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Assessing Rubber Intercropping Strategies in Northern Thailand Using the Water, Nutrient, Light Capture in Agroforestry Systems Model

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ABSTRACT

The Water, Nutrient, Light Capture in Agroforestry Systems (WaNuLCAS) model was used to evaluate and understand the impact of crop management on intercropping scenarios and competition between rubber and associated annual crops. The intention was to identify sustainable production systems with economic benefits for small-scale landholders in Thailand. The WaNuLCAS model was used to predict maize and rubber productivity under various management scenarios of intercropping and sole cropping in the Phitsanulok province (16°55' N, 100°32' E), Thailand. Model scenarios were simulated for rubber (clone RRIM600) grown with spacings of 2.5 × 7 m, 3 × 7 m and 3 × 8 m under sole cropping and intercropping with maize. The yield of maize was substantially influenced by rubber-tree spacing in the intercropping systems. After 3 yr, the average yield of maize was decreased from 7 to 3 $t.ha^{-1}$ by rubber tree growth if organic fertilizer was not applied. Organic fertilizer application mitigated the negative influences of rubber trees until the seventh cropping season. After 8 yr, the maize yield decreased to 0.4 $t.ha^{-1}$. Hence, rubber intercropped with maize with the application of recommended chemical fertilizer plus organic fertilizer was the best way to mitigate competition between rubber and maize. In the long term, the rubber tree girth and wood volume from sole cropping were higher than from the rubber intercropping systems. With a higher rubber tree density, the rubber tree girth and wood volume increased more slowly.

Keywords: Intercropping practice, rubber, WaNuLCAS model

INTRODUCTION

Para rubber (*Hevea brasiliensis*) is an economic crop of Thailand and since 1989, rubber growing in Thailand has gradually shifted from its traditional area in the south and east to the north and the northeast of the country (Chantuma *et al*., 2012). The planting area underwent more change after the Thai government launched the 160,000 ha rubber planting project (Chantuma *et al.*, 2005). The total area of rubber plantation in Thailand was 2.93 million ha in 2009 (Rubber Research Institute of Thailand, 2010). In 2013, the total rubber cultivation area in Northern Thailand (in 17 provinces) was 0.20 million ha (5.5% of the total rubber cultivation area in Thailand), while the expansion of new plantations in both lowland and upland areas was at a high rate (Thai

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Rubber Association, 2013). Therefore, farmers in Northern Thailand nowadays are replacing former main crop varieties such as rice, sugarcane and cassava with monoculture plantations of rubber trees. In new growing areas, rubber growers typically plant Para rubber ranging from about 0.65 to 21.0 ha per household) with almost 50% of households owning from 1.62 to 3.24 ha of rubber plantation (Fox and Castella, 2013). The benefits and trade-offs of rubber plantations have been controversial and have been discussed by Ziegler *et al*. (2009) who noted that rubber plantation, being a monoculture, competes with food crops for land, having effects on agrobiodiversity and food security issues, such as decreasing plant cover of the soil, loss of forests, decreasing soil fertility and increasing soil erosion. Furthermore, they noted the lack of income for small-scale farmers was related to some social impacts because rubber trees normally take 5–6 yr to reach the stage where they can be tapped.

Using a rubber intercropping system is an option to solve these problems. Rubber trees can be grown in combination with indigenous plants and other fruit trees, food crops and other species. Such a pattern allows farmers not only to harvest rubber but also to collect food crops, herbs, fuelwood and wood for construction and also increases agrobiodiversity, soil fertility, and reduces soil erosion (Khan and Khisa 2000; Rodrigo *et al*., 2001; Pansak *et al*., 2008; Xianhai *et al*., 2012). However, rubber intercropping system productivity is influenced by soil properties, climate and the management of and competition with other crops when they are planted together with rubber.

