Journal of Tropical Crop Science Vol. 6 No. 1, February 2019
www.j-tropical-crops.com

Modification of Rubber (*Hevea brasiliensis Muell*. Arg.) Spacing for Long-term Intercropping

Sahuri[A]*, Andi Nur Cahyo[A], Risal Ardika[A], Iman Satra Nugraha[A], Aprizal Alamsyah[A], and Nurmansyah

[A] Sembawa Research Centre, Indonesian Rubber Research Institute
[B] Plant Production Department, College of Food and Agriculture, King Saud University
Jl. Raya Palembang-Betung Km 29, Palembang 30001, Indonesia

*Corresponding author, email: sahuri_agr@ymail.com

Abstract

Low prices of rubber has been a serious problem to rubber growers in Indonesia. Rubber-based intercropping systems offers a practical solution to this issue and increasing overall productivity, for example by growing upland rice and maize between the rubber tree rows. This study was aimed to determine the suitable spacing in rubber planting to facilitate long-term rubber-based intercropping systems. A field experiment was established in a smallholder rubber plantation in the Tanah Laut Regency, South Kalimantan with area of 50 ha. Two planting patterns of rubber clone PB260 were tested: (1) single row planting pattern (SR) by 6 m x 3 m, and (2) double row planting pattern (DR) by 18 m x 2 m x 2.5 m. The experiment showed that the girth of the rubber trees with the SR system at the 1st tapping year was slightly larger than that in the DR system, even though statistically it was not significant. The latex yield per tree of SR and DR systems were similar, however, latex yield per hectare of SR system was higher than the DR system due to a higher tree population in the SR system. The DR system was technically suitable for long term intercropping, because when the rubber tree reached 8 to 9-year-old, the light penetration was > 80% at distance of about 4 m from the rubber tree rows. Economically, DR system can increase the added values for rubber farmers because it allows long term intercropping. Rubber-based intercropping with DR system is suitable to be applied, especially by smallholders, with a marginal benefit cost ratio of around 2.07.

Keywords: *Hevea*, intercropping system, rubber planting pattern, spatial arrangement

Introduction

Rubber is as source of income for more than 12 million Indonesian people (Nancy et al., 2013), and is one of the important sources of foreign exchange (Rosyid, 2007). The income from growing rubber in Indonesia has been fluctuating due to the fluctuations of the rubber price (Sahuri and Rosyid, 2015). The global rubber market price tends to decrease (SICOM, 2018), resulting in serious problems including 1) farmers started to stop new or replanting rubber and changed professions; 2) conversion of rubber plantation into other crops; 3) decreases in farmer welfare level and purchasing power; 4) increasing crimes; and 5) poor quality of health and education, particularly in smallholders community (Syarifah et al., 2015). Intercropping rubber with other economical food crops, for example upland rice, maize, soybean, long bean, pineapple, chili, and banana, offers a potential solution to this problem, because intercropping can increase land and rubber productivity (Rodrigo et al. 2001; Rodrigo et al., 2004; Xianhai et al., 2012; Sahuri, 2017a).

Benefits of intercropping rubber and food crops compared to monoculture of rubber includes 1) reduced weed growth in rubber planting area (Pathiratna, 2006; Pathiratna and Perera, 2006; Sahuri, 2017b; Sahuri, 2017c); 2) girth growth of the intercropped rubber is better than that in monoculture (Rodrigo et al., 1995; Wibawa and Rosyid, 1995; Weifu et al., 1999; Rodrigo, 2001; Pathiratna, 2006; Ferry et al., 2013; Tistama et al., 2016; Sahuri, 2017b; Sahuri, 2017c; Sahuri, 2017d); 3) intercropping can increase rubber production (Ogwuche et al., 2012; Snoeck et al., 2013); 4) intercropping can increase soil organic matter (Rodrigo et al., 2004; Rodrigo et al., 2005; Pansak, 2015; Tistama et al., 2016; Sahuri, 2017b); and 5) potentially increase farmers income in addition to producing foods for their own consumption (Raintree, 2005; Ogwuche et al., 2012; Snoeck et al., 2013; Sahuri, 2017b; Sahuri, 2017c; Sahuri, 2017e).

Generally, farmers in Indonesia grow rubber trees using single planting distance of 6 m x 3 m (550 trees/ha), or 7 m x 3 m (476 trees/ha) (Rosyid, 2007; Rosyid et al., 2014; Sahuri, 2017a; Sahuri, 2017e), hence the intercrops can only be planted until rubber plants are one to two years old (Xianhai et al. 2012; Rosyid et al. 2014; Sahuri 2017a; Sahuri 2017b; Sahuri, 2017e). Areas that can be used for intercrops is around 50 to 60% of rubber total area (Wirnas, 2007 ; Sigar and Rahadian, 2008; Rosyid et al., 2014; Sahuri and Rosyid, 2015; Sahuri et al., 2016; Sahuri, 2017b; Sahuri, 2017c; Sahuri, 2017d). However, with planting distance of 6 m x 3 m, the canopy of two-year-old rubber trees have covered the areas between rows and reduced the light intensity to 50 to 60% (Wirnas, 2007; Widiharto, 2008; Marwoto et al., 2018; Fikriati, 2010; Sahuri, 2017a; Sahuri, 2017c; Sahuri, 2017e).

