used in Germany (Shrivasta and Ulrich, 1976), Sweden (Johnston et al., 1967) and Britain (Johnston and Bradley 1963, Bradley et al., 1966) as well as in a number of other countries (e.g. France, Finland, Norway). Estimates of volume production are helpful in planning when to harvest or how much to remove in a thinning operation. These estimates can also assist with financial analysis and the tax implications of a timber harvest. There are two main approaches to estimate volume production. The first one is by stem analysis, wherein calculations are derived from the segmented stems and the second one is by estimation via obtainable volume equations or volume tables.

The dbh, height and form factor are the parameters required for the basic volume estimation of a single tree. The stem mass can be stated either in volume or in weight, depending on the final product. Likewise, there are two options for measurement of tree height: total height and merchantable height. The normally used measures of stem form (form factor) are fractions of volume of a tree related to a pillar with diameter equal to tree dbh. The volume equation may be commonly written as follows:

$$V = f\,(D, H, F) \qquad \textbf{eq.(2)}$$

Where

V= Stem Volume
D= Stem diameter at breast height
H= Stem Height
f= Stem Form factor

Relationship between single tree volume and basal area

The relationship between volume and basal area enables the estimation of individual tree volume by measuring only the dbh (basal area). It is impossible to assess all variables for every tree in each sample plot due to the limitation of time and money. In both natural forests and plantations, dbh measurements can be attained at low cost. It is difficult to measure the heights of large dense stands. In forest management, dbh measurement is a regular practice, particularly in plantations. The allometric regression was applied to fit the following equation for selected species.

$$V = \gamma * G^{\beta} \qquad \textbf{eq. (3)}$$

Where

V= Individual tree volume, up to top diameter 5 cm (m^3)

G= Individual tree basal area (m^2)

γ and β = Intercept and regression coefficient

The relationship between volume and basal area of individual trees using equation 3 are shown in figures 10-15 and the parameters are given in table 4. The relationship between individual tree basal area and respective volume for all the species proved to be observed strong. *Pinus maximinoi and Pinus pseudostrobus* appear to be the best volume manufacturers compared to others four species.

Table (4): Parameter values for the relationship between volume and basal area of individual trees

Species	γ	**B**	**R**
Pinus caribaea	15.5459	1.2069	0.92
Pinus kesiya	11.5356	1.1185	0.89
Pinus maximinoi	16.7669	1.1805	0.97
Pinus oocarpa	10.1813	1.0836	0.94
Pinus patula	16.0163	1.2375	0.96
Pinus pseudostrobus	15.4482	1.1623	0.98

