

Assessment of agronomic practices among natural rubber farmers in Sintang District, West Kalimantan, Indonesia

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Manuscript received: 19 July 2025. Revision accepted: 10 November 2025.

Abstract. *Supriyanto, Ruliyansyah A, Arifin N, Pramulya M, Sulistyowati H. 2025. Assessment of agronomic practices among natural rubber farmers in Sintang District, West Kalimantan, Indonesia. Asian J Agric 9: 754-765.* Smallholder rubber farmers play a crucial role in maintaining the sustainability of the rubber sector in Indonesia; however, their productivity and management practices remain suboptimal. This study assessed the agronomic practices of 470 smallholder rubber farmers in Sintang District, West Kalimantan, Indonesia, using a descriptive-quantitative approach. Data were collected through structured interviews and analyzed using descriptive statistics and Pearson correlation to examine relationships among human resource capacity, socio-economic conditions, and agronomic performance. The results indicate that the majority of farmers are in the productive age group, have low to moderate education, and rely on rubber farming as their primary livelihood. However, farmers tend to prioritize routine operational tasks, such as tapping and latex collection, while key agronomic practices that require more technical knowledge and capital—such as fertilization, the use of certified planting materials, and pest and disease control—remain under-implemented. Correlations indicate that education and access to extension services are positively correlated with the adoption of better agronomic practices, including the use of certified seeds, recommended plant spacing, and proper fertilization. Social roles and group participation also show significant relationships with collective agronomic behavior. These findings highlight the importance of strengthening farmer capacity and institutional support to promote productive and sustainable rubber cultivation among smallholder farmers in Sintang District, West Kalimantan, Indonesia.

Keywords: Agronomic practices, human resource capacity, rubber sustainability, smallholder rubber, West Kalimantan

Abbreviations: GAP: Good Agricultural Practices

INTRODUCTION

Natural rubber (*Hevea brasiliensis* Muell. Arg.) plays a critical role in the global economy as the primary natural source of cis-1,4-polyisoprene. This biopolymer serves as an indispensable raw material for more than 50,000 industrial products. These include approximately 400 types of medical devices, adhesives, engineering goods, and, most prominently, automotive tires, which account for about 70% of total rubber consumption (Laroche et al. 2021; Salehi et al. 2021). As a tropical crop, rubber thrives under specific agroecological conditions, requiring high temperatures (26-32°C), abundant rainfall, and consistent humidity year-round. These requirements make Southeast Asia the world's most crucial rubber-producing region, accounting for around 90% of global production. In 2023, global natural rubber output was estimated at 13.42 million tons, of which approximately three-quarters originated from Thailand, Indonesia, Vietnam, Malaysia, and neighboring countries (Inkonkoy 2022; MRC 2023).

In Indonesia, rubber continues to serve as a strategic agricultural commodity, not only as an export earner but also as a primary source of livelihood for rural populations. The total area of rubber plantations in 2022 reached 3.77 million hectares, with smallholder farmers accounting for 92.81% of production (Directorate General of Plantations, Ministry of Agriculture, Republic of Indonesia 2022).

More than 2.5 million households rely on rubber as their primary source of income, reflecting the commodity's significant socio-economic importance. However, despite its potential, Indonesia's rubber industry faces persistent structural and technical challenges. These include a prolonged decline in global rubber prices since 2011, low productivity levels compared to neighboring countries, and the spread of leaf fall disease (*Pestalotiopsis* sp.), which has been reported to reduce yields by up to 50% (Febbiyanti et al. 2022; Permana and Diyasti 2022). Such challenges have adversely affected farmer welfare, contributing to rural poverty and encouraging the conversion of rubber plantations to alternative crops such as oil palm or fast-growing timber species (Penot and Ilahang 2021; Supriyanto et al. 2023).

West Kalimantan Province is one of Indonesia's key rubber-producing regions, accounting for approximately 13.8% of the national rubber plantation area. Within the province, Sintang District holds the largest share, covering about 95,482 hectares or 18.08% of West Kalimantan's total rubber area (Central Bureau of Statistics of Sintang 2024). In Sintang, rubber has long been considered a strategic crop both economically and socially, providing livelihoods for more than 59.55% of plantation farmers (West Kalimantan Province Plantation and Livestock Service 2021). However, as in many other smallholder-dominated regions, the productivity of rubber plantations in

Sintang remains low, averaging far below the potential yield achieved in commercial or research-managed estates.

The low productivity of smallholder rubber farms is strongly linked to the quality of agronomic practices applied at the field level. Agronomic practices encompass a range of activities, including land preparation, planting methods, crop spacing, fertilization, pest and disease management, tapping techniques, and post-harvest handling. Each of these components significantly influences latex yield, tree health, and long-term plantation sustainability. However, empirical studies that comprehensively assess these practices among smallholder farmers remain limited. Most previous research has focused on socio-economic or marketing dimensions, leaving gaps in understanding the actual field-level agronomic performance of smallholder systems (Azis et al. 2021; Hidayat et al. 2022; Imelda et al. 2023a).

This knowledge gap poses a challenge for the design of effective interventions. Without robust baseline data on farmers' agronomic behavior, national and regional programs aimed at revitalizing the rubber industry risk being misaligned with field realities (Khanal et al. 2021). Against this background, this study aims to (i) identify agronomic practices adopted by natural rubber farmers in Sintang; (ii) evaluate their alignment with best practice recommendations; and (iii) link agronomic practice issues with the human resources and socio-economic conditions of farmers. These findings are expected to provide empirical evidence to support targeted extension policies, guide sustainable plantation management, and ultimately revitalize rubber plantations, thereby improving the welfare of rubber farmers.

MATERIALS AND METHODS

Study area

The research was conducted in Sintang District, West Kalimantan Province, Indonesia, in 2022. The research location covers the entire administrative area of Sintang District (1°05' North Latitude and 0°46' South Latitude and

110°50' East Longitude and 113°20' East Longitude), which consists of 14 sub-districts (Figure 1).

