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Original article

Evaluating Inter-row Light Intensity and Root Distribution of a *Hevea brasiliensis* (Kunth) Müll. Arg. Plantation in Chiang Rai Province for Selective Planting of Inter-row Trees

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ABSTRACT

This study investigates the differences in light intensity between pararubber rows and the root distribution of pararubber (*Hevea brasiliensis* (Kunth) Müll. Arg.) (RRIM600), in order to select suitable trees to plant between the rows of pararubber. The study was carried out in a monoculture pararubber plantation in Chiang Rai Province, with tree age ranging 1-10 years and a spacing of 3 m × 7 m Light intensity varying from 60 - 85%, was found in pararubber aged 1-3 years old, and continuously decreasing to 10 - 20% after the age of 6 years. Root distribution also varied with age and was affected by the direction from the stem and was the highest in East - West side of the tree at age 5 years old. Root dry biomass was the highest in the age of 5-6 years old. Root dry biomass showed a positive correlation with the canopy area (r = 0.70). There was no difference in root distribution along the 3 m distance away from the base indicating of uniformly distributed root over the distance. Selection of inter-row species should be based on the variation in light intensity and root distribution of pararubber. We suggest planting any species between rows when the pararubber trees are 1-3 years old because at this stage, pararubber roots are not fully developed and also with a high light intensity. Caution should be taken when pararubber trees are between 4-7 years old, due to the highest growth along with a more developed canopy area and root system of the pararubber. After age 7, shade tolerant species are recommended due to very low light intensity in the inter-rows and that the growth and root system of pararubber are fully developed.

Keywords: Pararubber, light intensity, dry root biomass, shade tolerant species, inter-row species

INTRODUCTION

Pararubber (*Hevea brasiliensis* (A. Juss) Muell.Arg) plantations in Thailand have increased by 22% during the period of 2007 to 2010 (Rubber Research Institute, 2012), with the largest areas existing in the Southern (66.05%), followed by the North Eastern (20.26%), Eastern and Central (11.43%), and

North (5.26%)(Office of agricultural economics, 2016). Generally, pararubber plantations are restricted only to the Southern parts and some area in the Eastern provinces of Thailand, due to limiting factors including topography (slope < 35%), high rainfall (1,250 mm/year), temperature (26 - 30 °C), and soil properties for growth (loamy clay or sandy loam) (Rubber Research Institute, 2010). However, pararubber plantations are currently found in other parts of the country, especially in Northern Thailand, where monoculture at high elevations with steep slope, is commonly practiced (Rubber Thai, 2007). Agroforestry systems are proposed as a mean to sustainably enhance soil properties with multilevel roots. As such, growing plants with annual crops, such as a cover crop or other trees, will prevent the soil from erosion which is the problem with monoculture (Gotz *et al*., 2004) such as soil erosion, landslide and water toxicity from heavy fertilizer application, occur (Petmak *et al*., 2014). Example of such effects took place on May, 2006, with landslides in Tombon MaePoon Amphoe Laplae, Uttaradit province (Santi and Suttisak, 2012), in Amphoe Lom Sak, Phetchabun province on August, 2011 and Amphoe Pan, Chiang Rai province on May, 2014. These incidents have caused damage on asset, residence and people's lives (Likhit, 2014).

Agroforestry is a concept of planting inter-row species in the plantation to increase the utilization of an area. It can be used to ameliorate erosion, primarily through surface litter cover and organic matter and diversity (Subhrendu and Evan, 1996). Root systems in forests tend to sustain soil and water with more tension when compared to monoculture or plantation (Nilaweera and Nutalaya, 1999; Schmidt *et al.*, 2001), as different root depths improve soil texture and cohesion, making it much stronger than soil with a monoculture root system (Payaksiri *et al*., 2014). However, inter-row species have to grow under the shade of pararubber canopy and must not inhibit the growth of pararubber. Previous studies suggested some inter-row species that can be planted with pararubber with no effect on growth and latex production of pararubber, such as jackfruit with the 5-year-old plantation of BPM24 in Nakhon Si Thammarat province (Parechana and Sukkua, 1998A). Root distribution of pararubber needs to be assessed in order to select suitable inter-row species. Many studies have investigated the root distribution with different methods but only a few studies have performed such analyses in a series of plant ages. Sadudee and Jiso (2008) studied the root distribution of 12-year-old RRIM600 at 0 - 100 cm soil depth using minirhizotron technique and found that root distribution decreased when soil moisture reduced. Nuansee *et al*. (1992) used nuclear techniques with roots of the 4 - 5 year old, in Songkhla and Krabi province, and found that the root distribution was dense at depths of 0 - 15 cm and at a distance of 1 m from the trunk. Nevertheless, most studies focusing on the inter-row light intensity and root distribution of pararubber were conducted in the Southern part of Thailand, while such information from the Northern part is still lacking.