Intercrops planted under > 50% shade will have decrease yields up to 60% as reported in upland rice, maize, and soybean compared without shade conditions (Wirnas, 2007; Marwoto et al., 2008; Widiharto, 2008; Sahuri, 2017e). Therefore, modification of rubber planting distance from single spacing to double spacing should be examined (Rodrigo et al., 2004; Xianhai et al., 2012; Sahuri, 2017a). Double plant spacing will allow more sunlight to intercept between rubber row (Xiongfei and Nengfa 2004; Raintree 2005; Rodrigo et al. 2004; Xianhai et al. 2012; Sahuri, 2017a).

Double spacing is also suitable for long-term rubber intercropping due to higher sunlight penetration (Xiongfei and Nengfa, 2004; Rodrigo et al., 2004; Xianhai et al., 2012; Sahuri, 2017a). Double plant spacing of 14.1 m x 2.4 m x 2.4 (500 trees/ha), will allow intercropping up to five years with light intensity arround 70 to 80% of open area (Rodrigo et al., 2004). With double spacing of 20 m x 4 m x 2 m (416 trees/ha) intercrops can be planted throughout life cycle of rubber plants (Xianhai et al., 2012). In addition, Raintree (2005) reported with plant spacing of 18 m x 2.5 m x 2 m (400 trees/ha) intercrops can be grown in a longer durations, and more resistant to high speed winds. Therefore, it is necessary to conduct a research with focus on rubber spacing that allow high sunlight intensity for the intercrops without suppressing rubber growth and production. The purpose of this study was to determine suitable spacing of rubber trees to allow long-term intercropping with upland rice and maize.

Materials and Methods

Research was carried out in Batu Ampar Village, Tanah Laut Regency, South Kalimantan Province and covering 50 ha from 2008 to 2017. Rubber experiment used two planting patterns of rubber clone PB260, namely: (1) single row planting pattern (SR) of 6 m x 3 m (population 550 trees ha^{-1}), and (2) double row planting pattern (DR) of 18 m x 2 m x 2.5 m (population 400 trees ha^{-1}). Measurement of rubber trees used a simple random sampling method by comparing SR and DR system with 120 sample trees per plot. Data were collected on rubber girth from one to eight years after planting (YAP), bark thickness at eight YAP using caliper to measure distance between bark outest layer and cambium layer, rubber yields at seven and eight YAP, canopy spread at eight YAP. Light penetration was measured using LI-COR Line Quantum Sensor. Light penetration was measured by comparing light intensity in the areas under and without rubber canopy. The measurement of light penetration was replicated three times. Tapped rubber are trees with a trunk girth of about 45 cm, measured 100 cm from the ground. Tapping system was half-spiral conducted every two days for a year of tapping ($1.2S^{-1}$. $D2^{-1}$). Rubber yield per hectare was calculated in grams per tree per tapping ($g.t^{-1}.t^{-1}$) multiplied by the number of tapped populations per ha with the total effective tapping days for one year is 150 days. The fertilizer types and dosages applied to the rubber trees were presented in Table 1.

Two crops, maize “Pioneer” and rice “Inpago”, were intercropped with rubber trees. The experiment was arranged in a split plot design with three replications. The main plot of the experiment was rubber spacing system consisted of single row planting pattern (SR) and double row planting pattern (DR). The sub-plot

Table 1. The fertilizer applied to rubber trees.

Fertilizer type	Amount of fertilizer ($kg.\ tree^{-1}.year^{-1}$) applied to rubber trees		
	Before four years after planting	Five years after planting to period before tapping	Tapping period
Ammonium sulphate	0.75	0.60	0.85
Super phosphate	0.78	0.50	0.44
Potassium chloride	0.50	0.50	0.70
Kieserit	0.23	0.20	0.15

the intercrops, maize and rice. Planting distance of maize is 80 cm x 20 cm (population 62,500 plants ha^{-1}) and upland rice is 40 cm x 10 cm (250,000 plants ha^{-1}). Number of farmers included in the study of upland rice and maize is 25 farmers each. Yields were measured on upland rice and maize intercropped with one to three-year-old rubber trees. The areas planted with upland rice or maize is 500 m^2 each. The plots were minimum soil tillaged and weeded prior to planting. Plot distance from rubber tree rows is 1 m. The dosage of fertilizers applied to the intercrops were presented in Table 2.

Experiment Layout

Two planting pattern systems were studied: (1) single row planting pattern (SR) with distance between rows is 6 m and between plants is 3 m, or a population 550 trees per ha; (2) double row planting pattern (DR) with double row planting distance of 18 m, distance between narrow lines is 2 m, and distance between trees is 2.5 m, or a population 400 trees per ha. (Figure 1).