Research design

This research used a quantitative-descriptive approach using a field survey method. This approach allowed researchers to systematically measure various agronomic variables and obtain an accurate picture of the actual conditions of smallholder rubber plantations in the field.

Data type and sources

The data in this study consisted of primary and secondary data. Primary data were collected through interviews and direct observations of rubber farmers in Sintang District. Respondents consisted of 470 farmers spread across all sub-districts in Sintang District. Secondary data were obtained from relevant agencies, particularly the Sintang District Agriculture and Plantation (2022), as well as data from the West Kalimantan Provincial Government Plantation and Livestock Office (2022). Other secondary data used were data from the Central Bureau of Statistics of Sintang (2022) and the West Kalimantan Provincial Statistics Agency (2022).

Population and sampling technique

The population in this study comprised all smallholder rubber farmers in Sintang District. The farmer respondents were selected using a purposive sampling technique, taking into account the distribution of farmers, the distribution of their rubber plantations, and the productivity level of their rubber plantations, based on the latest data from the Central Bureau of Statistics of Sintang (2022). The minimum sample size was determined using the Slovin formula (Tejada and Punzalan 2012).

$$n = N / (1 + Ne^2)$$

Where:

n: The minimum required sample size of rubber farmers.

N: The population size of rubber farmers in Sintang District.

e: The tolerable margin of error

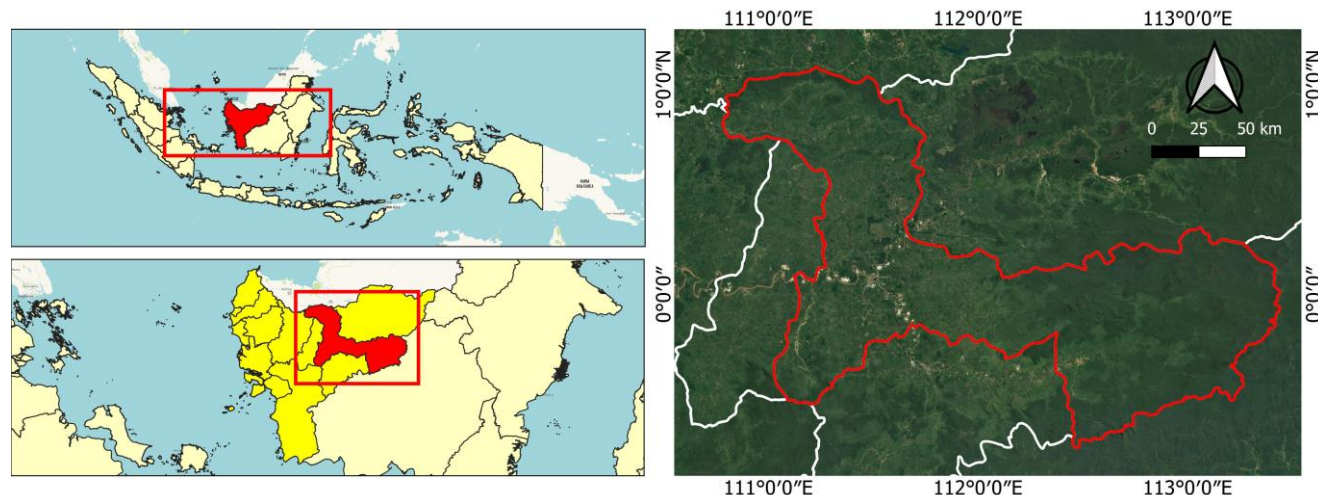


Figure 1. The research site map of Sintang District, West Kalimantan, Indonesia

Meanwhile, the distribution of sample farmers was determined based on the area of rubber plantations in each sub-district and the number of farmers per sub-district. The sample inclusion criteria were farmers with rubber plantations of at least 0.2 ha and willing to be interviewed. The distribution and number of rubber farmer respondents per sub-district are shown in Table 1.

Data collection techniques

Data were collected using several techniques, including a structured questionnaire, semi-structured interviews, and direct field observation. The structured questionnaire for the sample farmers covered six main sections: farmer socio-economic characteristics; planting material sources; land preparation and planting techniques; fertilization and other input use; pest and disease control; tapping techniques; and post-harvest handling. Semi-structured interviews were conducted with three key farmers (farmer group leaders) and relevant plantation officials to expand further the information obtained through the questionnaire. The appropriate officials interviewed in this study were the head of the Sintang District Plantation and Food Service and two agricultural extension workers in Sintang District. Direct field observation was conducted to verify the agronomic practices implemented by the farmers.

Research instrument

The main instrument used in this study was a questionnaire developed based on relevant literature and the national rubber cultivation standards issued by the Directorate General of Plantations, Ministry of Agriculture, Republic of Indonesia (2014) and SKKNI No. 184 of 2018 (Minister of Manpower Decree No. 184 of 2018).

Data analysis

Primary data obtained from interviews with farmers was standardized. This standardization included the use of terminology in rubber cultivation techniques, land area units, weight units, length units, distance units, volume units, and commodity price units. The data were then analyzed using descriptive statistics techniques, social and economic condition index scoring, agronomic practice index scoring, and correlation analysis. Descriptive statistics were used to present the frequency distribution of agronomic practices as percentages, means, and standard deviations. The agronomic condition of rubber farmers in Sintang District is expressed as the percentage of farmers who implement agronomic practices in accordance with Good Agricultural Practices (GAP), then categorized into the following categories: "very good" if >80% of farmers implement practices in accordance with GAP, "good" if 60% - 80% implement practices in accordance with GAP, "adequate" if 40% - 60% of farmers implement practices in accordance with GAP, and "poor" if only 20% - 40% of

farmers implement agronomic practices in accordance with GAP, and "very poor" if only <20% of farmers implement agronomic practices in accordance with GAP based on the national rubber cultivation standards (Directorate General of Plantations, Ministry of Agriculture, Republic of Indonesia 2014) and SKKNI No. 184 of 2018 (Minister of Manpower Decree No. 184 of 2018).