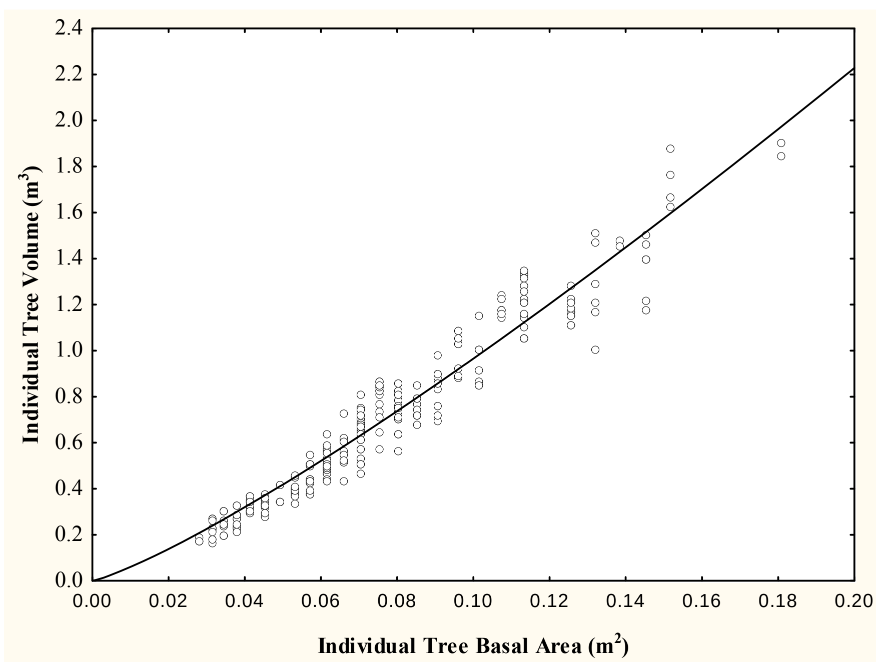

Figure (10) The relationship between volume and basal area of *Pinus caribaea*

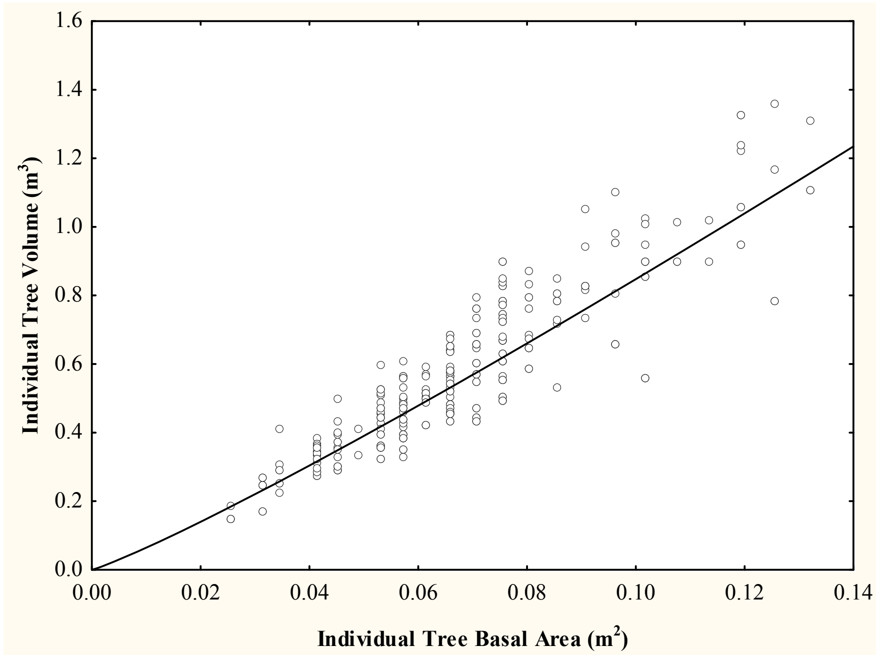

Figure (11) The relationship between volume and basal area of *Pinus kesiya*

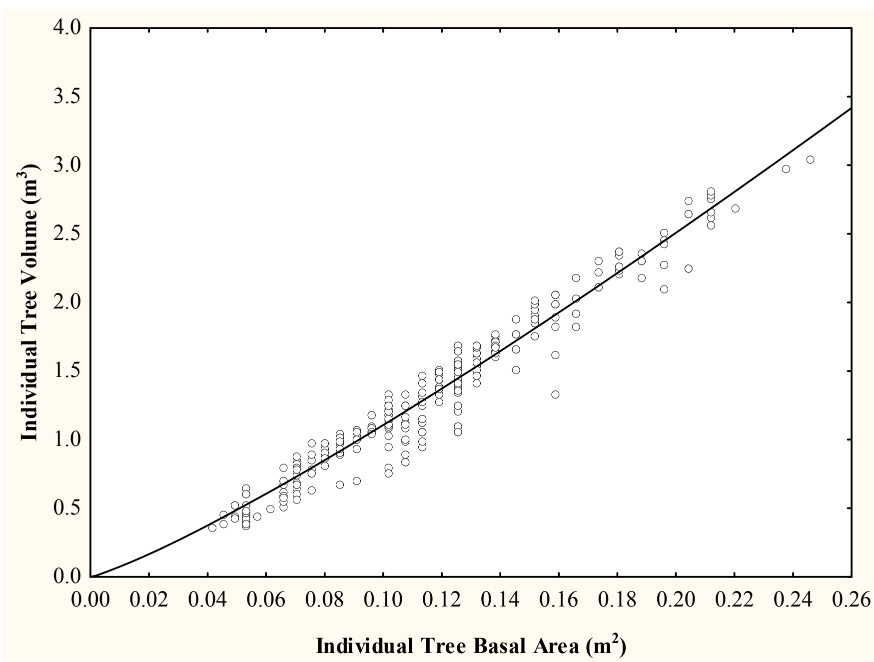

Figure (12) The relationship between volume and basal area of *Pinus maximinoi*