In this study, we aimed at building a data base for pararubber in the North of Thailand whose environments are different when compared to those in the Southern Thailand. A measure of inter-row light intensity and the information about root distributions of pararubber are needed in order to establish criteria for inter-row species selection in the

Northern part of Thailand. The objectives of this study was therefore to investigate the light intensity and root distribution in between the 1 - 10 year old pararubber rows in Tombon Chiangkian, Amphoe Thoeng, Chaing Rai Province.

MATERIALS AND METHODS

Study site

The study area was a monocultural pararubber plantation in Tombon Chiangkian Amphoe Thoeng, ChiangRai Province (5°17'6.823''N, 113°54'23.503''E), with the size of about 1.41 km^2. (Figure 1). The climate is monsoonal with 3 seasons - summer (February - May), monsoon (June - October), and winter (November - January). During the study period, the annual rainfall averaged at around 1,627 mm The average annual temperature and relative humidity were between 19 - 28 °C and 66 - 84%, respectively. The genetic variety of pararubber in the study area was RRIM600, which was planted at a spacing of 3 m × 7 m trees between the ages of 1 to 10 years were randomly selected for the study. The study was conducted during March to August, 2014, when the pararubber canopy was completely green, after leaf flush during January February period.

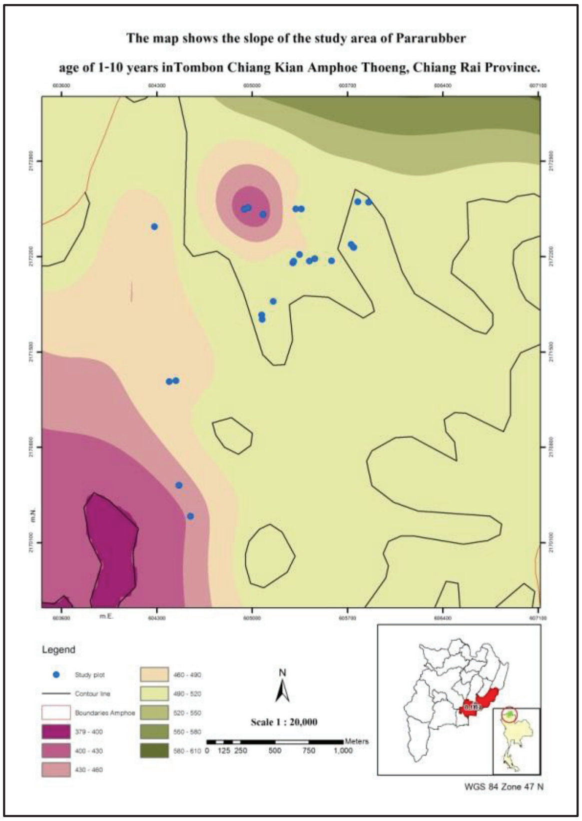

Figure 1 Map showing slope of the Pararubber plantation with 1 - 10 year-old trees within a study area of about 1.41 km^2, in Tombon Chiang kian Amphoe Thoeng, Chiang Rai Province.

Measurements

1. Light intensity

Automated light intensity sensors (Model HOBO UA-002-64, Pendant Temp/Light, 64 K, Onset Computer Corporation, Bourne, MA, USA) were installed on the top of the canopy (2 sensors) and in between rows of pararubber trees (2 sensors), of 3 individual pararubber trees, between the ages of 1 to 10 years (Figure 2). This procedure was repeated at 3 locations which were to be treated as replicates. The sensors were set to collect data at every 10 seconds for 3 days. To eliminate possible confounding effect from light variation during each day, the light intensity was expressed as percentage of the amount of light on the inter-row area to the amount of light at the top of the canopy. This light measurement would be referred to as "inter-row light intensity" (I_{row}) hereafter. I_{row} measurements were conducted from 6 am to 6 pm and averaged to a final value for trees of each age.