Data Analysis

Data was analyzed with ANOVA; significant differences between means were further separated using Duncan Multiple Range Test (DMRT) at 5% using Statistical Analysis System 9 (SAS). Growth measurement were analyzed using paired samples test (Gomez and Gomez, 1995). Economic analysis of upland rice and maize as intercrops used input-output analysis method (R/C Ratio) (Soekartawi, 1995) by applying the formula as follows:

$$R / C = Po . Q / (TFC+TVC)$$

where:
R = revenue
C = cost
Po = production cost
Q = production
TFC = fixed cost
TVC = variable cost

Profitability was classified into
R / C Ratio >1= profitable farming
R / C Ratio 1 = farming is at break even
R / C Ratio<1 = farming is not profitable

The technological feasibility was carried out by analyzing marginal benefit cost ratio (MBCR). MBCR is farm income improvement pattern minus farmer income farmer pattern, divided by farming costs improvement pattern minus farmer farming costs.

Table 2. The fertilizer applied to rubber intercrops.

Rubber intercrops	Fertilizer type ($kg.ha^{-1}$)			Organic fertilizer ($kg.ha^{-1}$)	Dolomit ($kg.ha^{-1}$)
	Ammonium sulfate	Super phosphate	Potassium chloride		
Upland rice	200	200	100	1,500	500
Maize	350	250	100	1,500	750

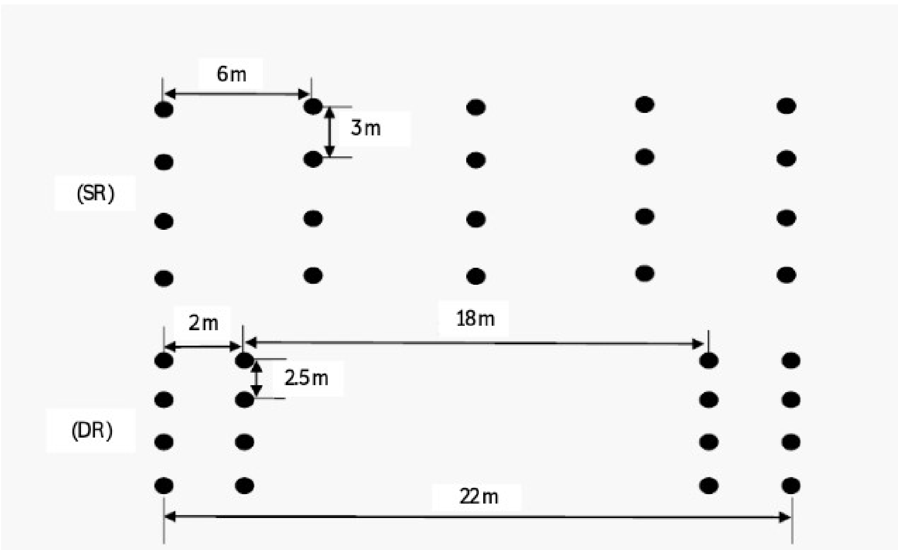

Figure 1. Experiment layout of rubber planting patterns system: (1) single row planting pattern system (SR); and (2) double row planting pattern system (DR)

Intercropping advantage was determined using the Land Equivalent Ratio (LER) analysis for a known plant population density of the intercropping system and compared to known optimum plant population density of monocrop scenarios:

$$LER = \sum_{j=1}^{n} \frac{Yj,i}{Yj,s}$$

yj,i = yield of intercrop component (kg. ha^{-1})
yj,s = yield of monocrop component (kg. ha^{-1})
n = number of component crops

Results and Discussion

Stem Girth

Generally, the girth growth in rubber with double row planting pattern system (DR) was good and reached maturity at 4.5 years old. The rubber girth of eight-year-old trees with single row planting pattern system (SR) was 56.10 cm whereas with DR was 55.20 cm (Figure 2), so it was nine mm larger even though statistically was not significant (P = 0.484).

Overall, the growth of rubber girth at one to eight years with SR and DR system was not significantly different, but the growth rubber girth on 1st of mature period with the SR system was slightly higher than that with DR system. These results are in line with research result of Rodrigo et al. (2004); Raintree (2005); and Xianhai et al. (2012). The latex yield per tree with SR and DR system was similar. The SR system, however, has more trees per unit area, therefore the latex yield per tree is actually higher than that DR system.

Bark Thickness

The bark of the 8-year-old rubber trees with DR system was slightly thicker (0.78 cm) than that with SR (0.76 cm), even though statistically was not significant (P = 0.237; Figure 3).