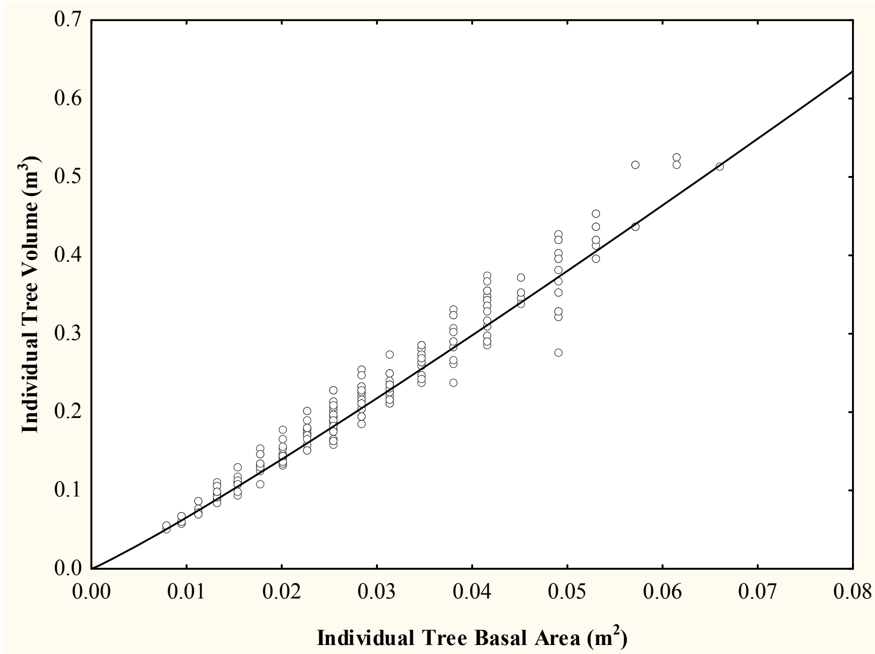

Figure (13) The relationship between volume and basal area of *Pinus oocarpa*

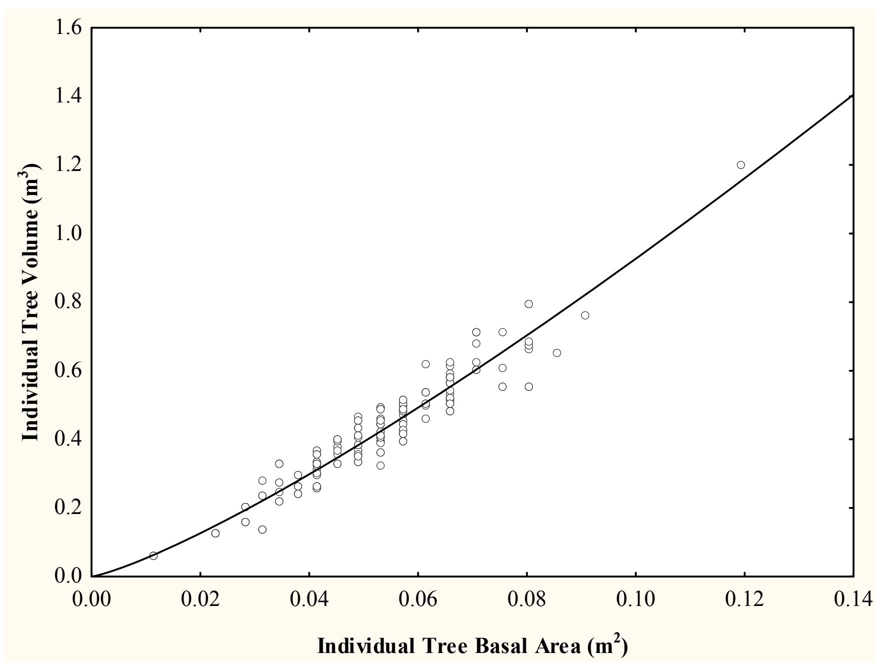

Figure (14) The relationship between volume and basal area of *Pinus patula*

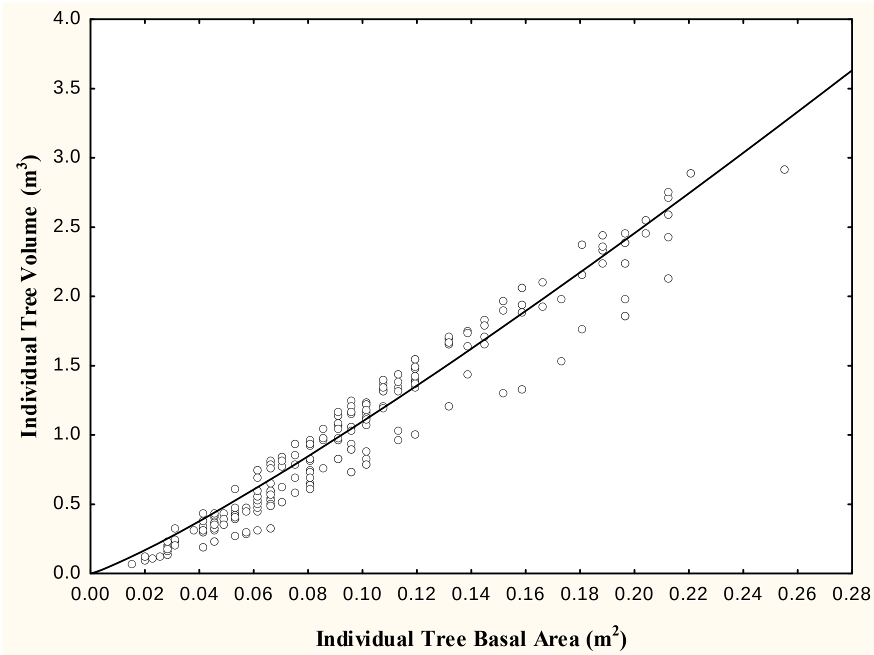

Figure (15) The relationship between volume and basal area of *Pinus pseudostrobus*