Competition between rubber trees and crops can involve shading by the trees which reduces the available light at the crop canopy and involves root competition between trees and crops for water and/or nutrients in the top soil; such competition can be reduced by the appropriate choice of tree species and its management (Van Noordwijk and Hairiah, 2000). The Water, Nutrient and Light Capture in Agroforestry Systems (WaNuLCAS) model was developed to represent tree-soil-crop interactions in a wide range of agroforestry systems where trees and crops overlap in space or time or both (van Noordwijk and Lusiana, 1998; van Noordwijk *et al*, 2004). The WaNuLCAS model was selected for the current study because it can be used to evaluate various management options in tree intercropping systems based on site-specific information and the farmer's management objectives. Hence, this study aimed to evaluate and understand the impact of crop management based on intercropping scenarios and minimum competition among associated crops by using WaNuLCAS with the intention to reduce the pressure on natural resources and to develop sustainable production systems with economic benefits for small-scale landholders.

MATERIALS AND METHODS

Model description

The WaNuLCAS model information below is drawn from van Noordwijk and Lusiana, (1999). The model was developed to represent tree-soil-crop interactions in a wide range of agroforestry systems where trees and crops overlap in space and/or time, that is in simultaneous and sequential agroforestry. The model represents a four-layer soil profile, with four spatial zones (Figure 1). The model allows monitoring of the above ground and below ground competition for growth factors such as water, nutrients (N and P) and light between trees and crops over a wide range of production systems. The model can be used for agroforestry systems ranging through intercropping, mono cropping, shifting cultivation, fallow systems and alley cropping. The WaNuLCAS model version 4.0 was used in this study. A key feature of the model is the description of water and nutrient uptake based on the root length densities of the tree and crop, plant demand factors and effective nutrient supply at a given soil water content. Light capture is treated on the basis of the leaf area index (LAI) of both the crop and rubber tree components and their relative heights in each zone.

Plant growth is simulated on a daily basis by multiplying the potential growth by the minimum of two stress factors selected from light, water, nitrogen or phosphorus. The daily growth cycle considers the following sequence of calculations: LAI, canopy height, relative light capture, potential growth rate (considering the light use efficiency of the plant stage), transpiration demand (considering the potential water use efficiency), actual water uptake and actual nitrogen uptake (van Noordwijk and Lusiana, 1999).

Field data used for simulation

The field experiment was carried out at Ban Huai Phai, Wang Thong district, Phitsanulok province, Thailand (16° 55' N, 100°32' E) at an altitude of 209 m above sea level. The trial was established on a moderate slope ranging from 12 to 30%. However, the slope gradient in this simulation was set to 12% which was the average slope gradient in the field experiment. Monoculture rubber trees (clone RRIM 600) were planted in 2008, 2011 and 2013 at 7 × 3 m tree spacing (Figure 2). The soil classification was carried out according to Soil Survey Staff (2014) and was classified as a fine-loamy, mixed, semiactive, isohyperthermic Typic Haplustult with 13% sand, 48% silt, and 39% clay in the topsoil (0–25 cm) and a bulk density (BD) of 1.55 $g.cm^{-3}$. The topsoil had a pH (H_2O) of 5.5, an organic matter content (OM) of 3%, an available P (Bray II) content of 11.51 $mg.kg^{-1}$ and an exchangeable K content of 10.1 $mg.kg^{-1}$. The average annual rainfall is 1200 mm. The rainy season starts in mid June and ends in October. The average maximum temperature is 33°C with an average minimum of 23°C. The relative humidity ranges from 64 to 85%. The average daily sunshine is longest in January (approximately 9.4 $hr.d^{-1}$).