Scoring of farmers' social and economic conditions. Data on farmers' socio-economic conditions that are not in numerical form are converted into numerical form by converting the most ideal conditions as the highest reference number, and the least ideal conditions as the lowest reference number (number 1).

Agonomic practice index scoring. Non-numerical agronomic practice data is assessed and converted into a specific score. The worst-rated agronomic practice is converted to the lowest score (1), and the best-rated agronomic practice is converted to the highest score. The assessment is based on the GAP for rubber cultivation (Directorate General of Plantations, Ministry of Agriculture, Republic of Indonesia 2014). A relationship analysis was conducted using the Pearson correlation test to examine the relationships among farmer socio-economic characteristics, agronomic practices, and rubber farmer productivity (Moore et al. 2017).

Research ethics

This research was conducted after obtaining verbal consent from each respondent prior to data collection, maintaining the confidentiality of farmers' identities and personal information, and without any manipulation of the data or research results.

Table 1. Area of rubber plantations, number of rubber farmers, and number of respondents

Sub-district	Area of rubber plantations (ha)*	Number of rubber farmers*	Number of respondents
Ambalau	3,583	2,040	25
Binjai Hulu	5,539	2,312	25
Dedai	15,347	7,478	70
Kayan Hilir	6,477	2,839	25
Kayan Hulu	6,180	2,755	26
Kelam Permai	10,924	5,475	29
Ketungau Hilir	4,769	2,577	30
Ketungau Hulu	4,914	2,393	26
Ketungau Tengah	6,441	2,717	23
Sepauk	12,046	5,859	78
Serawai	4,020	2,040	20
Sintang	3,483	1,264	32
Sungai Tebelian	7,854	4,142	30
Tempunak	9,688	5,532	31
Total Sintang District	101,265	51,443	470

Source: *: Central Bureau of Statistics of Sintang (2022)

RESULTS AND DISCUSSION

Growth of rubber farmers in Sintang District

Rubber plantations in Sintang District are spread across all sub-districts. The area of rubber plantations in the Sintang District increased by 9% from 2015 to 2020. The area's sub-districts that experienced a significant increase were Kayan Hulu, Ambalau, Dedai, Ketungau Tengah, and Ketungau Hulu. On the other hand, the Serawai Sub-district experienced a 6% decrease in the area. Meanwhile, the number of rubber farmers in Sintang District increased by 5% from 2015 to 2020. The most significant increases in the number of farmers were observed in Kelam Permai sub-district (39%), Ambalau sub-district (32%), and Kayan Hulu sub-district (11%). Meanwhile, the Ketungau Hulu Sub-district recorded a 2% decrease in the number of rubber farmers (Table 2). This result differed from the situation in Thailand, where the increase in rubber plantations has continued to rise significantly, by approximately 37% (around 1.3 million ha) from 2013 to the present (Sowcharoensuk 2022). This situation is likely related to the income level of rubber farmers. In Thailand, the income of rubber farmers remains high because their productivity is high, despite rubber prices generally declining. Meanwhile, amid declining rubber prices in Indonesia, farmers' incomes are declining due to low productivity (MRC 2023). For example, in 2021, Thailand's rubber productivity reached 1.38 tons of dry rubber/ha, while Indonesia's was only 0.81 tons/ha (Directorate General of Plantations, Ministry of Agriculture, Republic of Indonesia 2023). Generally, high incomes lead farmers to continue building new plantations (Montoro et al. 2025).

The area, age, and planting system of farmers' rubber plantations

The results of this study indicate that more than 93.62% of rubber farmers in Sintang District have relatively small landholdings of less than 5 ha; in fact, 39.15% of them own less than 2 ha. Meanwhile, only about 6.38% of farmers own more than 5 hectares of land (Table 3). These results indicate that, generally, rubber farmers in Sintang District

are small-scale farmers with limited land, and on average, the area of rubber plantations owned by farmers is only around 2.46 hectares. Furthermore, upon closer examination, it is found that almost half of the farmers (42.6%) have scattered rubber plantations, resulting in an average plantation size of only 1.72 hectares per farmer. It appears that limited ownership of rubber plantations is a common phenomenon worldwide, as the average area of rubber plantations owned by farmers in India and Thailand is also nearly the same, ranging from 1.52 to 1.81 ha in India and 1.49 to 1.97 ha in Thailand (Diepart et al. 2023). Meanwhile, 61.36% of farmers' land area in Nepal is less than 1 ha (FRTC 2021), and in Malaysia, the average is less than 2.5 ha (Ramli et al. 2021). Except in Thailand and Vietnam, the small landholdings of rubber farmers are often cited as a factor contributing to low productivity and poor farmer welfare (Khanal et al. 2021; Sutrisno et al. 2023).

Currently, the majority of rubber plants in Sintang District are in their productive stage (6-30 years), accounting for approximately 81.28%. Meanwhile, approximately 12.34% of the plants are not yet producing, and approximately 6.38% are mature (over 30 years old). Farmers' rubber plantations in Sintang District use two planting systems: 43.19% use monoculture, and 56.81% use mixed systems. In mixed plantations, farmers typically plant rubber alongside various fruit trees, including cempedak, durian, jackfruit, petai, mango, jengkol, banana, rambutan, pineapple, and langsung. Some farmers also plant rubber alongside forest plants, such as Tengkawang, and other types of wood, as well as other plantation crops, including oil palm, cocoa, and pepper (Figure 2). Some farmers plant rubber with seasonal crops such as cassava and sweet potatoes. Based on the literature, these two planting systems are also standard practices among farmers in Malaysia, Thailand, Vietnam, India, and Cambodia, although the proportions vary (Leepromrath et al. 2021; Diepart et al. 2023). Thus, mixed cropping is a model that is developing in various countries, especially in Southeast Asia. The mixed cropping system is considered more environmentally friendly from many sides because it is more similar to the agroforestry system (Leepromrath et al. 2021).

