Litter Fall and Rubber Leaf Decomposition in Rubber Agroforest and Monoculture Rubber Plantation in Southern Thailand

Rinmanat Waiyarat

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Ecology (International Program)
Prince of Songkla University
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I hereby certify that this work has not been accepted in substance for any degree, and is not being currently submitted in candidature for any degree.

....Signature
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Candidate

ชื่อวิทยานิพนธ์ การร่วงหล่นของซากพืชและการย่อยสลายของใบยางพาราในสวนยางพาราแบบวนเกษตรและสวนยางพาราเชิงเดี่ยวในพื้นที่ภาคใต้ของประเทศไทย
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บทคัดย่อ

การปลูกยางพาราแบบเชิงเดี่ยวมีผลทำให้มีการเปลี่ยนแปลงพื้นที่ป่าให้เป็นพื้นที่การเกษตร โดยเฉพาะในแถบเอเชียตะวันออกเฉียงใต้และประเทศจีน โดยการปลูกพืชแบบเชิงเดี่ยวอย่างเข้มข้น ส่งผลกระทบต่อระบบนิเวศในแง่ของการหมุนเวียนของธาตุอาหาร กระบวนการย่อยสลายของซากพืช ขณะที่คาดกันว่าสวนยางแบบวนเกษตร จะมีความสมดุลของธาตุอาหารมากกว่า การศึกษาครั้งนี้จึงมีจุดประสงค์เพื่อเปรียบเทียบปริมาณการร่วงของซากพืชและการอัตราการย่อยสลายของใบยางพารา ในสวนยางพาราแบบวนเกษตรและสวนยางพาราแบบเชิงเดี่ยวอายุ 20 ปี จำนวนสามคู่ในพื้นที่ภาคใต้ของประเทศไทยเป็นระยะเวลาหนึ่งปี จากการศึกษาพบว่าปริมาณซากพืชที่ร่วงหล่น ในสวนยางพาราแบบวนเกษตร (พืชที่ปลูกแซมในพื้นที่สวนยางพาราแบบวนเกษตร อายุ 7-13 ปี และมีความหนานแน่น 400-1200 ต้น/เฮกตาร์) มากกว่าเมื่อเทียบกับสวนยางพาราแบบเชิงเดี่ยวในทุกเดือน ทำให้มีปริมาณซากพืชรวมในสวนยางพาราแบบวนเกษตรมากกว่าสวนยางพาราเชิงเดี่ยวร้อยละ 50 ซากพืชมีการร่วงหล่นมากในช่วงฤดูแล้งในทุกพื้นที่ศึกษา พบความผันแปรเชิงเวลาของการร่วงหล่นของซากพืชระหว่างพื้นที่ภาคใต้ฝั่งตะวันออกและตะวันตก การศึกษาการย่อยสลายของใบยางพารา พบว่าใบยางพาราในสวนยางพาราแบบวนเกษตรย่อยสลายได้เร็วกว่าสวนยางพาราแบบเชิงเดี่ยวอย่างมีนัยสำคัญ และมีอัตราการย่อยสลายในฤดูแล้งต่ำเมื่อเทียบกับฤดูฝนในสวนยางพาราทั้งสองแบบ อัตราการย่อยสลายซากพืชในสวนยางพาราแบบวนเกษตรสูงกว่าสวนยางพาราแบบเชิงเดี่ยว เนื่องจากการมีค่าความชื้นสัมพัทธ์ในระบบที่สูงกว่า ซึ่งเป็นผลมาจากการมีจำนวนชั้นเรือนยอด เปอร์เซ็นต์การปกคลุมเรือนยอด และการมีความหลากหลายของซากพืชมากกว่าสวนยางพาราแบบเชิงเดี่ยว ดังนั้นการมีโครงสร้างที่ซับซ้อนของสวนยางพาราแบบวนเกษตรจึงสนับสนุนการหมุนเวียนของธาตุอาหารในระบบมากกว่าสวนยางพาราแบบเชิงเดี่ยว

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ABSTRACT

Rubber monoculture recently replaces large tracts of tropical rain forests in South East Asia and China. Such intensive tree monoculture farming can largely impact to ecosystem in terms of nutrient cycling through impairing litter production and decomposition process. Alternatively, rubber agroforest is theoretically proposed to be more nutrient balance. This study investigated litter production and rubber-leaf litter decomposition rates between three paired of 20 years old rubber agroforest and rubber monoculture in southern Thailand for one year. There was more litter in rubber agroforest in every month compared to rubber monoculture. Intercropping trees (7-13 years old with density of 400-1200 tree/ha) provide 50 percent more leaf litter to rubber agroforest. More litter production in dry season in both habitats. Geographical variation in peak of litter production between east and west of Thailand peninsular is recognized. Rubber leave litter in rubber agroforest decomposed significantly faster than in rubber monoculture. Litter decomposition rate also much lower in dry season compared to rainy season both in rubber agroforest and rubber monoculture. The higher decomposition rates in rubber agroforests is driven by higher relative humidity resulted from more canopy layers, more cover percentage and mixture of litter. Complex structure of rubber agroforest can thus support functional nutrient cycling.

ACKNOWLEDGEMENT

This work was funded by Thailand Development and Promotion of Science and Technology (DPST) Scholarship, and Prince of Songkla University Graduate Fund. Owners of rubber agroforest and rubber plantation are acknowledged for their support of the study sites and kind services during the field work. I would like to thank Assist. Prof Dr. Sara Bumrungsri, Assoc. Prof. Dr. Ashara Pengnoo, and Assist. Prof. Dr. Pramoth Kheowvongsri who inspired the idea and mainly gave suggestions for this study. Lastly, I would like to thank all friends in the laboratory and family for suggestion and assisting in the work.