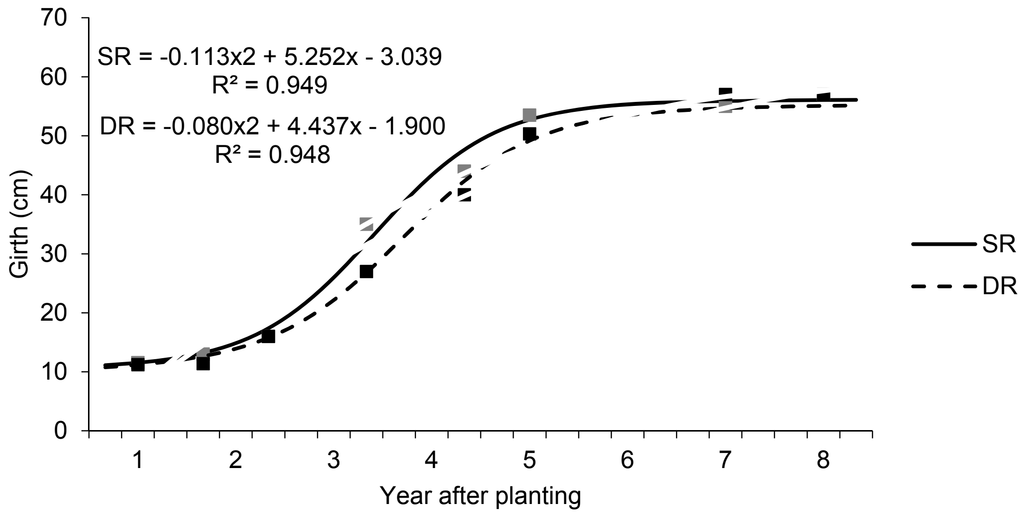

Figure 2.The effect of planting patterns on rubber girth; SR: single row planting pattern; DR: double row planting pattern

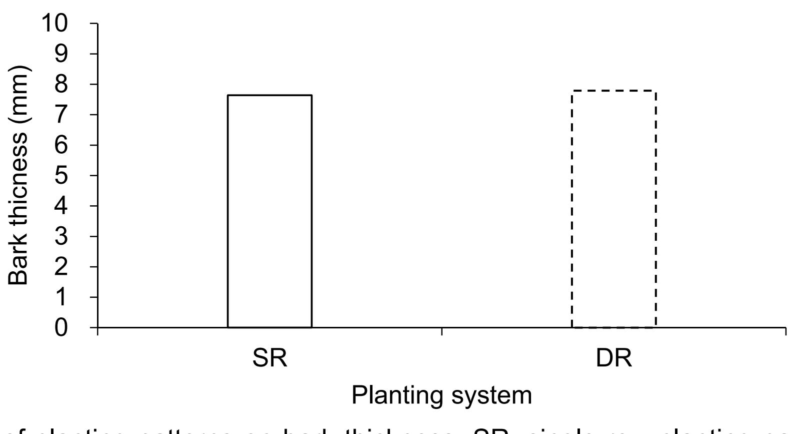

Figure 3.The effect of planting patterns on bark thickness; SR: single row planting pattern; DR: double row planting pattern.

Latex Yield

Latex yield of the rubber trees with the SR and DR system were not significantly different (P = 0.798). However, the latex yield per hectare of the SR system is significantly higher than the DR system (Table 3). This is because the population in the SR system is more than the DR system, and the latex yield per hectare depends on the latex yield per tapping of the individual tree and the number of trees per hectare. With the DR system rubber trees can be intercropped longer than with SR system. Rubber with SR system can only be intercropped until rubber trees were two-year-old, whereas with the DR system rubber trees can be intercropped throughout the production lives. This is because the DR system provides more space than the SR system, providing sufficient light and nutrition for the intercrops, so DR system can potentially increase productivity of rubber plantations. Revenues obtained from intercrops are expected to overcome the decrease in yield due to larger plant spacing, which has been reported by Xiongfei and Nengfa (2004); Rodrigo et al. (2004); Raintree (2005); and Xianhai et al. (2012).

Table 3. The effect of planting pattern system on latex yield

Planting system	Yield ($g.p^{-1}.s^{-1}$)	Latex yield ($kg.\ ha^{-1}.years^{-1}$)*
Single row	23.92a	1,614.60a
Double row	24.17a	1,450.20b

Note: values followed by the same letters within the same column were not significantly different according to DMRT at 5%. *Average production in grams per tree per tapping ($g.t^{-1}.t^{-1}$) multiplied by the number of tapped trees per ha and the total effective tapping days in one year (150 days).

Canopy Spread

At the age of 8 years after planting (YAP) rubber canopy had spread and covered the areas between rows. Canopy dispersal in the DR system was significantly greater (4.46 m) than the SR system (2.48 m) (P = 0.042). Canopy in the DR system spreads to around 4.46 m, while the SR system is 2.48 m. This means that the area that was not shaded in the DR system is 9.08 m, in contrast to only 1.04 m in the SR system. Overall, the uncovered land area of the 8-year-old rubber trees with the DR system was 45.40%, whereas with the SR system it was 12.48%.

Light Penetration

The average light penetration in the center of the SR system is 22.35% (Figure 4) whereas in the narrow row of the DR system is 15.6% (Figure 5). This means that the light penetration in SR system is < 30% at each point of measurement. Meanwhile, the penetration of light in the DR system is > 80% within 4 m of rubber rows. Therefore, the DR system is more suitable for a long-term rubber-based intercropping.