Table 2. Growth of farmers and area of rubber plantation 2015-2020 in Sintang District, West Kalimantan, Indonesia

Sub-district	Area of rubber plantation			The number of rubber farmers		
	Year of 2015 (ha)	Year of 2020 (ha)	Growth (%)	Year 2015	Year 2020	Growth (%)
Sintang	3,483	3,483	0	1,264	1,264	0
Tempunak	9,383	9,688	3	5,532	5,532	0
Sepauk	11,914	12,046	1	5,859	5,859	0
Ketungau Hilir	4,703	4,769	1	2,552	2,577	1
Ketungau Tengah	5,351	6,441	20	2,727	2,717	0
Ketungau Hulu	4,364	4,914	13	2,445	2,393	-2
Dedai	12,539	15,347	22	7,243	7,478	3
Kayan Hilir	6,172	6,477	5	2,839	2,839	0
Kayan Hulu	4,759	6,180	30	2,489	2,755	11
Serawai	4,266	4,020	-6	2,038	2,040	0
Ambalau	2,862	3,583	25	1,551	2,040	32
Sungai Tebelian	7,876	7,854	0	4,142	4,142	0
Kelam Permai	10,449	10,924	5	3,945	5,475	39
Binjai Hulu	4,992	5,539	11	2,312	2,312	0
Sintang District	93,113	101,265	9	48,953	51,443	5

Source: West Kalimantan Province Plantation and Livestock Service (2021)

Agronomic practices of smallholder rubber farmers in Sintang District

The assessment of agronomic practices among smallholder rubber farmers in Sintang District showed substantial variation in the adoption of recommended cultivation techniques (Table 4). Only a few practices were rated good or very good, while the majority were rated poor or very poor.

Vegetation origin and land clearing methods

Information on the vegetation origin of farmers' plantations is needed to determine whether farmers' rubber plantations result from forest encroachment. This information is required regarding deforestation, which is often associated with rubber commodities from Indonesia. Meanwhile, information on land-clearing methods is needed to determine whether they are environmentally friendly, as deforestation is often associated with forest fires arising from the process of clearing cultivated land (Pendrill et al. 2019). A total of 75.37% of farmers cultivated rubber on non-forest land, indicating that most plantations were established legally and did not contribute to deforestation. This reflects positive compliance with regional land-use regulations that encourage rubber planting on non-forest or degraded land (Huang et al. 2022). However, only 9.55% of farmers practiced land clearing without burning, classified as very poor, indicating that environmentally friendly land preparation remains a minimal practice. Similar conditions were also noted by Montoro et al. (2025), who emphasized the need for participatory approaches and local capacity building to

reduce environmentally harmful practices. The reason given by farmers is that of limited capital. That is likely related to the socio-economic conditions of farmers in Sintang District, where small farmers generally cultivate rubber plantations with minimal capital, so they use a land-clearing method considered relatively low-cost and easy: slash-and-burn (Jayathilake et al. 2023). Some respondents stated that they did not know or could not provide information about building their plantations because current plantation owners are generally the heirs of previous owners, who are often their children or grandchildren.

Table 3. Plantation area, plant age, and rubber planting system in Sintang District, West Kalimantan, Indonesia

	No. of farmers	Percentage (%)
The area of plantation		
<2 ha	184	39.15
2-5 ha	256	54.47
>5 ha	30	6.38
Total	470	100.00
The age of rubber		
<6 years	58	12.34
6-30 years	382	81.28
>30-50 years	23	4.89
>50 years	7	1.49
Total	470	100.00
Planting system		
Monoculture	203	43.19
Polyculture	267	56.81
Total	470	100.00



Figure 2. The condition of the rubber planting distance is in Sintang District, West Kalimantan, Indonesia. A and D: Irregular planting distance, B and C: Neatly arranged plantations with planting distance that meets the rubber GAP

Table 4. The assessment result of the agronomic practices of smallholder rubber plantations in the Sintang District, West Kalimantan, Indonesia

Agronomic activity	Number of farmers	Percentage (%)	Category
Number of farmers whose plantations were not established on forest land	355	75.37	Good
Number of farmers who carried out land clearing without burning	45	9.55	Very poor
Number of farmers who have used improved planting materials	124	26.32	Poor
Number of farmers who have used certified planting materials	59	10.11	Very poor
Number of farmers whose planting materials originated from registered breeders	75	15.92	Very poor
Number of farmers who applied the recommended planting spacing	236	50.1	Moderate
Number of farmers who applied fertilizers	86	18.05	Very poor
Number of farmers who used a complete range of fertilizers	26	5.52	Very poor
Number of farmers who applied fertilizers regularly	62	13.19	Very poor
Number of farmers who carried out weed control	428	90.87	Very good
Number of farmers who conducted weed control regularly (at least twice a year)	228	48.41	Moderate
Number of farmers who implemented pest and disease control	43	9.13	Very poor
Number of farmers who performed tapping with the recommended frequency	200	42.46	Moderate
Number of farmers who performed tapping at the recommended time (before 7:00 am)	410	87.05	Very good
Number of farmers who collected latex regularly	411	87.26	Very good
Number of farmers who processed the latex before marketing	37	7.86	Very poor
Number of farmers who sold their rubber directly to processing factories	2	0.42	Very poor

It is worth noting that the percentage of rubber plantations on forest land (due to forest encroachment) in this study was relatively small, accounting for only around 15% of the total rubber plantations in Sintang District. This result differs somewhat from findings from satellite imagery-based mapping, which indicate that Indonesia has the most extensive deforestation of rubber plantations in Southeast Asia (Pendrill et al. 2019; Wang et al. 2023). This difference is likely due to variations in the use of the term 'forest'. In West Kalimantan, farmers generally do not categorize bushes as forests. When mapping from satellite imagery, bushes are often misinterpreted as forests.