Rinmanat Waiyarat

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CHAPTER 1

INTRODUCTION

Over 40 million hectares of primary forest have been cleared since 2000 (FAO, 2010). Especially, in Southeast Asia, the land was converted mainly for agriculture land use, and cash crops plantations (Stibig et al., 2014). Rubber (Hevea brasiliensis Müll. Arg.) is a major economic tree crop of tropical areas of the world, especially Southeast Asia (Kumagai et al., 2015). More than 1,500,000 ha of land were estimated to convert to rubber plantations in southern China, Thailand, Vietnam, and Cambodia during 2003 to 2010 (ANRPC, 2010). In addition to remarkably negative effect of mono-cropping plantation on ecosystems such as biodiversity loss, environmental degradation, and reducing of biomass carbon as indicated in previous studies (Wu et al., 2001; Mann, 2009; Qju, 2009), impairing nutrient cycling could be another negative effect of rubber monoculture. However, our understanding on ecological process of nutrient cycling in monoculture rubber plantation is still largely limited. Litter fall and litter decomposition are mechanisms of plants to transfer nutrient substances back into soils. They contribute to the regulation of nutrient cycling and primary productivity, and to the maintenance of soil fertility in terrestrial ecosystems (Aerts and Caluwe, 1997; Olson, 1963; Prescott, 2004; Shiels, 2006). Land use change for agricultural practice causes rapid decreases in soil quality (Islam and Weil, 2000). Then, understanding the nutrient cycling in the agricultural system is vital because plant productivity depends on this nutrient balance (Ouédraogo et al., 2001). For ecosystem sustainability, a managed land use should imitate structure and functioning of natural ecosystems (Ewel, 1999). Agroforestry is one of land use management practice, plays on the trees and their quality for enhancing productivity and sustainability of farming system. For a simple understanding, agroforestry combines agriculture and forestry into an integrated production system to get the maximum benefits (Nair, 1998). In rubber agroforests in Thailand, farmers either plant timber; herb or fruit trees or allow natural succession of native trees between or within rows of rubber trees in their farms. Such the practice leads to be a higher plant diversity, and more canopy complexity compared to monoculture farming. Currently, very a small number of farmers apply the agroforestry system in their rubber farms, and none has studied on litter dynamics and litter decomposition in the rubber agroforest.

Thus, this study aims to compare litter production and rubber leaf litter decomposition between the rubber agroforest and the rubber monoculture. We hypothesized that there should be more litter production and faster rate of leaf litter decomposition in the rubber agroforest than in the rubber monoculture. The knowledge from this study will elucidate whether the rubber agroforest is more sustainable than the rubber monoculturein in terms of nutrient cycling.

A definition of agroforestry

Agroforestry refers to land-use systems in which trees or shrubs are grown in association with agro-forest agricultural crops, pastures or livestock, and in which there are both ecological and economic interactions between the trees and non-tree components of the system (Young, 1989). Nair (1998) also defined agroforestry as one of sustainable approaches for land-use management where both agriculture and forestry combine into an integrated production system to get maximum benefit. The fundamental goal of agroforestry is to help soil fertility and support the growth of associated crops.

Project objective

The purpose of this study was to

1) Compare litter productions and rubber-leaf litter decomposition rates between rubber agroforest and rubber monoculture.

CHAPTER 2

MATERIALS AND METHODS

Study sites

The study was conducted in three pairs of rubber agroforests and rubber monoculture in southern Thailand. Two of these pairs were in east coast namely Chana (6°55′59.7′′N 100°40′08.5′′E) and Namnoi, Songkhla province (7°04′08.0′′N 100°31′31.1′′E), while one was in west coast, Natohming, Trang provice (7°33′12.04′′N 99°30′38.8′′E). The annual rainfall during study period (January to December 2013) was 2,180 mm. There are two main seasons which slightly vary in their periods between the west and east coast of Thai peninsula. The rainy season in west coast occurs from May to October, while it is during August to January in east coast based on 10 years (2005-2014) rainfall data. The main dry season was started from mid-February to mid-April. The average temperature was lowest in October to December (26.74 ºC) and peaked in April (28.56 ºC). In each study site, a pair of rubber agroforest and rubber monoculture close to each other (mean 30 ± 5 meters) was selected to control for soil characteristic and ground water content. These farms were the third rubber planting cycles which were conversed from primary forest for more than 70 years. The farms have rubber tree (*Hevea brasiliensis* (A. Juss) Muell. Arg) in similar age (ca. 20 years old) with density of rubber trees ranged 375-468 trees per 1 ha. The average basal areas (m^2/ha) of rubber trees in rubber agroforest and rubber monoculture were (mean ± SD) 33.5 ± 5.6 and 28.1 ± 5.4, respectively. These study sites are mostly surrounded by rubber plantations. In rubber agroforests in this study, timber species were mostly planted between the rows of rubber trees, and, in some farm, they were planted within rubber tree rows. These timber trees are *Dipterocarpus alatus*

Roxb., *Aquilaria crassna* Pierre ex Lec. and, *Hopea odorata* Roxb. These timber trees are 7-13 years old, with sum basal area of 4-12 m^2/ha, and density of 400-1200 trees/ha. In rubber monoculture, ground covered was only covered with short grasses during a non-tapping period in late dry season (February - May). The soil texture in the study sites is sandy loam. The average soil pH, soil organic matter (%), total nitrogen (%) and organic carbon (%) in rubber agroforest were 5.13 ± 1.92 (range 3.93 – 7.35), 1.43 ± 0.42 (range 0.97 – 1.78), 0.07 ± 0.01 (range 0.06 – 0.08) and 0.84 ± 0.24 (range 0.57 – 1.04). The average soil pH, soil organic matter (%), total nitrogen (%) and organic carbon (%) in rubber monoculture were 4.81 ± 1.31 (range 3.75 – 6.28), 1.17 ± 0.40 (range 0.74 – 1.53), 0.07 ± 0.02 (range 0.05 – 0.08) and 0.78 ± 0.09 (range 0.72 – 0.89).