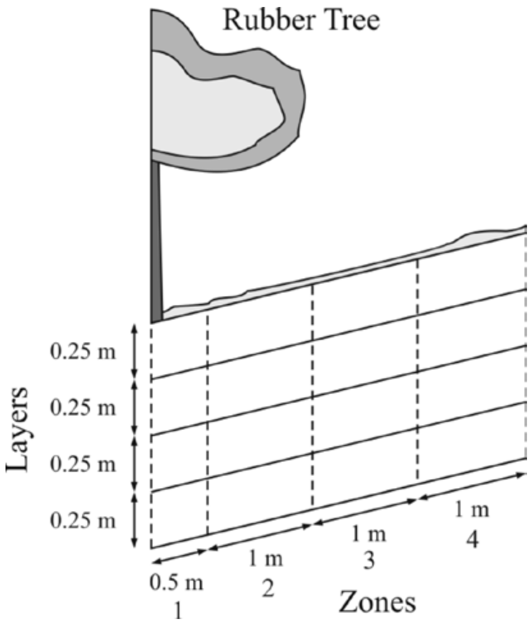

Figure 1 General layout of soil layers and spatial zones in the Water, Nutrient and Light Capture in Agroforestry Systems model. Modelled rubber trees were planted in zone 1 (adapted from van Noordwijk and Lusiana, 1999).

Model calibration and validation

In all simulation runs, the total length of the four zones was set to 3.5 m wide and 1 m deep. The width in zone 1 was set to 0.5 m and in zones 2–4 was 1 m. Each soil layer was defined as 0.25 m deep and it represents the soil profile. WaNuLCAS was first calibrated to model the dynamics of the growth increment of Para rubber trees in the rubber monoculture treatment based on the environmental conditions of Ban Huai Phai, North Thailand.

Soil parameterization

The pedotransfer function was used to calculate water movement in the soil (Wösten *et al*., 1998). The soil texture and chemical properties used to run the model are presented in Table 1. Simulations were done with minimum tillage conditions together with no nutrient (N, P) and water limitations. The slope gradient was adjusted to 12%.

Tree parameterization

The growth (girth) increments of rubber trees that were used in this calibration were measured on 2-, 4- and 6-year-old rubber trees at the experimental site. Measurements were made on 20 plants for each growing stage (2-, 4- and 6-year-old rubber trees). The girth of rubber tree development was calibrated in the tree library of the WaNuLCAS model adjusting values for maximum growth rate, fraction of growth reserve, leaf weight ratio and canopy parameters (Table 2) until the best goodness of fit (GOF) of observed