Panting materials and plant spacing

Regarding planting materials, 26.32% of farmers used improved varieties, 10.11% utilized certified seedlings, and 15.92% sourced from recognized breeders. For farmers who have used superior rubber clones, the current variety is generally PB 260. This suggests that the genetic quality of planting materials remains low, limiting the potential productivity. Studies by Cahyo et al. (2024) and Fitriana et al. (2024) confirmed that access to certified, high-yielding clones remains a significant challenge for smallholders, often constrained by limited institutional and market linkages (Khanal et al. 2021). The recommended planting spacing was followed by 50.1% of farmers, classified as moderate. Proper spacing enhances canopy management and facilitates intercropping options in rubber-based systems (Cahyo et al. 2024).

Plant maintenance

However, fertilization practices were notably poor; only 18.05% of farmers applied fertilizers, 5.52% used complete nutrients, and 13.19% fertilized regularly. These results indicate very poor adoption levels and reflect constraints in capital and extension support. Fitriana et al. (2024) reported similar findings in Riau Province, where input limitations and low fertilizer efficiency significantly constrained smallholder productivity. These results differ

from rubber cultivation in Thailand, where fertilization is carried out relatively regularly (Kullawong et al. 2020).

In contrast, weed management practices were widely adopted: 90.87% of farmers reported conducting weed control, categorized as very good, and 48.41% reported doing so at least twice per year (moderate). Weed control is a fundamental activity that influences plant growth and latex yield, particularly in low-input systems (Montoro et al. 2025) and during the juvenile phase (Chiarawipa et al. 2023). These results indicate that rubber farmers in Sintang District view weed control in rubber plantations as a critical aspect of rubber cultivation, particularly because it is closely related to the tapping process. Uncontrolled weeds will complicate the tapping process, which must be carried out early in the morning (in dark situations). However, the reasons for this control seem to be different from the reasons for recommended weed control, such as to reduce the level of plant competition (Ansong et al. 2021), increase latex yields (Habibulloh et al. 2023), intercropping efforts, and land conservation (Balaji et al. 2023).

Nevertheless, only 9.13% of farmers conducted pest and disease control, reflecting weak adoption of crop protection practices—a trend also reported by Azwar et al. (2025), who highlighted limited access to pest management knowledge among rural smallholders. Pests and diseases will significantly impact the results and sustainability of rubber farming businesses (Chen et al. 2023). In Sintang District, the most common pests found in farmers' rubber gardens are termites (25.22%), followed by other pests. Meanwhile, based on field observations, the most common diseases found are *Pestalotiopsis* sp. leaf fall disease and root disease, generally characterized as white root fungus disease (*Rigidoporus lignosus*). These results align with those of other studies, which consider *Pestalotiopsis* leaf fall disease the most disruptive disease to rubber production in Sintang District (Febbiyanti et al. 2022; Permana and Diyasti 2022; Ayu et al. 2024). This result should also be a significant concern, given that the current leaf fall disease outbreak has spread and significantly

reduced yield. These results also indicate that the capacity of rubber farmers in Sintang District remains inadequate, particularly in controlling pests and diseases in rubber plants.

Rubber tapping

The main rubber product is rubber plant sap, obtained through routine wounding of the tree's bark. Rubber tapping must be carried out according to specific rules, particularly those governing tapping frequency and technique. In Sintang District, the tapping practices demonstrated relatively better performance. 42.46% of farmers tapped at the recommended frequency, while 87.05% performed tapping before 07:00 am, classified as moderate and very good, respectively. Early tapping increases latex flow and reduces oxidative coagulation (Aji et al. 2022). These findings suggest that farmers have a reasonable understanding of the effects of tapping time on latex yield, likely derived from local experience rather than formal training. However, if we look closely at the rubber tapping technique, many farmers still do not follow the recommended technical guidelines. For example, tapping too close to the soil surface (even into the roots) (Figures 3.A-C). However, this problem does not seem to be limited to Sintang District, as it also occurs in other rubber-producing countries, such as Malaysia, Myanmar, and African countries (Samuel et al. 2021).

The results of farmers' tapping in the Sintang District are liquid latex, sheets, and cup-lumps. The most significant proportion is in the form of cup-lumps, which is 73.19%. In liquid latex form, it is less than 1%. Findings in the field indicate that the cup-lump currently varies in shape depending on the container used. It is known that some items are in the form of bamboo lumps because the container is made from bamboo pieces. In practice, the container is not only made of bamboo (Figure 3.A) but also includes coconut shell pieces (Figure 3.C), plastic pieces from mineral water bottles (Figure 3.B), and other materials. Based on farmers' experience, the price of rubber in bamboo lumps was higher because it was considered higher quality (with a higher dry rubber content). It was suspected that this was related to the water

content and the dirt in the rubber, which is less in this form. The container's narrower surface area allowed less dirt from the outside to accumulate, and the dry rubber content was higher. This can be considered a technological innovation implemented by farmers to enhance production quality, reflecting local wisdom.