For each individual pararubber trees, the diameter at breast height (DBH; measured at 1.3 m from the base) was determined using a measuring tape, while the total height was estimated by trigonometric methods (West, 2009). The canopy area was measured by averaging North - South and East - West radius of the canopy using equation; canopy area = πr^2 (m^2). A relationship between the I_{row} and canopy area was then determined using a linear regression in order to investigate the simple and direct relationship between two parameter.

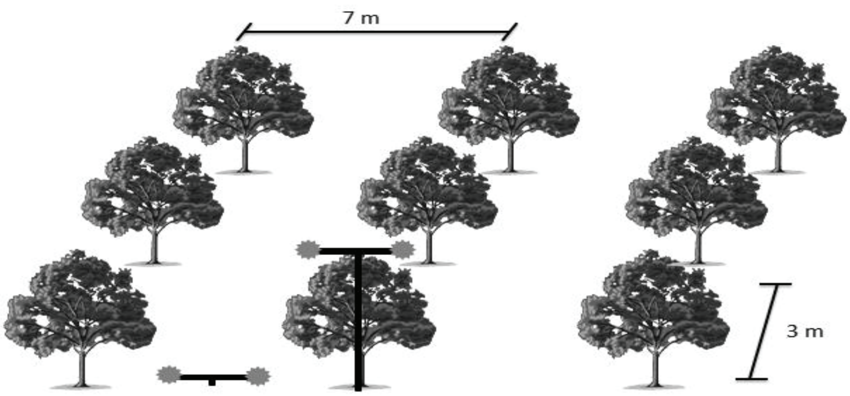

Figure 2 Light sensors establishment at each pararubber tree for measuring the percent of light at inter-row area when compared to light at the canopy (inter-row light intensity (I_{row})) (N = 54, 2 sensors × 3 individual tree × 3 days × 3 locations).

This study was based on completely randomized block design with 3 replications (each locations as a separate block). Analysis of variance (ANOVA) among the 10 age levels was tested and a mean comparison was done with Duncan's Multiple Range method, at a significant level < 0.05, to differentiate among the means of I_{row}, DBH, height and canopy area at various ages (1 to 10 years).

2. Root distribution

Root distribution was measured using the dry root biomass technique. As Chukomneon *et al.* (1998) reported that the pararubber roots are distributed mostly from soil surface up to a depth of 15 cm, we therefore determined the dry root biomass by excavating a plot sized 20 cm × 20 cm with 20 cm depth. Three individual trees were randomly measured at each age level. For each plant, 24 plots were excavated in 4 directions (North, South, East and West) and at 50 cm interval of 3 m in distance from the base as shown in Figure 3. In each plot, all roots with diameter < 0.3 cm were collected because this fine root with high surface area work on water and mineral uptake (Tagliavini *et al*., 1993) which in turn, directly affects the growth of pararubber. After cleaning the roots with running water to remove the loose soil, samples were oven-dried at 80 °C for 48 hours and their dry weight was measured to obtain the dry root biomass. The dry root biomass study was based on a 3-way factorial with completely randomized design (CRD), with the main factors being the age (10 levels), direction (4 levels), and distance from the base (6 levels). Differences between the interactions and main factors were tested using ANOVA and mean comparison was done using Duncan's Multiple Range, at a significant level < 0.05.