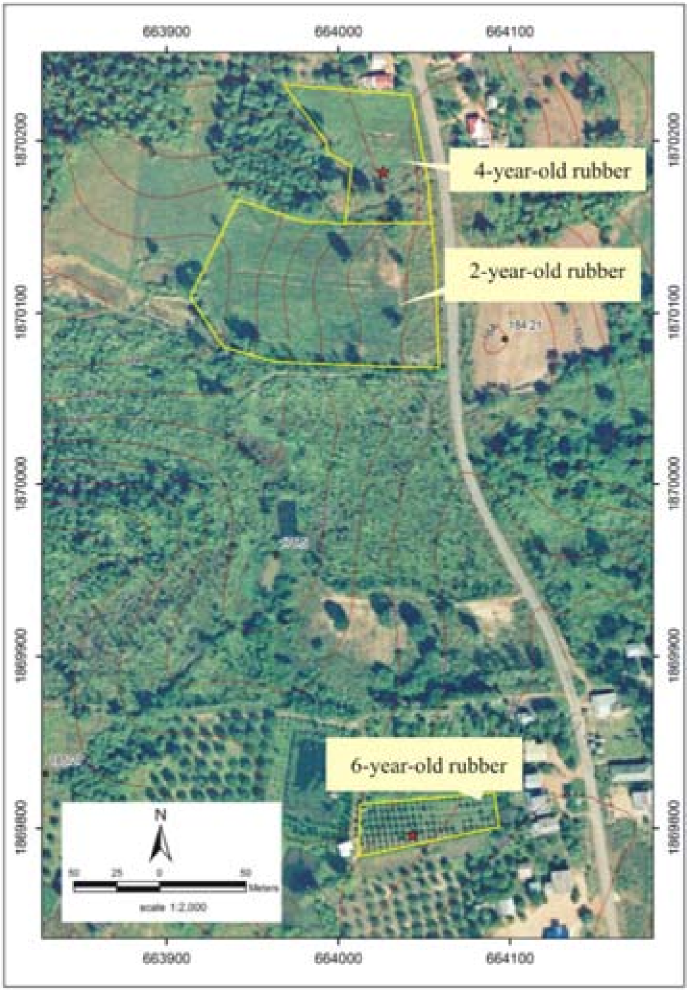

Figure 2 Location of the study site: Wang Thong district, Phitsanulok province, lower northern Thailand.

Table 1 Soil properties for pedotransfer input in the four zones.

Soil depth (cm)	pH (H_2O)	OM (%)	Total N (%)	P ($mg.kg^{-1}$)	K ($mg.kg^{-1}$)	BD ($g.cm^{-3}$)
0–25	5.5	3.04	0.21	11.51	10.10	1.55
25–50	4.9	1.93	0.21	11.51	4.77	1.61
50–75	4.5	0.52	0.14	3.33	3.18	1.63
75–100	4.6	0.60	0.14	3.33	3.18	1.63

and simulated growth (girth) increments was achieved. Rubber tree parameters were derived from actual measurements or based on a literature review (Yahya, 2007). Data of rubber growth (girth) increments of 3-, 4-, 5-, 6- and 12-year-old trees used in model validation were taken from the literature. These data were collected during 2013 in the Wang Thong district, Phitsanulok province, Northern Thailand (Kungpisdan *et al*. 2013). The field trial information on tree management, including the planting date, timing and amount of fertilizer application, was entered into the management options spreadsheet of the WaNuLCAS file in the Excel software package (version 2010; Microsoft Corp.; Redmond, WA, USA).

Model scenarios

After calibration and validation, WaNuLCAS was used to simulate four scenarios of rubber management options for a period of 10 yr:

(1) Maize rubber intercropping at three levels of tree spacing. The three levels of rubber tree spacing were 2.5 × 7 m (571 trees.ha^{-1}), 3 × 7 m (476 trees.ha^{-1}) and 3 × 8 m (416 trees.ha^{-1}). N and P were applied to maize at amounts of 60 kg.ha^{-1} N and 14 kg.ha^{-1} P based on farmer's practices and each was applied in two portions, half at planting time and half at a month after planting. N and P were applied to rubber at an amount of 4.5 kg.ha^{-1} N and 4.5 kg.ha^{-1} P twice per year. Maize was planted once a year for 10 yr. In the simulation of rubber intercropping with maize, the rubber trees were planted in zone 1 and the maize was planted in zones 2–4.

(2) Maize rubber intercropping at a spacing of 3 × 7 m plus fertilizer of 60 kg.ha^{-1} N and 14 kg.ha^{-1} P together with compost (organic fertilizer) at 1 t.ha^{-1}.

(3) Rubber monocropping was simulated with three levels of tree spacing consisting of 2.5 × 7 m, 3 × 7 m and 3 × 8 m. N and P were applied to rubber trees at amounts of 4.5 kg.ha^{-1} N and 4.5 kg.ha^{-1} P, respectively, and without organic fertilizer.

(4) Rubber monoculture was simulated at a spacing of 3 × 7 m. N and P were applied to rubber trees at amounts of 4.5 kg.ha^{-1} N and 4.5 kg.ha^{-1} P, respectively, together with compost (organic fertilizer) at 1 t.ha^{-1}.

Maize grain yields, tree girth and wood volume were used to assess the effect of organic input and spacing on the rubber system performance.

Table 2 Description of Water, Nutrient and Light Capture in Agroforestry Systems (WaNuLCAS) model parameters, default and modified values used for model calibration.