Productivity of rubber in the Sintang District

The productivity of rubber farmers in Sintang District was relatively low, at approximately 103.48 kg lump cup per hectare per month, or around 1,240.46 kg/ha/year lump cup. This productivity was equivalent to approximately 620.23 kg (0.62 tons) of dry rubber per hectare per year, assuming an average dry rubber content of up to 50%. This productivity was still lower than Indonesia's national productivity, which reaches 0.81 tons of dry rubber per ha/year (Central Bureau of Statistics 2021), or compared to Malaysia's rubber productivity, which could reach 1.4 tons of dry rubber per ha per year (Ali et al. 2020; MRB 2023) and Thailand 1.6 tons/ha/year (Huang et al. 2017). It was also still lower than India's national productivity, which ranged from 1.4 to 1.7 tons/ha/year (Anuja et al. 2012). However, the data was higher than the published data of BPS Sintang District (0.4 tons/ha/year) (Central Bureau of Statistics of Sintang 2022). It was also higher than the average productivity of rubber in West Kalimantan (0.44 tons of dry rubber/ha) (Central Bureau of Statistics Indonesia 2022). However, it should be noted that this productivity does not consider plantations that are not yet producing. Therefore, the productivity in this study refers to the actual productivity of farmers whose rubber trees are productive and tapped. Suppose productivity is calculated at the district level, taking into account plantations that are still not producing, plantations that are old/damaged, the productivity will be much lower, which is around 0.38 tons/ha/year, lower than the Central Bureau of Statistics of Sintang data in 2022 (0.4 tons/ha/year). These results are thought to have occurred because, among rubber farmers in Sintang District, many productive rubber plantations remain untapped for various reasons. For example, rubber farmers only tap when rubber prices are high.

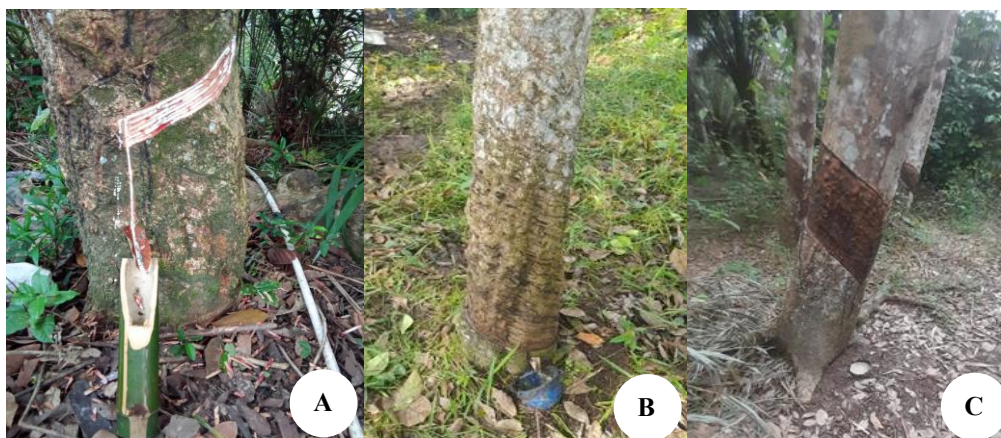


Figure 3. Rubber tapping techniques and farmers' latex collection tools in Sintang District, West Kalimantan, Indonesia. A Bamboo tube, B, Plastic bowl, C. Coconut shell pieces

Meanwhile, when rubber prices are low, they do not tap. This certainly causes the total amount of rubber production to differ between high and low prices. This kind of thing generally happens to farmers with side jobs, allowing them to find other sources of income that are considered more profitable.

Relationship between farmers' human resource capacity and agronomic practices

The Pearson correlation analysis (Table 5) revealed that the relationship between human resource capacity and agronomic practices among smallholder rubber farmers in Sintang District varied across indicators. In general, education level and participation in training showed stronger positive correlations with several agronomic activities, while age and secondary occupations tended to show negative relationships.

Education level was positively correlated with the use of certified and improved planting materials ($r=0.098$, $p<0.05$; $r=0.055$, $p<0.10$, respectively), indicating that more educated farmers tend to adopt better-quality seedlings (Table 5). That aligns with previous findings that formal education enhances farmers' ability to understand technological recommendations and assess the long-term benefits of quality inputs (Fitriana et al. 2024; Montoro et al. 2025). However, education had no significant relationship with most other agronomic actions, suggesting that practical experience and local learning may play a stronger role in daily farm management.

Farmer age showed weak negative correlations with several practices, including the use of improved seeds ($r=-0.080$, $p<0.041$), the use of certified seedlings ($r=-0.076$, $p<0.05$), and pest and disease control ($r=-0.140$, $p<0.01$). This pattern indicates that younger farmers are generally more open to innovation and tend to adopt improved management practices. Similar trends were observed by Cahyo et al. (2024), who reported that generational differences significantly affect innovation adoption in rubber-based agroforestry systems.

Training participation showed positive and significant correlations with several agronomic practices, including the use of certified seeds ($r=0.112$, $p<0.01$), fertilization ($r=0.104$, $p<0.05$), and weed control ($r=0.131$, $p<0.01$). These results suggest that training plays a crucial role in

improving farmers' technical behavior and decision-making capacity. Farmers who participated in agricultural training tended to apply recommended techniques more consistently, particularly in environmentally friendly land management and nutrient application. Montoro et al. (2025) emphasized that participatory training and co-design of knowledge can effectively enhance smallholders' understanding of sustainability principles in rubber farming.

Institutional participation (membership in farmer groups or cooperatives) also showed strong and significant correlations with agronomic actions such as land clearing method ($r=0.340$, $p<0.00$), fertilization ($r=0.292$, $p<0.01$), pest and disease control ($r=0.220$, $p<0.01$), and use of certified seedlings ($r=0.132$, $p<0.01$). This finding highlights that social capital and farmer networks contribute to better adoption of GAP, consistent with findings by Azwar et al. (2025) in Riau Province and Fitriana et al. (2024) in Jambi, who both emphasized that collective action facilitates access to training, inputs, and market information.