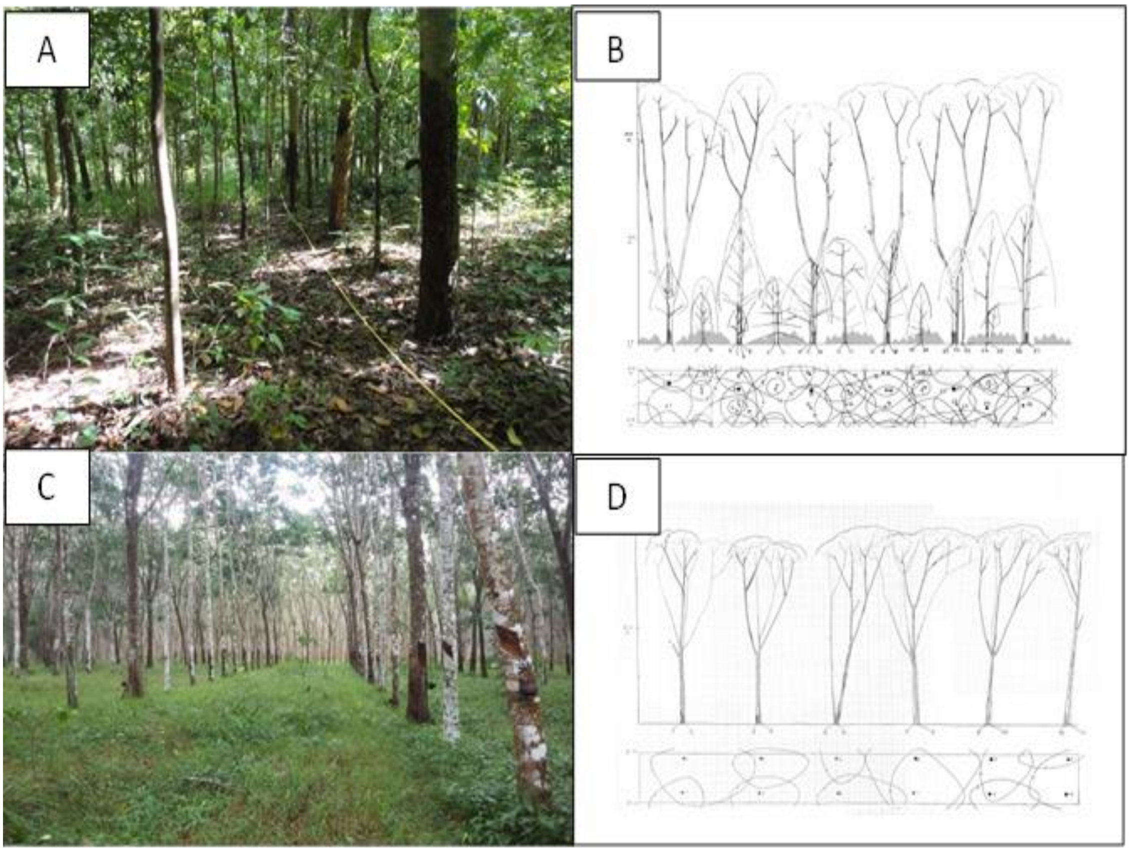

Figure 1. Sample sites of the study and profile diagrams of rubber agroforest (A, B) and rubber monoculture(C, D) in Namnoi, Songkhla

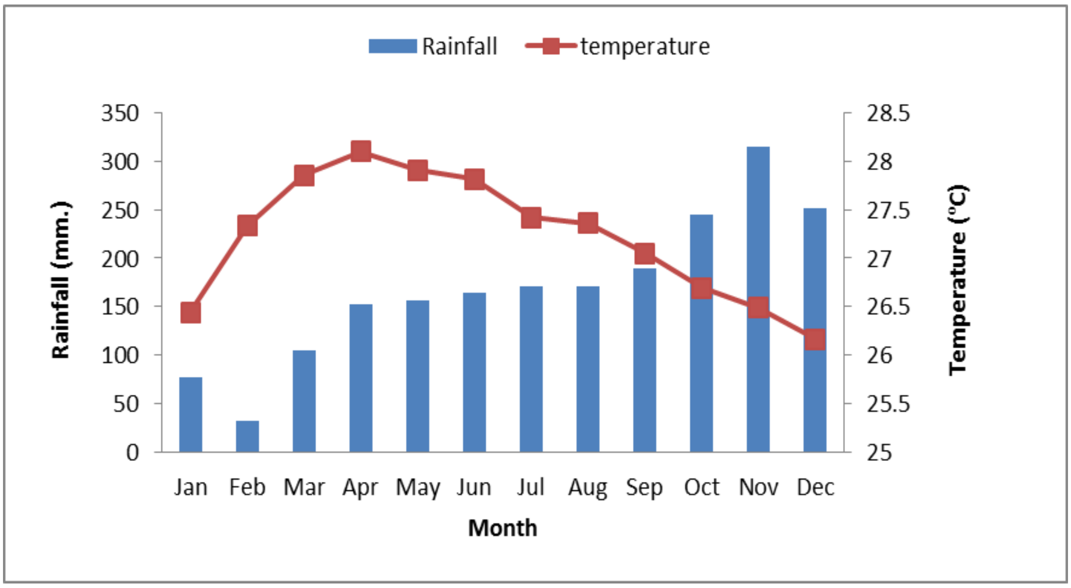

Figure 2. Mean of rainfall and temperature (2005-2014 years average) in Songkhla andTrang province

Environmental measurement

Monthly rainfall during the study was collected by the Meteorological Center which is near each study site. The temperature and relative humidity were hourly measured with data loggers (Tenmars, Model: TM-305U) which placed 1.5 m above ground. Soil pH and soil moisture content were randomly collected. Ten soil samples were combined for one sample representative in each study site and sent to determine soil propriety in the laboratory at Central analytical center, Faculty of Natural Resources, Prince of Songkla University. The canopy cover percentage was determined using a densiometer to sample 5 sampling points: center and every corner of three 30 m x 30 m plot in each site.

Measurement of litter fall and litter decomposition

Litter fall production was collected by litter traps (1 m^2). Fifteen litter traps were placed randomly 1 m above ground in each site. Ninety traps in total were placed in all study sites. The litter traps were made from PVC frame and 1 mm nylon mesh netting. Litter was collected once a month for a year. It was oven-dried at 60-70 °C for 48 hours. All samples were separated into: leaves, branches, fruits and flowers, and weighted with digital scale.

Decomposition rate across habitat type was measured using a litterbag technique. Litterbags (20 cm x 20 cm) were made from 1 mm nylon mesh material and two small holes (1 cm^2) were made in both sides of litterbag allowing macroinvertebrates to access to litter (Barlow, 2007). Each litterbag was filled with 6 grams of oven dried rubber leaves collecting in rubber plantation during dry season in February, 2012. These leaves were oven dried at 60 °C for 48 hours. In each study site, 90 litterbags were placed systematically on soil surface in the end of December 2012 for dry season treatment and the second set of 90 litterbags for rainy season treatment was set in the end of September 2013. After that, 6 litterbags in each study site were collected every month and transported to the laboratory. Soil was removed from litter and litter was oven-dried at 60-70 °C for 48 hours. The dry weight of decay litter was calculated as original dry weight (6 g) - dry weight of remaining litter. The decomposition rates coefficient, *k* value, was calculated from the decay curve using the following equation: $\ln(M_0 / M_t) = k * t$ (M_0=initial mass of litter, M_t=remaining mass at a certain time, t = the amount of time passed since the initial measurement) and k = the decomposition constant). As proposed by Olson (1963), the time required for $t_{50\%} = 0.693/k$ and $t_{95\%} = 3/k$, respectively.

Statistical analysis

Generalized linear mixed model was applied using lme4 package, with litter fall production and decomposition rate as dependent variables, since litter fall production and decomposition rate (*k*) did not show a normal distribution after a normality test (Shapiro Wilk test) was applied. For litter fall, fixed factor is habitat type while random factor are study sites and traps. Repeated measures general linear model was used to express the habitat type and seasonal variation.

To examine the effect of habitat type with decomposition rate, habitat type was the fixed factor and study sites and traps were random factors. To express the affected in decomposition rate by season (dry and rainy), repeated measures general linear model was used. T-test was used to compare mean monthly temperature, relative humidity, canopy cover, and soil moisture content between habitat types. All statistical analyses were applied using R program (R Development Cored Team version 3.2.0, http://www.R-project.org). Mean ± SD was used throughout.