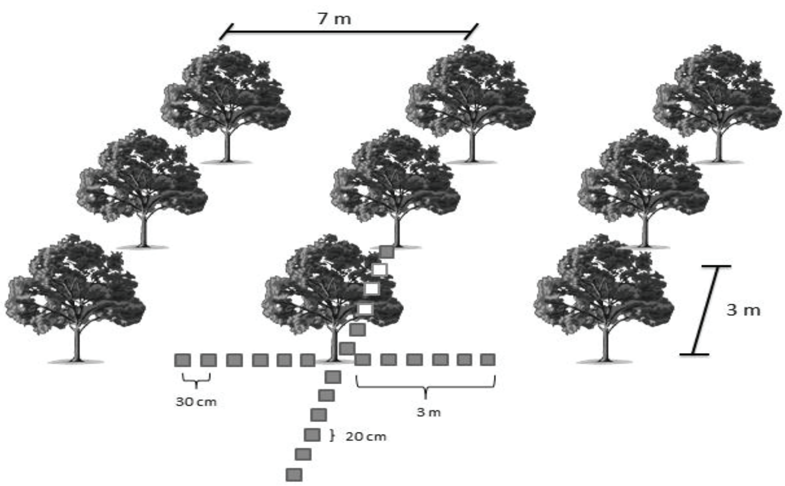

Figure 3 Setup for the measurement of dry root biomass at each plot sized 20 x 20 x 20 cm and away from the tree base in 4 directions (North, South, East, and West), at 50 cm interval and up to 3 m in each direction.

Soil in each subplots were collected to measure the soil moisture content using the gravimetric method. Soil samples were measure for the wet weight and then oven-dried at 110 °C for 48 hours and dry weight was recorded. Soil moisture was calculated as

$$\frac{\text{(wet weight - dry weight)}}{\text{dry weight}} \times 100$$

Finally, relationships between dry root biomass and the canopy area, dry root biomass and soil moisture, and soil moisture and I_{row} were determined using the linear regression.

RESULTS AND DISCUSSION

Agroforestry not only improve farmer's economic situation, but also increases the plant diversity in the area, enhancing the soil vitality and preserving water resources (Howard and Ramachandran, 1987; Nuberg *et al*., 2009 and Trat Agroforestry Research, 1998). In areas with high elevation and steep slope as in the Northern part of Thailand, soil erosion occurs naturally. It is estimated that forest cover can decrease soil erosion by more than 60% when compared to land void of vegetation (Sohan *et al*., 2013).

Inter-row species selection to be introduced into the plantation area should be based on certain criteria, including shade tolerance and no interference with the productivity of the plantation, which is the amount of latex in this case (Kangpissadan *et al*., 2004). This study found that the I_{row} decreases as pararubber age increases (Figure 4) which agrees with the farmers' long-term observation. However, our results offered quantitative assessment of the amount of light intensity between the pararubber rows in actual field conditions which can be used further as a benchmark for inter-row selection with pararubber plantations.

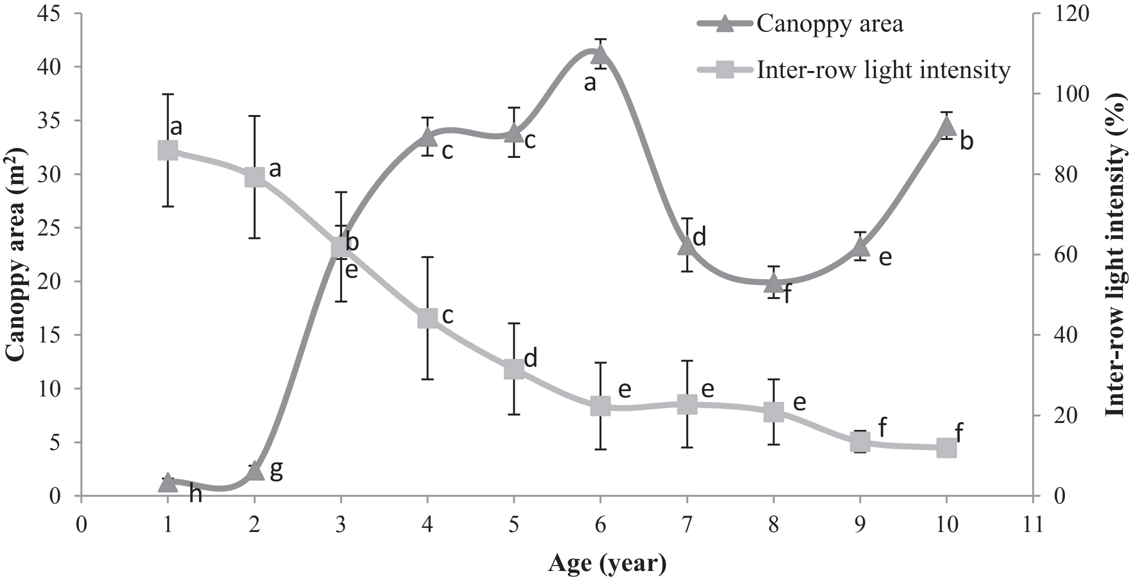

Figure 4 Relationship between inter-row light intensity (I_{row})(line with squares) and the canopy area (line with triangles) with the age of pararubber trees. Different lower case letters above each marker indicate the statistical difference among ages at the significant level of $p < 0.05$.