The presence of a secondary occupation was negatively correlated with most agronomic practices, including the use of certified seeds ($r=-0.205$, $p<0.01$), fertilization ($r=-0.086$, $p<0.05$), recommended spacing ($r=-0.110$, $p<0.008$), and proper tapping time ($r=-0.147$, $p<0.01$). This suggests that farmers who engage in off-farm activities tend to invest less time and resources in rubber farming, leading to lower adoption of best practices. Kongmanee et al. (2022) noted similar behavior among part-time farmers, who often prioritize short-term income stability over long-term plantation management.

The findings indicate that human capital factors such as education, training, and institutional participation are key drivers of sustainable agronomic behavior. In contrast, higher age and secondary employment may reduce technical engagement and attention to detail in plantation management. Strengthening capacity-building programs, particularly through continuous training and cooperative-based extension, would enhance the farmers' technical competence and readiness for sustainability certification schemes (Cahyo et al. 2024; Azwar et al. 2025; Montoro et al. 2025).

Table 5. Relationship between farmers' human resource capacity and agronomic practices

Agronomic activity	Education level (r, Sig.)	Farmer age (r, Sig.)	Training participation (r, Sig.)	Institutional participation (r, Sig.)	Secondary occupation (r, Sig.)
Land clearing method	-0.070(0.435)	0.008(0.436)	0.004(0.463)	0.340(0.000)	-0.013(0.390)
Use of improved seeds	0.098(0.016)	-0.080(0.041)	0.030(0.260)	0.076(0.051)	-0.107(0.010)
Use of certified seeds	0.055(0.116)	-0.076(0.050)	0.112(0.008)	0.132(0.002)	-0.205(0.000)
Recommended spacing	0.021(0.327)	-0.046(0.114)	0.026(0.285)	0.096(0.021)	-0.110(0.008)
Fertilization	0.023(0.310)	-0.041(0.187)	0.104(0.012)	0.292(0.000)	-0.086(0.031)
Weed control	0.023(0.310)	-0.010(0.414)	0.131(0.002)	0.056(0.115)	-0.015(0.369)
Pest & disease control	0.044(0.172)	-0.140(0.001)	0.037(0.209)	0.220(0.000)	-0.070(0.064)
Tapping frequency	-0.015(0.373)	0.050(0.141)	-0.030(0.261)	-0.024(0.299)	0.006(0.445)
Tapping time (before 07:00 am)	-0.032(0.245)	0.060(0.098)	-0.043(0.175)	-0.018(0.351)	-0.147(0.001)

Relationship between farmers' socio-economic conditions and agronomic practices

The correlation analysis (Table 6) indicates that several socio-economic factors significantly influence the agronomic practices of rubber smallholders in Sintang District. Land area showed a weak, negative correlation with most agronomic activities, including land-clearing method ($r=-0.080$; $p<0.05$), use of superior seeds ($r=-0.121$; $p<0.01$), fertilization ($r=-0.107$, $p<0.01$), and use of certified seeds ($r=-0.131$; $p<0.01$). This suggests that farmers with larger holdings tend to perform less intensive agronomic practices, possibly due to labor constraints or limited supervision on wider plantations. Similar findings were reported by Kühling et al. (2022) and Imelda et al. (2023a), who noted that small-scale farmers are generally more attentive to plot management compared to those with larger holdings.

Social roles were mostly insignificantly correlated, indicating that community status or involvement in social activities has a limited influence on daily agronomic decision-making. In fact, social roles were negatively correlated with decisions about the use of certified seeds ($r=-0.159$, $p<0.00$). Only a weak positive correlation was found between social roles and tapping frequency ($r=0.078$; $p<0.05$), indicating that socially active farmers may share more knowledge about good tapping practices. This aligns with Rizal and Nordin (2022), who emphasized the roles of peer interactions and local leadership in disseminating GAP among smallholder farmers. Meanwhile, the source of capital was positively correlated with several agronomic practices such as the use of superior seeds ($r=0.239$; $p<0.01$), certified seeds ($r=0.165$; $p<0.01$), fertilization ($r=0.136$; $p<0.01$), and pest and disease control ($r=0.325$; $p<0.01$). That indicates that access to formal or semi-formal financial sources significantly supports farmers' ability to adopt better technologies and farm inputs. Nasereldin et al. (2023) and Shani et al. (2024) found that capital accessibility is a critical determinant for smallholders to implement sustainable and recommended agronomic practices.

Farm productivity also showed significant and positive relationships with the use of superior seeds ($r=0.154$; $p<0.01$), fertilization ($r=0.127$; $p<0.003$), and tapping frequency ($r=0.127$; $p<0.00$). This implies that improved agronomic management directly contributes to productivity gains, consistent with previous findings in smallholder rubber systems in Indonesia and Thailand (Rohmayanti et al. 2022; Simon et al. 2022). Farm income had a weak

positive correlation with superior seed use ($r=0.108$; $p<0.01$) and fertilization ($r=0.088$; $p<0.05$). Higher income allows farmers to reinvest in improved inputs and maintain regular farm operations, forming a reinforcing cycle of productivity and profitability (Yamin et al. 2025). Conversely, the low or negative correlations between income and pest control ($r=-0.026$; $p>0.05$) suggest that pest management remains a neglected aspect among farmers regardless of income level.

The data suggest that socio-economic capacity, especially capital availability and productivity, are key determinants for the adoption of sustainable agronomic practices among rubber smallholders in Sintang District. This highlights the need for policies that enhance financial access, farmer training, and collective organization, which in turn can improve productivity and environmental compliance in the smallholder rubber sector (Martial et al. 2023).