CHAPTER 3

RESULTS

Environmental variables

The temperature in rubber agroforest (27.66 ± 0.85 ºC) was slightly lower than rubber monoculture (27.89 ± 1.57 ºC) which was not significantly different (T= -0.77, df= 53.97, $P>0.05$). However, the relative humidity in rubber agroforest was significantly higher than rubber monoculture (86.61 ± 7.37 % and 75.66 ± 8.97 %, respectively) (T= 5.66, df=67.45, $P<0.05$). Canopy covers in rubber agroforest (89.67 ± 7.96%) was significant greater than rubber monoculture (59.97±5.59%). Similarly, soil moisture content at 30cm depth in rubber agroforest (3.90 ± 0.64%) was significantly higher than rubber monoculture (2.00 ± 0.86%, T=2.98, $P<0.05$).

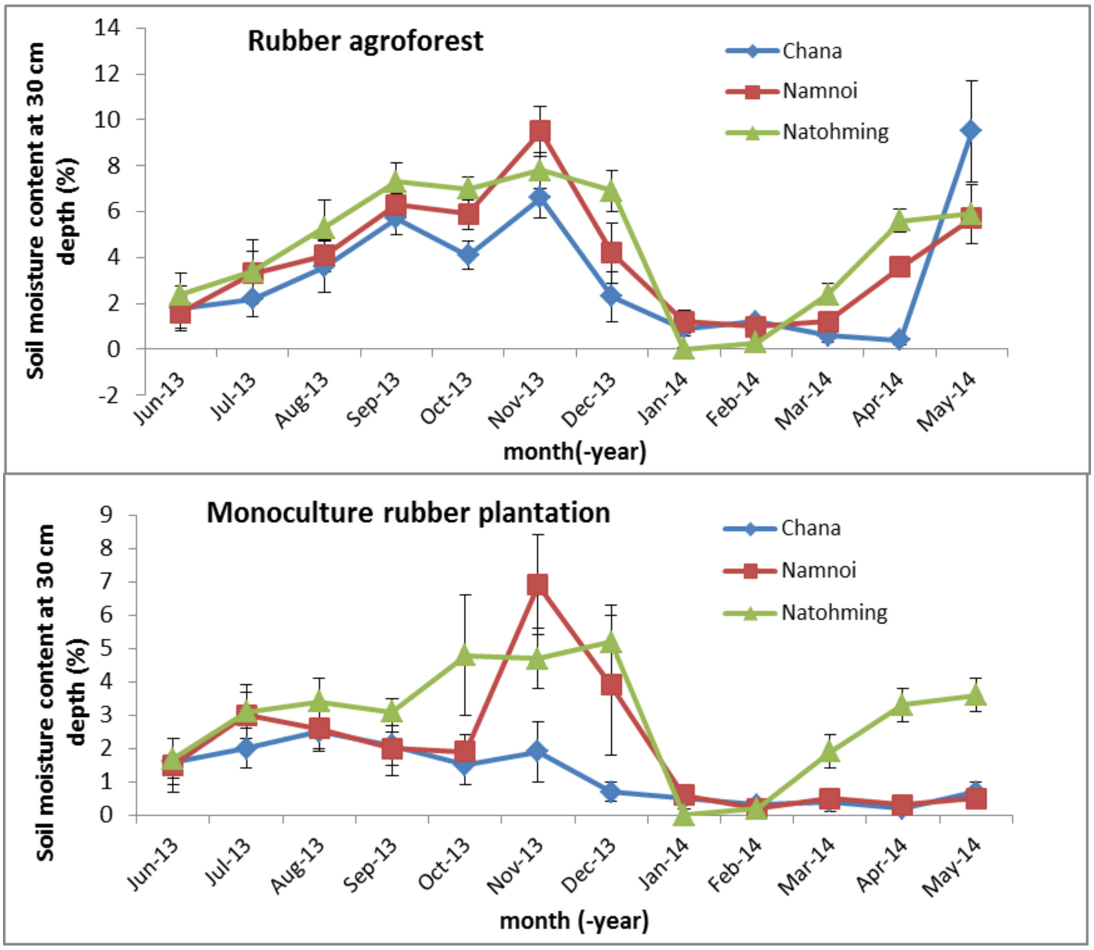

Figure 3. Mean of soil moisture content at 30 cm depth (%) from June 2013 to May 2014 in rubber agroforests and rubber monoculture

Litter fall

The total annual litter fall in rubber agroforest was 4.18± 0.35 Mg/ha/yr (range 3.81-4.55) which was significantly higher than that in rubber monoculture (2.56 ± 0.34 Mg/ha/yr, range 2.11-2.83). Generalized linear mixed model showed that habitat type was significantly affected the litter production (F=64.72, df=1, $P<0.05$). Furthermore, litter production was higher in every month in rubber agroforest compared to rubber monoculture. Leave fraction was the most contributors, represents about 80 percent of all litter production. Although mean monthly rubber leaves litter in rubber agroforest (0.20 ± 0.02Mg/ha/month) was slightly higher than that in rubber monoculture (0.17 ± 0.06 Mg/ha/month), it was not significantly different (F=0.62,df=1, $P>0.05$). Moreover, the rubber leaves litter production/basal area of rubber tree ratio in each study site found that it was not significantly different between rubber agroforest and rubber monoculture. In addition to rubber leave, rubber agroforest as 50% more leave litter input from intercropping plant species (0.11 ± 0.04 Mg/ha/month). Other litter fractions including branches, fruits and flowers, were similarly contributed in both habitats (0.02 ± 0.01, 0.02 ± 0.01 and 0.01 Mg/ha/month, in rubber agroforest, and 0.03 ± 0.01, 0.01 ± 0.01 and 0.02 ± 0.01 Mg/ha/month in rubber monoculture, respectively.

In terms of temporal pattern of litter production, although there was litter production throughout the year in both habitats, litter production was proportionally greater in dry season (0.34 ± 0.31Mg/ha/month) compared to rainy season (0.22 ± 0.21 Mg/ha/month). Generalized linear model suggested season and habitat type effect litter production (F=72.80 and F=97.28, df=1, $P<0.05$) and there was no interaction between habitat type and season (F=0.98, df=1, $P>0.05$). Geographical variation in temporal pattern of rubber leave litter production was recognized between the east (Namnoi and Chana, Songkhla) and west (Natohming,Trang) of the peninsular. In the east, a general peak of rubber leave litter in both agroforest and rubber monoculture was in March which is a middle of dry season except in rubber agroforest in Chana where a peak was in January. In contrast, peak of rubber leave fall in the west was one or two month earlier (January or February), a middle of dry season in that area (Figure 1). For other litter fractions, their production showed intermittent pattern. For branches litter, there are two periods of litter fall while flower litter was only once a year when the leaf bud in dry season. Two periods of fruit litter production in rubber agroforest but only one in rubber monoculture.