Growth comparison of pararubber trees at the ages of 1 - 10 years indicated that the biggest stem was of the 10-year-old trees, while the tallest canopy was of the 7-year-old ones. The 6-year-old trees had the highest canopy area as shown in Table 1. Pararubber canopy area has been reported to increase with age (Wilson and Ludlow, 1990), but our results showed that the reduction in canopy area occurred when trees were older than 6 years old (Figure 4, triangles). In the study area, the crown cover is pruned for latex harvest preparation at the age of 7 years causing lower canopy area but I_{row} not increase because the pruned branches were dry and they were pruned only at the lower part of the plant. The upper green branches of the canopy were not been removed because the aim of pruning is for fire prevention and also for the convenience of farmer when collecting the latex. That is why the I_{row} of 6 - 8 years old did not show any difference. Theerawatanasuk and Lekawiwat, (2011) also reported that during ages of 1 - 6 years , the diameter of pararubber trees BPM408, PB260, RRIM600, and Sathabanwijaiyang 408 increased continuously, but at 7 years old, the growing slowed down because energy from photosynthetsis is used for producing latex more than spending on growth. The difference in stem diameter can be due to the difference of soil types and nutrients (Bangjan and Yingchatchavan, 2006).

Table 1 Height, diameter at breast height (DBH), and canopy area of Pararubber for plants aged 1 - 10 years old.

Age (year)	Height (m)	Diameter at breast height (cm)	Canopy area (m^2)
1	3.56±0.16[i]	2.72±0.08[j]	1.30±0.31[f]
2	3.77±0.09[h]	3.02±0.06[c]	2.40±040.[e]
3	5.73±0.15[g]	5.90±0.47[h]	23.64±1.56[c]
4	6.6±0.10[f]	9.59±0.30[g]	33.50±1.77[b]
5	9.41±0.30[e]	10.35±0.45[f]	33.90±2.30[b]
6	15.02±0.60[b]	12.01±0.50[e]	**41.22±1.36[a]**
7	**15.25±0.20[a]**	19.06±0.82[b]	23.40±2.80[c]
8	13.04±0.41[d]	14.42±0.47[d]	19.91±1.47[d]
9	14.69±0.33[c]	16.99±0.39[c]	23.27±1.31[c]
10	15.00±0.11[b]	**22.88±0.67[a]**	34.53±1.26[b]

Note: Different superscript lower case letters in each column indicate the statistical difference at the level of $p < 0.05$, bold numbers indicate the highest value in a column with one standard deviation.

Light intensity around the inter-row area decreased as age increased because of larger leaf surface area leading to increased shading between trees. The highest I_{row} was at age 1 - 2 years old. I_{row} rapidly dropped when pararubber plants were between 3 - 6 years old (from 80% to 20% as indicated in Figure 4) and remained constant thereafter at a low intensity (10 - 20%) (Figure 4), which translated to a low I_{row}. Our results of light intensity variations across age confirmed with previous studies showing that the light intensity between rows decreased to about 20% after 5 years old until 25 years old in RRIM600 planted with 3 m × 7 m spacing in Indonesia (Wilson and Ludlow, 1990) and 20% for 9-year-old BPM24 planted with 2.5 m × 8 m spacing in the Southern Thailand (Parechana *et al*., 1998B)