The DR system is technically suitable for long term intercropping, because when the rubber trees are 8 to 9 year-old the light penetration to the areas between rows had reached > 80% at 4.0 m from the rows. The DR system can add values for rubber growers as this system allows longer period of intercropping. The potential of intercropped area of the SR and DR systems are 60% and 80% respectively. To keep the area between rubber rows open to sunlight rubber trees with a pine-branching type can be grown. This is in line with the results of Xiongfei and Nengfa (2004); Rodrigo et al. (2004); Raintree (2005); and Xianhai et al. (2012), show that double spacing is also suitable for long-term rubber intercropping due to higher sunlight penetration and with intercropping up to five years with light intensity arround 70-80% of open area and can be planted with intercrops longer and more resistant to high wind speed.

Intercrops Yield

In the SR system intercrops can only be planted until the rubber trees were 2-year-old, whereas in the DR system the intercrops can be planted until they were 3-year-old or more. This is because in the SR system, the canopy of the >2-year-old rubber trees had reduced light up to 60%. The yield of upland rice and maize intercrops per hectare on the SR and DR systems were similar. The yield of the first and second planting season for upland rice and maize crops in the SR system were 2,150 to 5,410 $kg.ha^{-1}$ and 1,950 to 4,950 $kg.ha^{-1}$, respectively. The yields of the first, second and third planting season of the upland rice and maize in the DR system were 2,210 to 5,230 $kg.ha^{-1}$, 2,150 to 5,400 $kg.ha^{-1}$, and 2,250 to 4,950 $kg.ha^{-1}$, respectively (Table 4).

The increase in income from food crops intercropped with rubber can be seen from the difference in income derived from the food crops and the costs incurred for the production. SR and DR intercrop systems had the R/C ratios of 1.86 and 1.93, respectively. Revenues from rice or corn intercropped with rubber with the DR system was IDR 42,649,775, which was greater than

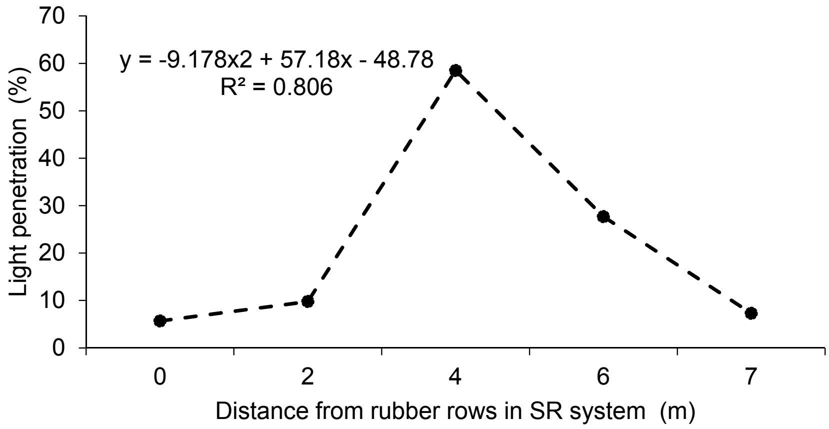

Figure 4. Light penetration between row of SR system at 8 YAP

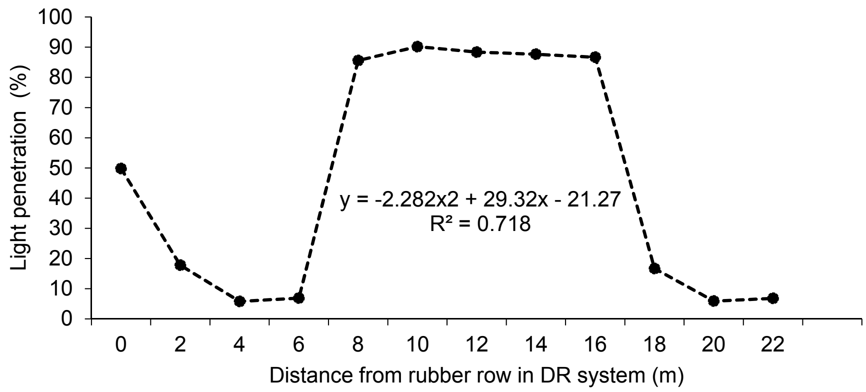

Figure 5. Light penetration between rows of the DR system at 8 YAP

Table 4. The yield of upland rice and maize as intercrops in SR systems and DR systems

Cropping System[1)]	1st year		2nd year		3rd year	
	1st period	2nd period	1st period	2nd period	1st period	2nd period
SR systems						
Upland rice (DGP kg.ha^{-1})[2)]	2,150	–	1,751		–	–
Maize (DGM kg.ha^{-1})[3)]	–	4,511	–	4,412	–	–
DR systems						
Upland rice (DGP kg.ha^{-1})[2)]	2,210	–	2,141	–	2,051	–
Maize (DGM kg.ha^{-1})[3)]	–	4,751	–	4,533	–	4,337

Note: The values in the same column were not significantly different according to DMRT at 5%; [1)] The population and areal of upland rice and maize as rubber intercrops are 60% of monocropping with a distance of upland rice and maize from the row of rubber trees is 1 m; [2)] Milled dry grain production (DGP) of upland rice in monocropping is 4,500 - 5,500 kg.ha^{-1} (Pringadi et al., 2012).[3)] Monocropping hybrid maize production of dry grain maize (DGM) is 7,500 - 8,500 kg.ha^{-1} (Sudiana and Martiningsih 2012).

the SR system of IDR 27,672,750 (Table 5).