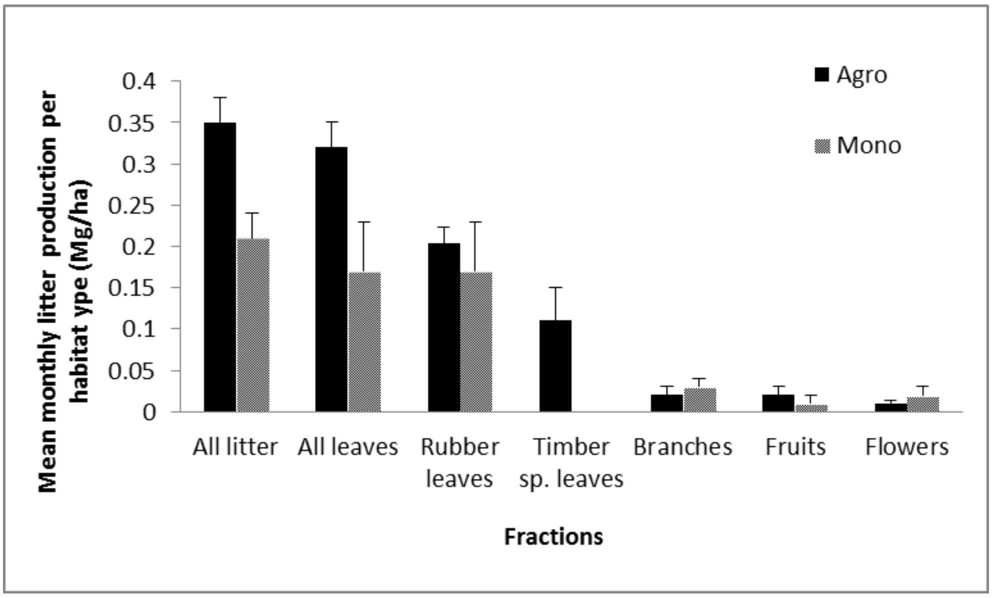

Figure 4. Mean monthly annual litter production in Agro and Mono (mean ± S.D.)

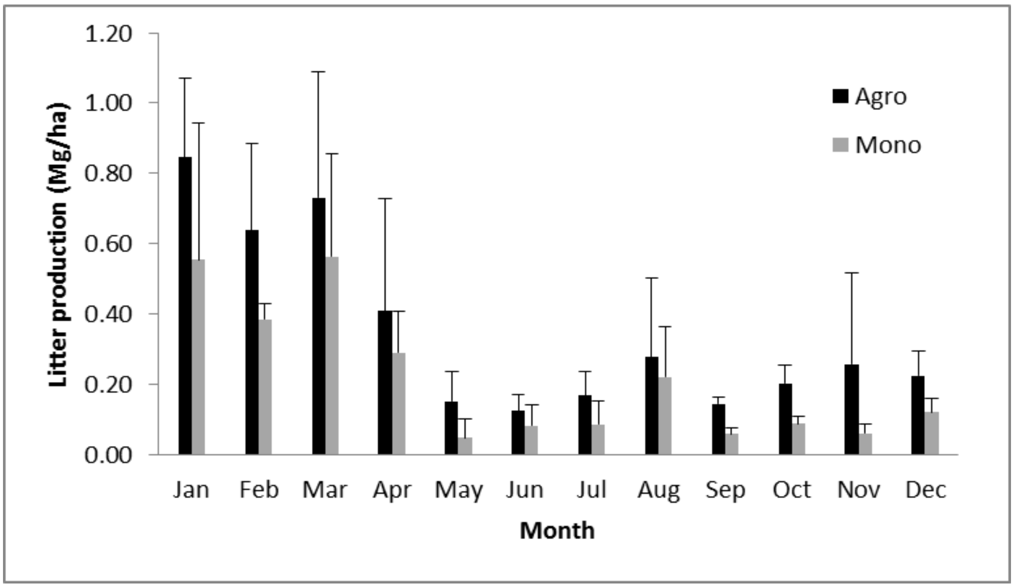

Figure 5. Mean monthly litter production in Agro and Mono

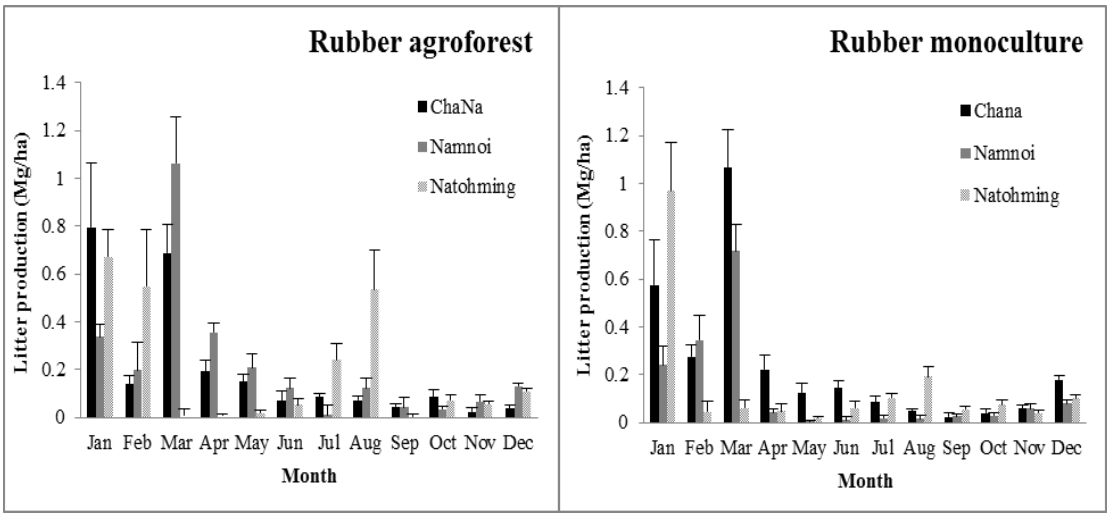

Figure 6. Rubber leaves litter fall pattern (Mg/ha) in each study sites both in Agro and Mono

Rubber leave decomposition

Generally, rubber leave gradually decay and almost done in one year period. The remaining of litter mass over one year in rubber agroforest (0.08 - 0.19 %) was lower than in rubber monoculture (0.80 - 2.40%). It appeared that there were site specific patterns in leave litter decomposition. Decomposition in both habitats in Chana was greater in the first half period compared to Natohming, but the latter was faster in second half period (Figure 7).