While the aboveground growth reached maximum at age 7 years base on the measurement in this study, the dry root biomass was the greatest at age 5 years. Dry root biomass was not different from the base up to 3 m away from the trunk indicating from the p-value of ANOVA (Table 2). of 0.1923 which explained the uniform distribution of pararubber root. Similar results had been reported with RRIM600 pararubber at 3 m × 7 m spacing in the Narathiwat Province with no difference in the root distributions at 0.5 m - 2.5 m away from the base (Chukomneon *et al*., 1998). The dry root biomass in the East-West direction at age 5 showed a higher, while for the other ages, there was no significant difference in each directions (Figure 5). This could be due to the variation in the planting layout of trees of various ages. At age 5, East-West direction of the trees was toward the 3 m spacing and the North-South direction faced the 7 m spacing, which may affect the amount of dry root biomass in present study because as the 3 m spacing, roots of another tree might interfere with the measured one. In summary, roots of pararubber uniformly distributed between the rows which would have less effect on inter-row species selection while the I_{row} would play an important role on the suitable species selection.

Table 2 Three ways factorial analysis for dry root biomass (g) of pararubber trees aged 1 - 10 years old in 4 directions (North, East, South, West), and at 6 different distances away from base (0, 50, 100, 150, 200, 250, and 300 cm away from the root base).

Source	DF	Type III SS	Mean Square	F Value	Pr> F
Age	9	574.562	63.840	86.2	<.0001**
Direction	3	3.521	1.173	1.59	0.1923
Age*Direction	27	78.618	2.911	3.93	<.0001**
Distance	5	7.391	1.478	2	0.0781
Age*Distance	45	40.221	0.893	1.21	0.1763
Direction*Distance	15	8.373	0.558	0.75	0.7290
Age*Direction*Distance	131	104.012	0.793	1.07	0.3009

Note: **The significance of mean difference at the level of $p < 0.05$.

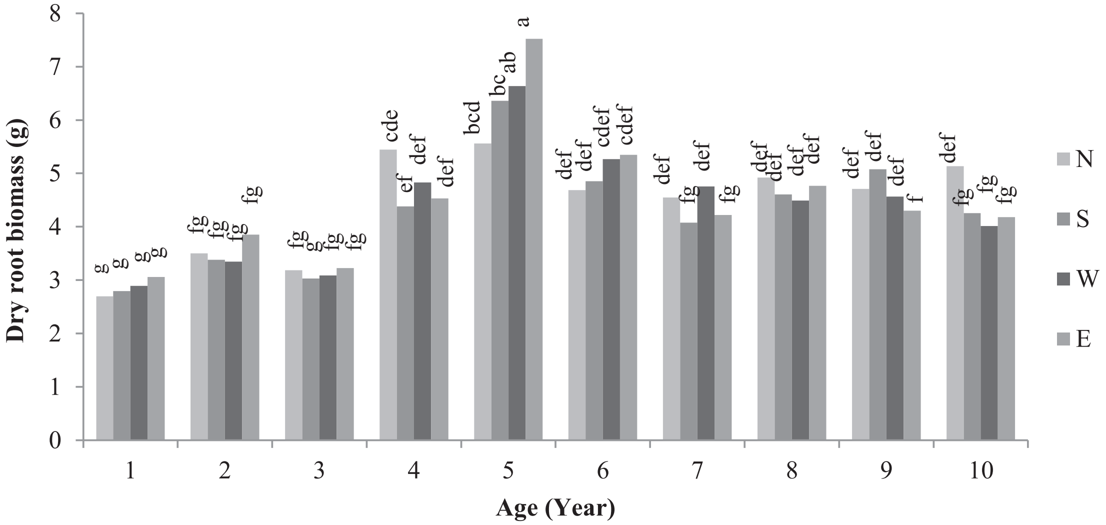

Figure 5 Dry root biomass interaction between pararubber plants of ages 1 - 10 years old and directions (North (N), South (S), West (W), East (E)). Lower case letters indicate the statistical difference among interactions at $P < 0.05$.

There are some wood species that has been reported to grow under pararubber canopy in Thailand *Azardirachta excels* (Jack) Jacobs*., Hopea odorata* Roxb., *Bamboo spp*., *Cotylelobium melanoxylon* (Hook.f.) Pierre, *Xylia xylocarpa* (Roxb.), *Shorea roxburghii* G.Don, *Dipterocarpus alatus* Roxb. (Kasetkamtamachat, 2011), and *Acacia mangium* (Dansakunpon *et al*., 1998). However, there were no report on how much I_{row} when those species were planted under pararubber canopy. Further study should be focused in I_{row} and shade tolerant species in the field study.