Land Equivalent Ratio (LER), which is the ratio of area required in a monoculture system to a unit area of intercropping system with the same management to give an equal amount of yield, was used to determine land productivity (Jalloh et al., 2003). Table 6 show the yields from different cropping scenarios. The total area required for rubber, upland rice and maize grown in monoculture to produce an equivalent of a one hectare of rubber-upland rice-maize intercrop is 1.87 (calculation below). This means the intercropping system has advantages compared to monoculture.

$$LER = \left(\frac{1{,}450.2}{1{,}614.6} + \frac{2{,}063}{5{,}010} + \frac{4{,}500.9}{8{,}016}\right)$$

$$= 0.89 + 0.41 + 0.56$$

$$= 1.87 \text{ ha}$$

Table 5. Economical analysis of intercropping of rubber trees with food crops with single and double row systems

Description	SR System[1)]		DR System[2)]	
	Value (IDR)[3)]	(%)	Value (IDR)[3)]	(%)
Upland rice seeds	350,000	2.35	525,000	2.37
Maize seeds	150,000	1.01	225,000	1.02
Land cultivation	600,000	4.02	900,000	4.07
Cost (A)	1,100,000	7.38	1,650,000	7.45
Fertilizer				
Urea	702,000	4.71	1,053,000	4.76
SP36	400,000	2.68	600,000	2.71
KCl	1,500,000	10.06	2,250,000	10.16
Dolomite	660,000	4.43	880,000	3.98
Cost (B)	3,262,000	21.88	4,783,000	21.61
Pesticide				
Carbofuran	240,000	1.61	367,500	1.66
Insectiside	240,000	1.61	360,000	1.63
Herbicide Round up	520,000	3.49	650,000	2.94
Cost (C)	1,000,000	6.71	1,377,500	6.22
Labour[4)]				
Planting	1,800,000	12.07	2,700,000	12.20
Manuring I	1,800,000	12.07	2,700,000	12.20
Manuring II, III,	1,080,000	7.24	1,620,000	7.32
Weed control	720,000	4.83	1,080,000	4.88
Pest and dissease control	450,000	3.02	675,000	3.05
Cost (D)	5,850,000	39.23	8,775,000	39.64
Harvest and postharvest				
Harvest	2,700,000	18.11	4,050,000	18.30
Transport	1,000,000	6.71	1,500,000	6.78
Cost (E)	3,700,000	24.81	5,550,000	25.07
Production cost (A+B+C+D+E)	14,912,000	100	22,135,500	100
Income	27,672,750		42,649,775	
Dry milled rice (12% water content)	9,542,750		15,384,775	
production of dry grain maize (17% water content)	18,130,000		27,265,000	
R/C ratio	1.86		1.93	
MBCR[5)]			2.07	

Notes : [1)] intercrop of 2-year-old rubber trees with food crops with SR system; [2)] intercrop of 3-year-old rubber trees with food crops with DR system; [3)] Based on prices in November 2017 in South Sumatra, Indonesia; [4)] regional minimum wage standard in South Sumatra in 2017; [5)] technological feasibility was analyzed with marginal benefit cost ratio (MBCR)

Table 6. The potential yield of rubber, upland rice and maize in monocropping and intercropping systems.

Cropping system	Plant population density (ha^{-1})	Yield ($kg.ha^{-1}$)
Monoculture		
Rubber	500	1,615
Upland rice	250,000	5,010
Maize	625,000	8,016
Intercropping		
Rubber	400	1,450
Upland rice	125,000	2,063
Maize	312,500	4,500

Note : Rice or maize population and growing area as intercrops is 60% of the monoculture system; distance of upland rice and maize crops from the row of rubber trees is 1 m.

Intercropping advantages can been described in many forms, including monetary economic terms, economic yield, biomass yield or dry matter yield. Land Equivalent Ratio (LER) is a more widely used concept, which is defined as the ratio of area needed under monoculture to a unit area of intercropping at the same management level to give and equal amount of yield (Jalloh et al., 2009). In terms of income, intercropping of rubber with upload rice or maize is more productive than monoculture system. Intercropping with SR system can be conducted until the rubber trees are two-year-old, and > three years with DR system before the light started to be limiting for the intercrop growth.

Conclusions

The results of the study showed that with the SR system the growth of rubber trees in the first tapping year was slightly better than with the DR system, but the differences were not significant. Latex yield per tree with DR and SR system was similar, but the latex yield per hectare was significantly higher with DR. The SR system can only be intercropped until rubber trees are about two-year-old, whereas with the DR system it can be longer. The light penetration in the areas between rows of eight-year-old rubber trees with SR system is not more than 30%, whereas with DR systems it was > 80%, measured at a distance of 4 m from the rubber tree rows. Technically, it is feasible to intercrop rubber trees with food crops. Economically, intercropping of rubber with food crops, with either SR or DR system, is profitable with R / C ratio of 1.86 and 1.93, respectively. Therefore, it is feasible to grow food crops intercropped with rubber trees with the DR sytem, particularly for smallholders, with a MBCR value of 2.07. Planting rubber with double row spacing of 18 m x 2 m x 2.5 m is recommended for longer-term intercropping.