Mean decomposition rates in rubber agroforest (6.57 ± 0.45g/year, range 6.24–7.09) were faster than in rubber monoculture (4.56 ±0.74 g/year, range 3.72–5.14). There was a highly significant effect of habitat type on decomposition rate (F=26.87, df=1, P<0.05). The half-life ($t_{50\%}$) in rubber agroforest and rubber monoculture were 0.11 ± 0.01 and 0.15 ± 0.02year (month), respectively. 95% mass loss ($t_{95\%}$) in agroforest and rubber monoculture were 0.46 ± 0.03 and 0.67 ± 0.11 year (month), respectively. Decomposition rates were significantly faster in rainy season compared to dry season both in rubber agroforest and rubber monoculture. Season had a highly significant effect on decomposition (F=102.41, df=1, P<0.05). Decomposition rate in rainy and dry season of rubber agroforest was 3.98 ± 0.64g/month (range 3.36–4.65) and 0.99 ± 0.18g/month (range 0.85-1.19), respectively. Similarly, the k value of rubber monoculture in rainy season was2.79 ± 0.48g/month (range 2.24 – 3.15) and it was 0.91± 0.28 g/month (range 0.60–1.15) in dry season, respectively. Thus, decomposition variation between these two habitats certainly clear during the rainy season (F= 8.84, df=1, P<0.05) but was not significant different during dry season (F= 0.08, df=1, P>0.05).

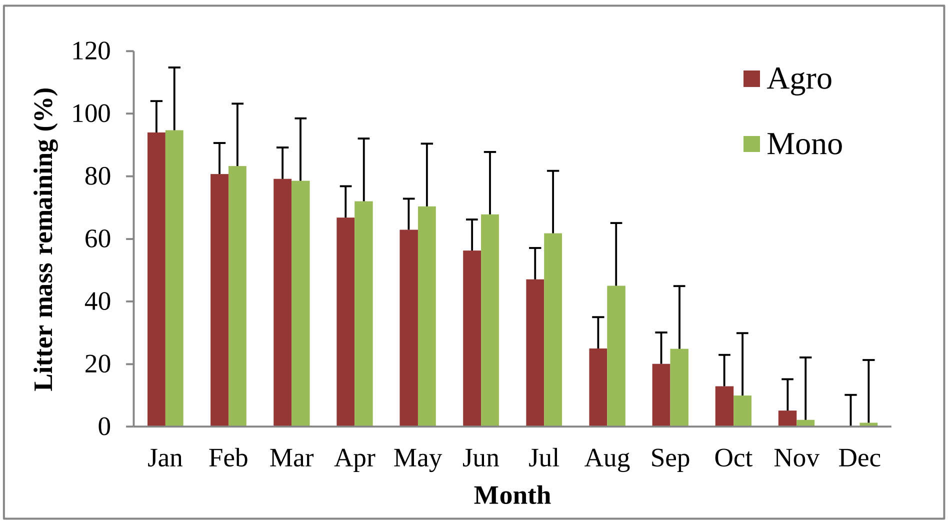

Figure 7. Litter mass remaining (%) in three paired rubber agroforest (Agro) and rubber monoculture (Mono) in 2013.

CHAPTER 4

DISCUSSIONS

Litter fall

It is clear that litter production in rubber agroforest is quantitatively higher than in rubber monoculture. In additional to litter production from rubber trees which found mostly in dry season, litter production from intercropping species was available year round. Consequently, rubber agroforest get more litter input than rubber monoculture in every month. The higher litter production in rubber agroforest is basically because of higher density of trees and also possibly because of plant composition. Wang, et al. (2008) studied litter production in mixed and monoculture of *Cunninghamia lanceolata* in China which tree density was control in both stands, they reported that mixed stand produced litter greater than the pure stand which can be explained by competitive production principle (Kelty, 2006). According to this principle, different plant species have different physiological and morphological characteristic which allow them to use resources more effective in mixed planting than in pure planting, Gama-Rodrigues et al. (2007) reported 29.4% more biomass in mixed stand compared to pure stand in 22 years old native tree plots. In the current study, litter fall concentrated during the dry period indicating that the physiological response to drought plays a major role in this process (Valentiet al., 2006). Generally, litter fall relates to a combination of increase temperature, decline humidity, and lowered soil moisture content. This is the first study that showed geographic variation in litter fall period between west and east coast of southern Thailand. This variation is influenced by two main monsoons, southwest and northeast monsoons, and the north-south Tenasserim mountain range. The southwest monsoon which starts in May brings a warm moist air from the Indian Ocean towards west coast of Thailand causing abundant rain over the country. The Tenassarim mountain ranges block such moist air and lead to fairly dry in east coast. Generally, rainy season in the west coast finishes in October. The northeast monsoon which starts in October brings the cold and dry air from China mainland over most of Thailand except the south. In the south, this monsoon carries moisture from Thai Gulf and causes mild weather and abundant rain along the eastern coast. Rainy season in this coast finishes in January (Thailand Climate, 2016). Thus, dry season in the west coast begins earlier than the east coast.

The litter production in this study both rubber agroforest (4.18 Mg/ha/yr) and rubber monoculture (2.56 Mg/ha/yr), fall within the range of litter fall production in tropical plantation (1.02-14.5 Mg/ha/yr, Batish et al., 2008), whereas litter fall in primary forest was 9.4 - 12.4 Mg/ha/yr and secondary forest was 5.4-13.4 Mg/ha/yr (Barlow et al., 2007). Litter production of rubber agroforest probably reach that of the secondary forest when woody tree grow up in the future but hardly reach that of primary forest since farmer normally clear-fell their farms when it reach 25-30 years old.

Decomposition

Rubber leave litter decomposition rate from the present study is comparable to a previous study in southern India which was 0.013 g/day (4.75 g/year) (Jobi, 2006). Overall, the results demonstrate that litter in rubber agroforest decompose at faster rate than that in rubber monoculture, and it was faster in rainy season compare to dry season. Decomposition variation between these habitats can be explained with the difference in site conditions (e.g. temperature and humidity) and litter quantity between them. Higher canopy covers and the presence of understory plants of rubber agroforest maintain higher humidity and soil moisture content in the system as previously found in cocoa agroforest in Sulawesi, Indonesia (Moser et al., 2010). Higher humidity and soil moisture content in rubber agroforest may increase microbial biomass and their activities that lead to faster litter decomposition. Zhang and Zak (1995) showed greater degree of closed canopy had more litter mass loss than lower one because the former provide more suitable conditions for microbial activities such as higher soil moisture, and lower light intensity. In addition, faster decomposition rate in rubber agroforest can be resulted from higher nutrient availability as a result of more litter from higher density of mixed planting trees. Soil nutrients availability associates with biotic communities of microbial decomposers and soil fauna in the systems. In addition, litter quality may also responsible for higher litter decomposition in rubber agroforest. In a study in density-controlled pure and mixed plantation in southern China, Wang et al. (2008) showed that the mixed stand had more microbial biomass and enzyme activities, and litter decomposition was slightly faster. Several previous studies also found that rate of leaf litter decomposition were slightly faster at the mixed forest than monoculture plantation (Pandey et al., 2007; Wang et al., 2008). Season strongly influence litter decomposition rate. In this study, litter decomposed faster in rainy than in dry season in both habitat types. This pattern is consistent with previous studies in Africa (Ngatia et al., 2014). It implies that factors related to season such as the radiation, atmosphere moisture, and rain play significant roles in litter decay, and these factors directly affect soil decomposer activity Raghubanshi et al. (1990) mentioned the microbial biomass and their activity increase in the rainy season. Consequently, the environmental (such as soil moisture and temperature) and biological events (such as litter inputs, microbial activities etc.) affect the dynamics of soil microbial biomass in the system (Tripathi and Singh, 2012). As a result, higher litter weight loss during the rainy season enhances nutrient availability for crop system and supports the initiation of plant growth (Dhanya et. al., 2013; Ranghubanshi et al., 1990). Mover, the study of Couteaux, at al (1995) reviewed litter quality also largely controls as the regular under favorable condition. However, this study has no reported of the litter quality.