Relationship between farmers' capacity, socio-economic conditions, and agronomic practices

The correlation analysis between farmers' human resource capacity and agronomic practices (Table 5) revealed diverse relationships across indicators. Educational level showed a positive, significant correlation with the use of improved planting materials ($r=0.098$; $p=0.016$) and certified seeds ($r=0.055$; $p=0.116$), although the relationships were weak. This indicates that education contributes to farmers' awareness of the importance of using high-quality planting materials. Penot and Iahang (2023) similarly found that higher levels of education enhance farmers' understanding and adoption of agronomic innovations. Participation in training programs and farmer institutions demonstrated stronger and more consistent effects on agronomic behavior. Training was significantly correlated with the use of certified seeds ($r=0.112$; $p=0.008$), weed control ($r=0.131$; $p<0.002$) and fertilization ($r=0.104$; $p=0.012$), while institutional participation was significantly associated with non burning land-clearing method ($r=0.34$; $p<0.00$), the use of certified seeds ($r=0.132$; $p<0.002$), fertilization ($r=0.292$; $p<0.00$), and pest and disease control ($r=0.220$; $p=0.00$). These findings highlight the importance of institutional support and field-based training in strengthening farmers' technical capacity. Imelda et al. (2023b) and Prayogo et al. (2025) also confirmed that institutional participation and continuous training significantly improve the adoption of GAP among smallholders.

Table 6. Relationship between farmers' socio-economic conditions and agronomic practices

Agronomic activity	Plantation area (r, Sig.)	Social role (r, Sig.)	Source of capital (r, Sig.)	Farm productivity (r, Sig.)	Farm income (r, Sig.)
Land clearing method	-0.080(0.042)	-0.043(0.177)	-0.005(0.461)	0.051(0.137)	-0.018(0.350)
Use of improved seeds	-0.121(0.004)	-0.055(0.166)	0.239(0.00)	0.154(0.00)	0.108(0.010)
Use of certified seeds	-0.131(0.002)	-0.159(0.00)	0.165(0.00)	0.032(0.244)	0.013(0.391)
Recommended spacing	-0.025(0.295)	0.034(0.232)	0.113(0.007)	-0.038(0.208)	0.033(0.235)
Fertilization	-0.107(0.010)	-0.075(0.052)	0.136(0.002)	0.127(0.003)	0.088(0.028)
Weed control	-0.055(0.117)	0.011(0.403)	0.015(0.370)	-0.062(0.088)	0.022(0.319)
Pest & disease control	-0.083(0.035)	0.027(0.282)	0.325(0.00)	0.008(0.429)	-0.026(0.286)
Tapping frequency	0.009(0.419)	0.078(0.046)	-0.015(0.376)	0.127(0.00)	-0.063(0.088)
Tapping time (before 07:00)	-0.018(0.343)	-0.032(0.246)	-0.039(0.200)	0.015(0.373)	-0.033(0.237)

The relationship between farmers' socio-economic conditions and agronomic practices (Table 6) revealed varying trends. Farm size and farm income were weakly but positively correlated with cost-intensive practices such as the use of improved planting materials ($r=0.108$; $p=0.010$) and fertilization ($r=0.088$; $p=0.028$). In contrast, the source of farming capital had stronger associations with agronomic innovation, especially in the use of improved planting materials ($r=0.239$; $p=0.00$) and pest and disease control ($r=0.325$; $p=0.00$). These results indicate that farmers with better access to capital are more able to adopt improved agronomic practices. Limited access to external financial sources remains a significant barrier to productivity improvement among smallholder rubber farmers (Tiemann and Douchamps 2023). Farmers who rely solely on personal capital often face difficulties purchasing fertilizers or certified planting materials, leading to low yields and declining plantation performance. Similarly, Imelda et al. (2023a) noted that income concentration from a single farming activity reduces farmers' ability to reinvest in agronomic improvement, ultimately constraining sustainability. Therefore, socio-economic factors interact strongly with farmers' human resource capacity in shaping sustainable rubber cultivation systems. This conclusion aligns with previous studies by Sukayat et al. (2023), which emphasize that the sustainability of smallholder plantation systems depends on the synergy among social, economic, and technical factors.

Implications for the sustainability of smallholder rubber farming

Overall, the findings suggest that improving human resource quality and strengthening socio-economic support are critical to enhancing the adoption of sustainable agronomic practices among smallholder rubber farmers. Development interventions should focus on improving farmers' technical capacity through field training, providing access to certified planting materials, and reinforcing farmer institutions. Such integrated approaches are expected to enhance both agronomic performance and competitiveness in the smallholder rubber sector in West Kalimantan. However, this study was limited to cross-sectional data and relied primarily on self-reported information, which may not fully capture variations in seasonal or long-term management practices. Future studies should incorporate longitudinal field measurements, evaluate the effectiveness of extension interventions, and explore socio-economic drivers influencing the adoption of sustainable agronomic technologies among smallholder farmers across different regions.

The study concludes that the overall level of implementation of agronomic practices among smallholder rubber farmers in Sintang District generally exhibits moderate agronomic performance, constrained by limited education, capital, and access to extension services. Key agronomic practices that require greater technical knowledge and capital—such as fertilization, the use of certified planting materials, and pest and disease management—are still poorly implemented. Strengthening farmer capacity through training, improving access to

quality inputs, and enhancing institutional and financial support are essential to increase productivity and ensure sustainability in smallholder rubber systems. Farmers with better education and active participation in training programs and farmer groups are more likely to adopt recommended cultivation techniques. Socio-economic conditions also play a decisive role. Farmers with greater access to capital and stronger social networks demonstrate higher adoption rates of improved planting materials and pest control measures. Conversely, limited financial access and low-income diversification remain major constraints to sustainable rubber farming. In summary, sustainable improvement of smallholder rubber farming in West Kalimantan requires an integrated strategy focusing on (i) strengthening farmers' human resource capacity through continuous training and institutional participation, (ii) improving access to certified planting materials and farm inputs, and (iii) enhancing financial inclusion and market linkages. These interventions are essential to transform smallholder rubber farming into a more productive and sustainable system.

ACKNOWLEDGEMENTS

The authors thank the Rainforest Alliance Indonesia for financial support for this project.

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