Acknowledgements

The authors thanked Ir. M. Jahidin Rosyid, MS as principal investigator who has provided his valuable input and suggestions in writing this paper. The authors gratefully acknowledged the Directorate General of Plantations, District Tanah Laut, for the permits and facilities provided throughout the study.

Author’s Contributions

All the listed authors had participated in the the research and reviewed the manuscript and also wrote the draft of the manuscript. All the listed authors had contributed to investigation and acquisition of data and were involved in sample analysis.

References

Ferry, Y., Pranowo, D. and Rusli. (2013). The effect of intercropping on the growth of immature rubber in a gradual felling system. *Buletin Riset Tanaman Industri* **4**, 225-230.

Fikriati, M. (2010). “Adaptation Test of Soybean (*Glycine max* (L.) Merr.) Shade Tolerance under Rubber in Rubber Smallholder in Sarolangun District, Jambi”. Thesis. Institut Pertanian Bogor, Indonesia. http://repository.ipb.ac.id/jspui/bitstream/123456789/27130/6/Bab%20I%20Pendahuluan%20A10dpr-3.pdf.

Jalloh, M. B., Sulaiman, W., Harun, W., Talib, J., Ramlan, M. F., Amartalingam, R., Sung, C. T. B., and Ahmed, O.H. (2009). A Simulation Model Estimates of the Intercropping Advantage of an Immature-Rubber, Banana and Pineapple System. *American Journal of Agricultural and Biological Sciences* **4**, 249-254.

Jalloh, M. B. (2003). “Modeling of Solar Radiation Interception and Biomass Production in an Intercropping System of Rubber with Banana and Pineapple”. PhD Thesis. University Putra Malaysia. http://webopac.upm.edu.my.

Marwoto, Wijanarko, A., and Subandi. (2008). Prospect of soybean cultivation in rubber plantation *In “*Proceedings of the National Rubber Agriculture” (M Supriadi, N Siagian, T. Kustyani, A. Rahmawan. Eds). Pp, 280-293, Indonesian Rubber Research Institute, Bogor, Jawa Barat, Indonesia.

Nancy, C., Agustina, D. S., and Syarifa, L. F. (2013). The potential of rubber wood produced by smallholder rubber to supply the rubber wood industry case study in South Sumatra Province. *Jurnal Penelitian Karet*, **31**,: 68–78.

Ogwuche, P., Umar, H. Y., Esekhade, T. U., and Francis, S. Y. (2012). Economies of intercropping natural rubber with arable crops: a panacea for poverty alleviation of rubber farmers. *Journal of Agriculture Social Science* **8**, 100–102.

Pansak, W. (2015). Assessing rubber intercropping strategies in Northern Thailand using the water, nutrient, light capture in agroforestry systems model. *Kasetsart Journal* **49,** 785−794.

Pathiratna, L. S. S., and Perera, M. K. P. (2006). Effect of competition from rubber on the yield of intercropped medicinal plants *Solatium virginianum* Schrad., *Aerva lanata* (L.) Juss. Ex. Schult and *Indigofera tinctoria* L. *Journal of the Rubber Research Institute of Sri Lanka* **87,** 36-45.

Pathiratna, L. S. S. (2006). Management of intercrops under rubber: implications of Competition and possibilities for improvement**.** *Bulletin of the Rubber Research Institute of Sri Lanka* **47,** 8-16.

Pringadi, K., Toha, H. M., and Guswara, A. (2012). NPK fertilization of upland rice as rubber intercrops in rubber immature. *Jurnal Soil Rens* **2,** 133-141.

Raintree, J. (2005). Intercropping with rubber for risk management, improving livelihoods in the Lao PDR. *Agriculture and Forestry Research* **2,** 41-46.

Rodrigo, V.H.L., Nugawela, A., Pathirathne, L. S. S., Kodikara, P. B., and Weeralal, J.L.K. (1995). Effect of planting density on growth, yield related factors and profitability of rubber (*Hevea brasiliensis* Muell. Arg.). *Journal Rubber Research Institute of Sri Lanka* **76,** 55-71.

Rodrigo, V.H.L., Stirling, C. M., Teklehaimanot and, Z., and Nugawela, A. (2001). Intercropping with banana to improve fractional interception and radiation-use efficiency of immature rubber plantations. *Field Crops Research* **69**, 237-249.

Rodrigo, V. H. L., Silva, T. U. K., and Munasinghe, E. S. (2004). Improving the spatial arrangement of planting rubber (*Hevea brasiliensis* Muell. Arg.) for long-term intercropping. *Field Crops Research* **89,** 327-335.