Parameter name in WaNuLCAS	Unit	Default value	Modified value
Max. growth rate	kg.m^{-2}	0.005	0.0067*
Max. canopy height above bare stem	m	12	7.4[1*]
Ratio between canopy width and height		0.66	0.48*
Max. canopy radius	m	8	3.6[1/]
Maximum leaf area index		5	5*
Ratio leaf area index min. and max.		0.1	0.5*
Relative light intensity at which shading starts to affect tree growth		0.9	0.7*
Extinction light coefficient		0.5	0.7*
Rainfall water stored at leaf surface	mm	0.7	1*

* = Modified value adapted from Yahya (2007).

[1] = Modified value adapted from field experiment data.

Evaluation of model predictions

The model's performance was assessed by comparing predicted values against observed data of the growth (girth) increment of the rubber trees. The coefficient of determination (R^2) was used as a measure of how close the observed and predicted results corresponded to a linear 1:1 relationship. According to Rykiel (1996), an R^2 value for calibration and validation of 0.5 was considered necessary to indicate a good relationship between a predicted and observed relationship, allowing for simulated results.

RESULTS

Model calibration and validation

In the WaNuLCAS calibration process, tree parameters (clone RRIM 600) were improved to better reflect site specific growth conditions. The resulting GOF values showed a better fit between observed and predicted values for the average girth of the rubber trees. The results of calibration demonstrated that the model predicted the girth of rubber trees with high correlation ($R^2 = 0.95$). The 1:1 graph (Figure 3) showed the model tends to overestimate for 4-year-old rubber trees.

The model validation used the average growth (girth) increment of rubber trees obtained from a literature review (Kungpisdan *et al.*, 2013). The data were not used for model calibration; hence, they were considered and used as an independent dataset. A comparison between the predicted growth (girth) increment of rubber trees versus observed values showed a reasonable model performance with a regression coefficient of 0.92 (Figure 4). However the 1:1 graph (Figure 4) showed the model tends to underestimate growth after tapping started and then at maturity.

Maize yield from alternative rubber tree row spacing and organic input for 10 cropping seasons

The model was parameterized for maize (*Zea mays* L.) yield from a previous study of Pansak *et al.* (2010). In the three levels of rubber tree spacing (2.5 × 7 m, 3 × 7 m and 3 × 8 m), the yield of maize was substantially influenced by rubber trees after 3 yr. The highest maize yield

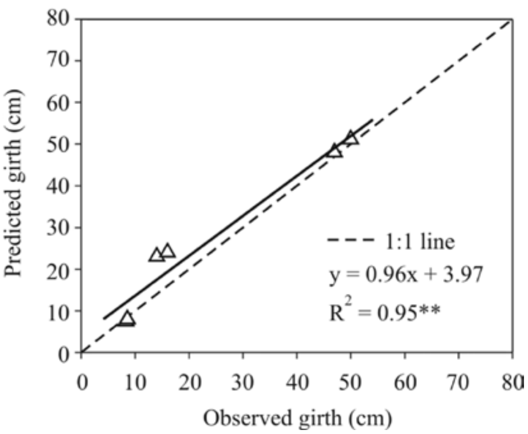

Figure 3 Relationship between predicted and observed rubber tree growth (girth) on 2, 4 and 6 year-old trees for model calibration. The solid line represents the regression curve and the dashed line is the one to-one line and R^2 is the coefficient of determination.