CHAPTER 5

CONCLUSTION

This study suggests that rubber agroforest offer more litter production, and enhance faster decomposition of litter than rubber monoculture. It implied that higher quantity and more regular nutrient return is added in rubber agroforest than in rubber monoculture in each year. Although more studies are needed to verify that rubber agroforest will produce more latex greater than in rubber monoculture, it is clear that rubber agroforest can maintain soil fertility better than rubber monoculture. As such, rubber agroforest is more sustainable in terms of nutrient cycling. Moreover, this study needs more information to propose rubber agroforest is more nutrient balance than in rubber monoculture. This study, we just reported only the litter input from litter production and litter releasing rate of rubber leaves. However, it might be a predictor for other study in the future.

Recommendations for further studies

The very small number of rubber agroforest available to this study may limit our rigid conclusion. Further work on the larger sample sizes as well as more detail study on the nutrients release of litter from different species during litter decomposition is needed. Rubber agroforest can be varied in terms of structure complexity and plant composition, more work on how different degree of complexity, different plant composition and plant competition will affect litter production and decomposition is recommended.

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Appendix

Table 1 The land use information

Information	Namnoi, Songkhla		Chana, Songkhla		Natohming, Trang	
	Agro	Momo	Agro	Momo	Agro	Momo
Start tapping rubber tree	Rubber tree 7 years old	Rubber tree 7 years old	Rubber tree 7 years old	Rubber tree 7 years old	Rubber tree 7 years old	Rubber tree 7 years old
Tapping period	02.00-05.00 am.	03.000-05.00 am.	07.00-09.00 am.	05.00-06.30 am.	01.00-06.00 am.	23.00-01.30 am.
Tapping frequency	every two or three days	every two or three days	every two or three days	every two or three days	every day and when raining and rubber tree drop leaf in dry period	every day and stop when raining and rubber tree drop leaf in dry period
Fertilizer information	Chemical fertilizer, manure and compost	Chemical fertilizer	Chemical and organic fertilizer	Chemical and organic fertilizers	Chemical and organic fertilizers	Chemical fertilizer

Table 1 The land use information (cont.)

Information	Namnoi, Songkhla		Chana, Songkhla		Natohming, Trang	
	Agro	Momo	Agro	Momo	Agro	Momo
Land use management	Cutting grass along the trail for tapping rubber before tapping period 1-2 times/years	Cutting grass along the trail for tapping rubber before tapping period 1-2 times/years	Cutting grass along the trail for tapping rubber before tapping period 1-2 times/years	Cutting grass along the trail for tapping rubber before tapping period 1-2 times/years	Cutting grass along the trail for tapping rubber before tapping period 1-2 times/years	Cutting grass along the trail for tapping rubber before tapping period 1-2 times/years

Agro- Rubber agroforest, Mono- Monoculture rubber plantation

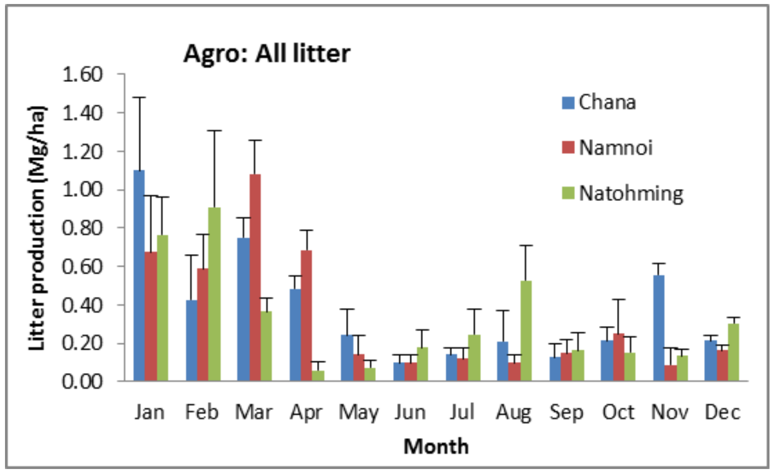

Figure 1. Litter fall production pattern of all litter in rubber agroforests.

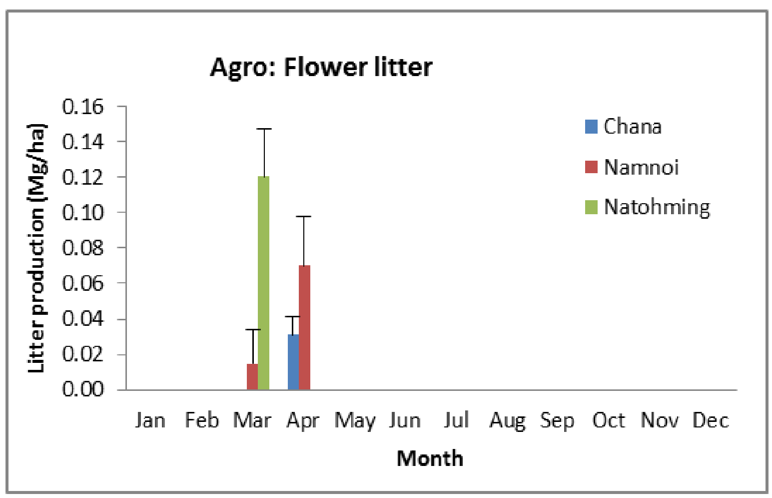

Figure 2. Litter fall production pattern of flower litter in rubber agroforests

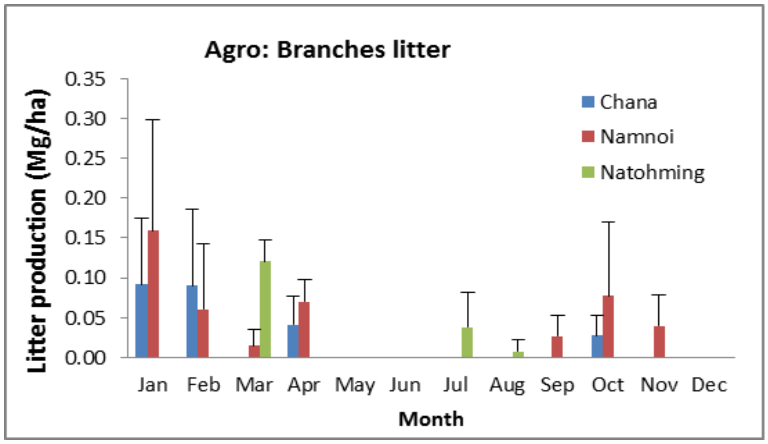

Figure 3. Litter fall production pattern of branch litter in rubber agroforests.