Dry root biomass tended to increase with canopy area ($R^2 = 0.408$, p-value < 0.05) (Figure 6). This result was similar to a study of the canopy area and root development of Olive trees (Chiraz, 2013), which a high positive relationship ($R^2 = 0.94$) was reported. However, dry root biomass tended to have no correlation with soil moisture ($R^2 = 0.06$, p-value = 0.0047) (Figure 7). Rain events during the field collection (2 - 3 times per week) might with the results leading the insignificant relationship in Figure 7.

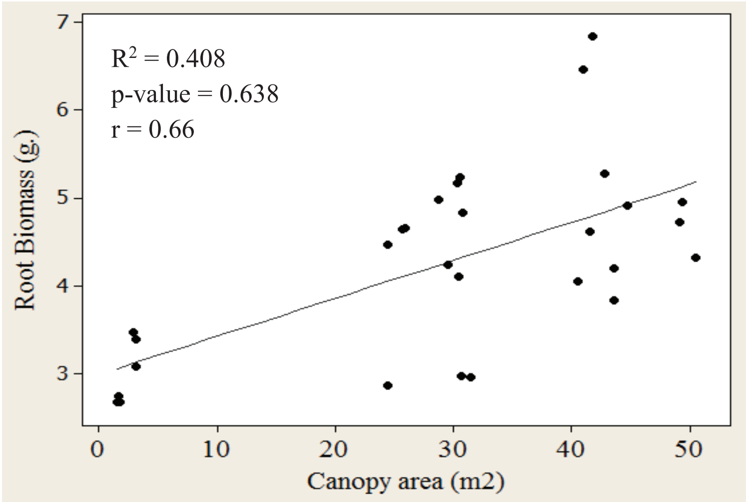

Figure 6 Relationship between the canopy area and dry root biomass in pararubber plantation for trees aged 1 - 10 years old. The correlation coefficient indicates a positive relationship (R^2 = 0.41), which means that when the canopy area increases the dry root biomass also tends to increase.

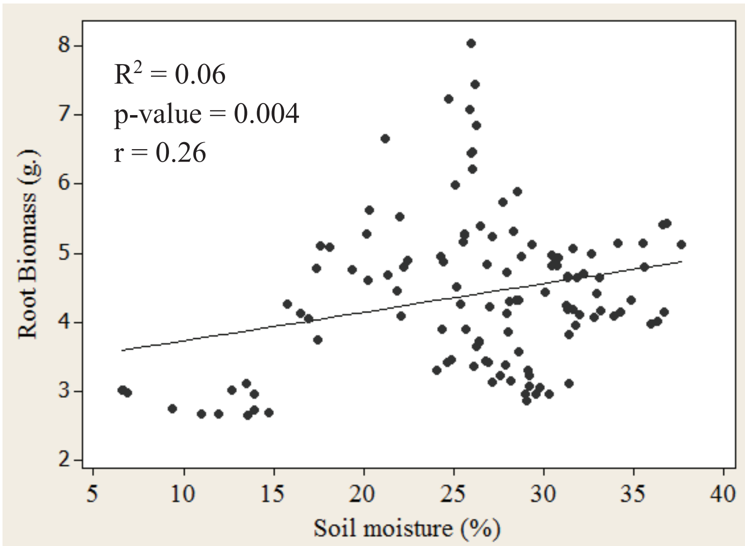

Figure 7 Scatter plot between the soil moisture content and the dry root biomass in pararubber plantation for plants aged 1 - 10 years old. The correlation indicates a positive but weak relationship (R^2 = 0.06), because in sometime collected is rainy day so high moisture.

CONCLUSION

Agroforestry in pararbber plantation in the Northern part of Thailand are considered necessary in order to conserve soil and water in the area. Inter-row species selection should be based on the amount of light between the pararubber rows and no interference with pararubber roots. In this study, the inter-row light intensity was high when the pararubber trees were young (1 - 3 years old) ranging from 60 - 85% of the light above canopy and declining after 6 years of age. Dry root biomass was the highest in the 5 - 6 years old pararubbers which was positively related to canopy area.

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