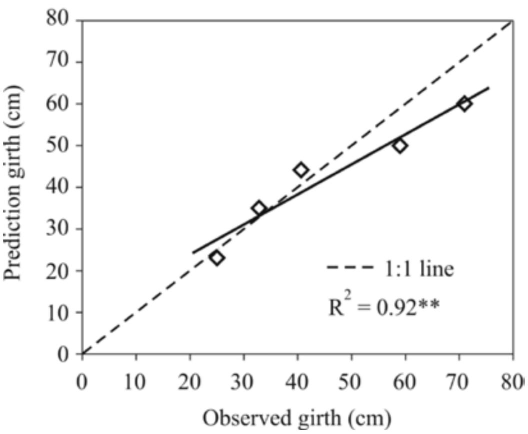

Figure 4 Relationship between predicted and observed rubber tree growth (girth) for model validation. The solid line represents the regression curve and the dashed line is the one to-one line and R^2 is the coefficient of determination.

was found when maize-rubber intercropping was accompanied with chemical fertilizer and organic input. If farmers did not use organic inputs together with fertilizers in the third cropping season, maize yields decreased by about 58% compared to the first year. Organic fertilizer application mitigated the negative influence of rubber trees until the seventh cropping season. After 8 yr of rubber growth, the maize yield decreased to about 0.4 $t.ha^{-1}$ in all treatments (Figure 5).

Rubber growth and wood volume under intercrop systems and monoculture with and without organic input

After 10 yr, there was a difference in the rubber girth increment and wood volume between the intercropped systems and monoculture trees, with the rubber monoculture performing better compared to the intercropped systems (Table 3). Rubber monocropping values were higher than for the intercropped systems at the same density. The girth and wood volume of the rubber monocropping and intercropped systems decreased with higher planting density. The use of organic input improved the rubber growth (girth) increment and wood volume in the intercropped systems and in the monoculture of rubber trees and even mitigated the negative impact of maize-rubber intercropping.

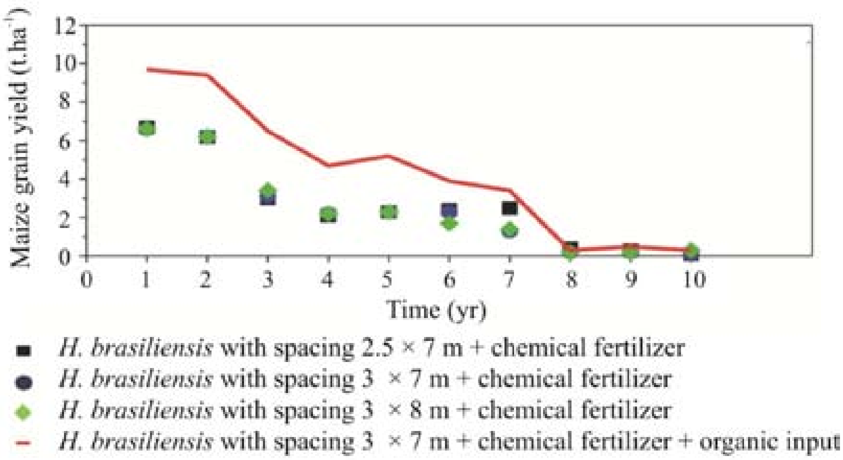

Figure 5 Effect of rubber spacing and organic inputs on simulated maize yields.

Table 3 Rubber growth (girth) and wood volume of 10 year-old rubber stands under different cropping systems and organic fertilization.

Tree density per hectare (tree spacing)	Monocropping		Intercropping	
	Wood volume ($m^3.ha^{-1}$)	Girth (cm)	Wood volume ($m^3.ha^{-1}$)	Girth (cm)
No organic fertilizer				
571 (2.5 × 7m)	59	51	48	48
476 (3 × 7 m)	60	55	51	52
416 (3 × 8 m)	61	59	52	55
Organic fertilizer				
476 (3 × 7 m)	70	110	109	69