Pinus pseudostrobus appears to be the greater volume producer in contrast to other species, and then followed by *Pinus maximinoi*. *Pinus kesiya* shows poor volume production. The fitted lines for each species were extrapolated only within the observed individual tree basal area (dbh). That is, there was no extrapolation in figures.

Mean Annual Increment

Helms (1998) defined mean annual increment (MAI) as the entire increment of a tree or stand up to a known age divided by that age. In keeping with this, Maximum MAI values varied among the species. *Pinus maximinoi* had the highest maximum MAI of 16.05 m^3/ha, followed by *Pinus pseudostrobus* at 13.57 m^3/ha, the lowest maximum MAI value for *Pinus patula* of 5.03 m^3/ha, and *Pinus oocarpa* of 2.70 m^3/ha.

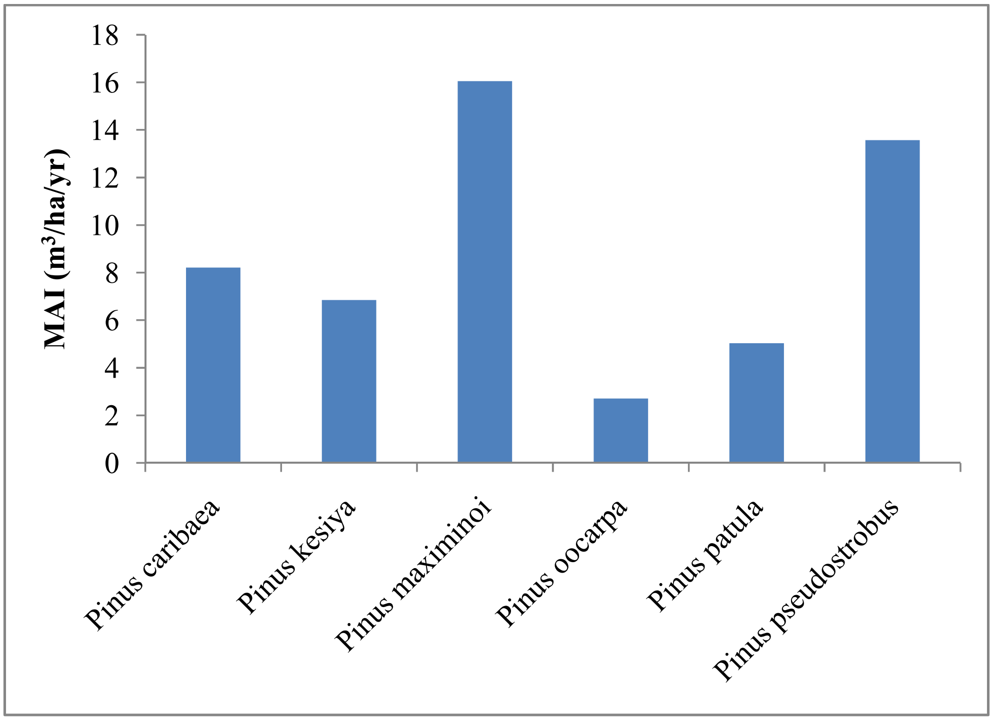

Figure (16) The mean annual increment of six tropical exotic pine species

7. Conclusions and Recommendations

(1) For the diameter-height relationship, Prodan function gave the fit for the six tropical exotic species and *Pinus maximinoi* showed very good height growth compared to other five tropical exotic pine species.

(2) Going to the volume and basal area, the allometric regression was applied. The regression was carried out for different species separately. The best productivity bearer among the six tropical exotic pine species was *Pinus maximinoi and Pinus pseudostrobus.* The biggest basal area was in *Pinus maximinoi* with 40.31 m^2/ha and *Pinus pseudostrobus* with 36.52 m^2/ha.

(3) Maximum MAI values varied among the species. *Pinus maximinoi* had the highest maximum MAI of 16.05 m^3/ha and the lowest maximum MAI value for *Pinus oocarpa* of 2.70 m^3/ha.

(4) More research should also be carried out for the proper development of the exotic tropical pine plantations. And also the comparative study of the exotic and native pine species in Myanmar should also be conducted.

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