Rodrigo, V. H. L., Stirling, C. M., Silva, T. U. K., and Pathirana, P. D. (2005). The growth and yield of rubber at maturity is improved by intercropping with banana during the early stage of rubber cultivation. *Field Crops Research* **91**, 23–33.

Rosyid, M. J. (2007). Effect of intercrops on rubber growth in participatory rejuvenation areas in Sarolangun, Jambi. *Indonesian Journal of Natural Rubber Research* **25,** 25-36.

Rosyid, M . J., Wibawa, G., and Gunawan, A. (2014). “Saptabina Usahatani Karet Rakyat: Pola Usahatani Karet”. Balai Penelitian Sembawa, Palembang, Indonesia.

Sahuri and Rosyid, M. J. (2015). Optimization of land between rubber rows using cayenne pepper (*Capsicumfrutescens* Linn.) as intercrops. *Warta Perkaretan* **34,** 77-88.

Sahuri, Cahyo, A. N., and Nugraha, I. S. (2016). Rubber-rice intercropping system at farmer level in tidal swamp, a case study in Nusantara Village, Air Sugihan, OKI District, South Sumatra Province. *Warta Perkaretan* **35,** 107-120.

Sahuri. (2017a). Improving rubber spacing system of rubber (*Hevea brasiliensis* Muell.Arg.) for long-term intercropping. *Journal of Indonesia Agriculture* **22,** 2443-3462.

Sahuri. (2017b). Adaptation trials of sweet sorghum as intercrops in immature rubber plantation. *Indonesian Journal of Natural Rubber Research* **35,** 23 – 38.

Sahuri. (2017c). Increasing of land productivity and smallholders income through rubber based food crops intercropping system. *Jurnal Lahan Suboptimal* **6,** 33-42.

Sahuri. (2017d). Effect of shorgum as rubber intercrops on the growth of immature rubber. *Jurnal Agroteknologi* **8,** 1- 10.

Sahuri. (2017e). Development of corn (*Zea mays* L.) in immature rubber period. *Jurnal Analisis Kebijakan Pertanian* **15,** 113-126.

Singapore Commodity Exchange Limited (SICOM). 2018. “Market Information*”* www.sgx.com. [October 10, 2018].

Sigar, P. and Rahadian, M. D. (2008). Economically value of corn commodities as rubber intercrops in rubber plantation *In “*Proceedings of the National Rubber Agriculture” (M.Supriadi, N.Siagian, T. Kustyani, A. Rahmawan, eds.) pp. 280-293, Indonesian Rubber Research Institute, Bogor, Jawa Barat, Indonesia.

Snoeck, D., Lacotea, R., Kéli, J., Doumbiac, A., Chapuseta, T., Jagoretd, P., and Goheta, É. (2013). Association of hevea with other tree crops can be more profitable than hevea monocrop during first 12 years. *Industrial Crops and Products* **43,** 578– 586.

Sudiana. I. M. and Martiningsih, N. G. A. G. E. (2012). Aplication of spacing and varieties technology of hybrid corn based organik. *Jurnal Ngayah* **3,** 33-43.

Syarifa, L.F., Agustina, D. S., Nancy, C., and Supriadi, M. (2016). Impact of rubber price low on the sosio-economif of rubber smallholders in South Sumatra. *Jurnal Penelitian Karet* **34,** 119-126.

Tistama, R., Dalimunthe, C. I., Sembiring, Y. R. V., Fauzi, I. R., Hastuti R. D., and Suharsono. (2016). Intercropping of shorgum and soybean for increasing of land productivity in rubber immature (*Hevea brasiliensis* Muell Arg). *Indonesian Journal of Natural Rubber Research* **34**, 61-76

Weifu, L., Zhongyu, Z. and Shoufeng, H. (1999). A review and prospect of intercropping in rubber plantation in China. *Jounal of Ecology* **18,** 43-52.

Wibawa, G and Rosyid, M. J. (1995). Peningkatan produktivitas padi sebagai tanaman sela karet. *Warta Perkaretan* **14**, 40-46.

Widiharto, A. (2008). Potensi dan implementasi pengusahaan jagung tanaman jagung pada perkebunan karet *In “*Proceedings of the National Rubber Agriculture” (M. Supriadi, N. Siagian, T. Kustyani, A. Rahmawan, eds.) pp. 280-293. Indonesian Rubber Research Institute, Bogor, Jawa Barat, Indonesia.

Wirnas, D. (2007). “Pemilihan Karakter Seleksi Berdasarkan Analisis Biometrik dan Molekuler untuk Merakit Kedelai Toleran Intensitas Cahaya Rendah”. Thesis. Post Graduate School. Insitut Pertanian Bogor. Bogor.

Xianhai, Z., Mingdao, C., and Weifu, L. (2012). Improving planting pattern for intercropping in the whole production span of rubber tree. *African Journal of Biotechnology* **11,** 8484-8490.

Xiongfei, Y and Nengfa, P. (2004). Intercropping patterns and their development in rubber plantations in Dehong District, Yunnan, China *In* “Proceedings of IRRDB Symposium 2004” (C. Qiubo, Z. Jiannan, and Weifu L, eds.), pp. 183-187. China Agriculture Press.