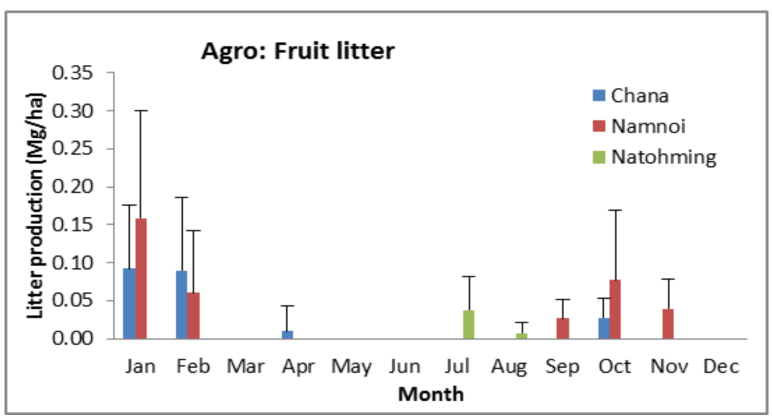

Figure 4. Litter fall production pattern of fruit litter in rubber agroforests.

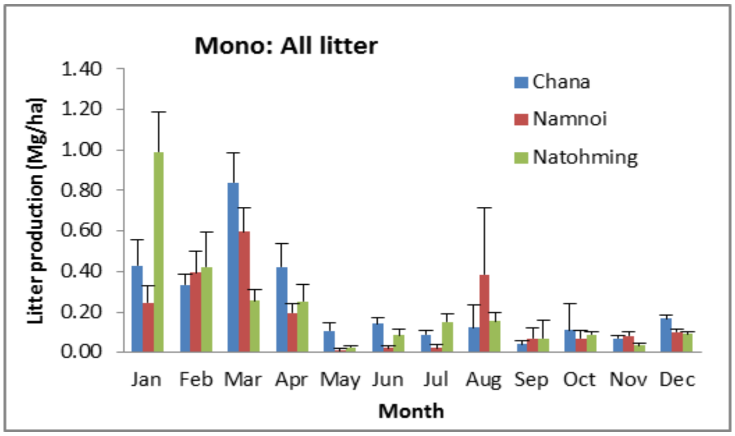

Figure 5. Litter fall production pattern of all litter in rubber monocultures.

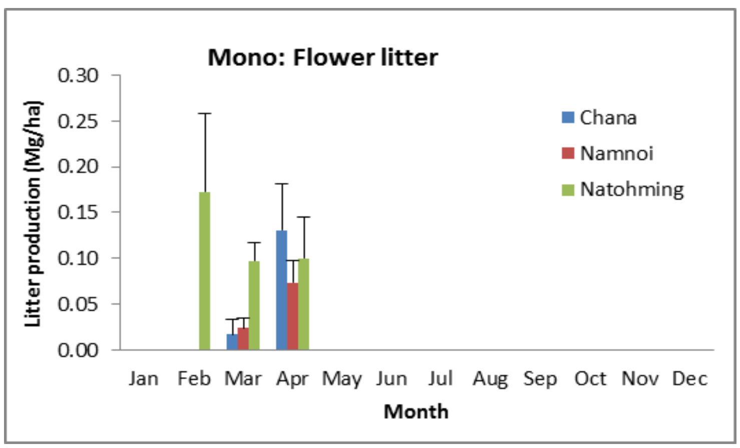

Figure 6. Litter fall production pattern of flower litter in rubber monocultures.

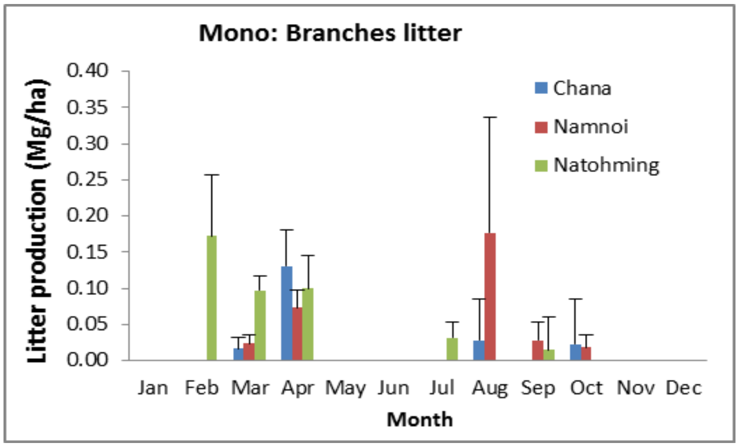

Figure 7. Litter fall production pattern of branch litter in rubber monocultures.

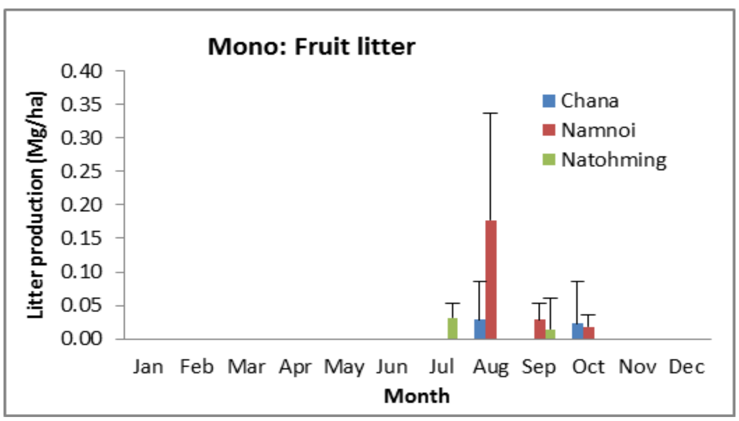

Figure 8. Litter fall production pattern of fruit litter in rubber monocultures.

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