DISCUSSION

The WaNuLCAS model was able to satisfactorily describe rubber growth (girth) increment for the research area after parameterization of tree growth values which were adapted to the clone that was used. However, the model validation showed that WaNulCAS tended to under predict rubber growth (girth) increments during the sixth and twelfth years of simulation. The under prediction could have been due to the diverse management options of famers; for example the fertilizer rates that were obtained from the literature review (Kungpisdan *et al.*, 2013). Moreover, the WaNuLCAS model uses meteorological data based on rainfall. In the current study, WaNuLCAS used 1 yr of rainfall data (2013) from an automatic weather station located at the study site for the 10 yr of simulation. Therefore, the rainfall distribution and total rainfall in the model may have differed from the amount of rainfall and its distribution pattern at the study site during 2008 and 2011. Rainfall has an effect on predicting water shortage that in turn is related to rubber girth increment and such an over prediction in girth increment simulation was also reported by Boithias *et al.* (2011) and Yahya (2007). In the current validation, an under prediction of girth increments was found in the maturity period (at age 6 and 12 yr), probably due to the inability of the model to adequately describe the morphology and branching characteristics of observed trees since the model uses default values that rely on a fixed ratio between the canopy radius and height and the maximum canopy radius to describe the shape of individual trees (van Noordwijk *et al.,* 2004). The reduction in the maize yield in the intercropping systems presented in this study may have been related to the establishment of trees resulting in variation in the light interception by the crops due to the spread of the tree canopy and competition for nutrient and water uptake at the tree-crop-soil interface. Other studies of tree intercropping systems have also reported the same trend; orange trees (*Citrus sinensis* L.) and avocado trees (*Persea americana* Mill.) were found to significantly reduce cacao (*Theobroma cacao* L.) yield to around 47% compared with cacao monocropping (Louis *et al*., 2013). Pinto *et al*. (2005) studied the plant growth and yield of sugarcane monocropping and agroforestry systems in Brazil. They showed that mature eucalyptus trees negatively affected the sugarcane growth and yield as the sugarcane dry matter decreased from 35.1 to 8.70 $Mg.ha^{-1}$ from the furthest to the closest position to a tree. Manuel (2011) also reported the growth of two timber trees—gmelina (*Gmelina arborea* R. Br.) and bagras (*Eucalyptus deglupta Blume*)—had a reducing effect on maize grain yield. Therefore, the application of organic and inorganic fertilizers in rubber intercropping can mitigate the competition for nutrients between rubber and maize and increase the soil structure for improved water infiltration and storage (Pansak *et al*., 2010). The positive impacts of organic and chemical fertilizer reducing nutrient competition were also stated in other studies (Schroth *et al*., 2001, Abebe *et al*., 2013). Moreover, Pansak *et al*. (2008) reported that the highest maize yield (5.5 $t.ha^{-1}$) was obtained from sole maize with chemical fertilizer together with mulching material (maize stover). After 10 yr, there were differences in the rubber girth increment and wood volume of the intercropped systems compared to the monoculture of rubber trees. Both parameters were higher under rubber monocropping than in the intercropped systems. However, the rubber tree girth increments were within the range reported by Chantuma *et al*. (2012). In both sole and intercropped rubber systems, tree spacing showed similar trends in tree girth increment and wood volume. With a higher tree density, the tree growth and wood volume were lower in all systems studied which was also stated by Bernardo *et al*. (1998) where a decreased spacing of *Eucalyptus* spp. decreased the diameter and total biomass. The spatial and temporal efficiency by which plants acquire growth resources determines the overall productivity of rubber plantations; hence the optimum planting density and suitable crop combinations strongly influence the performance of intercropping systems.

CONCLUSION

The WaNuLCAS model can be used as a tool to generate knowledge relating to land use and to support decision-making with regard to smallholder rubber plantations in Thailand. The model showed that rubber intercropping with maize using recommended fertilization together with the application of organic fertilizer was the best way to mitigate the competition between the rubber and the crop in intercropped systems. In the long term, the rubber tree girth and wood volume of sole cropping was higher than in rubber intercropped systems. With a higher rubber tree density, the rubber tree girth increases were smaller.

The results could be adopted to other regional areas and Southeast Asian countries where environmental conditions are similar.

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