# Rubber-based farming diversification: Current practices and their impact on economic sustainability of small-scale rubber farmers

A systematic review

Deliverable 1a

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## Executive summary

This report aimed to identify current and best practices of sustainable natural rubber production through a systematic review on diversification in agroforestry systems and its impact on economic sustainability. The report is based on evidence searched from 12 bibliographic databases and 22 grey literature sources including websites of relevant organisations, using a standard rigorous systematic review process. After multiple screening of 6,431 articles, 65 relevant full text articles were coded for current practices of rubber farming diversification systems, and 14 studies were eligible for qualitative synthesis of economic outcomes of rubber-based farming diversification systems. The evidence synthesised were from 10 rubber producing countries, most being in South and Southeast Asia (Thailand, Indonesia, Sri Lanka and Malaysia). Non-tree food crops and tree food crops were the most reported diversification systems. Durian, Mangosteen, Banana, Pineapple, Cassava, Rice, Maize, rattan, bamboo and timber trees were among the most studied intercropping systems. Livestock reared in rubber-based farming systems included goat, sheep, poultry and cattle. Due to the heterogeneity of economic measures used in the studies, meta-analysis of the outcomes was not possible. A qualitative synthesis approach was used instead. Of all the economic measures reported, net present value and net farm income were the most frequently used. For small-scale farmers, some studies have shown that monocrop rubber farming performs better than diversified farming systems. However, there are many other factors which were not considered when the economic outcomes were reported as none of the studies reviewed looked at the causal chain or provided comparative statistical analysis of the differences. Overall, the evidence points to the positive economic outcomes of farming diversification systems compared to mono rubber farming both in the short and long term. The most economically advantageous practice reported appeared to be rubber intercropped with fruit trees, particularly Durian trees.

# Contents

## 1. Introduction

On-farm diversification, in this study defined as farming activities aiming to add any new agricultural products to the current farming system to increase economic sustainability, has attracted a broad range of attention amongst academic researchers and policy makers. Economic debates around farming diversification tend to centre around efficiency gains of intensive mono-product system versus the synergistic gains of labour and land use and risk reduction of crop diversification (McNamara and Weiss, 2005; Roest, Ferrari and Knickel, 2018). The primary focus of this study is rubber-based farming diversification.

Rubber is an important cash crop for many smallholders and 90% of the world's natural rubber is produced on small-holdings (Association of Natural Rubber Producing Countries, 2019). Rubber is grown in more than 20 countries but only four dominate worldwide production. In these four countries, smallholders produce 93% of rubber in Malaysia, 90% in Thailand, 89% in India and 85% in Indonesia (Rubber Board 2005). Many of these smallholders, are however, facing poverty, with the main threat to livelihood deriving from price volatility for natural rubber on world markets (e.g. Anon, 2016; Stroesser *et al.*, 2018; Wee and Singaravelloo, 2018). Rubber can be produced naturally or synthetically, and since crude oil is one of the main raw materials of synthetic rubber, there is a strong correlation between the prices of crude oil, synthetic rubber, and natural rubber (Khin *et al.*, 2012). In the last 10 years, world market prices for natural rubber have fluctuated drastically. An all-time high of US$ 6.26 per Kilogram was recorded for smoked rubber sheets (RSS3) in February 2011 (source indexmundi) as a result of increased demand caused by recession-linked low prices in 2009 and supply disruptions caused by El Niño related low rainfall in the dominant producing countries in South-East Asia (Accenture, 2015). This was followed by a dramatic crash in natural rubber price (for example, in October 2019 the price was US$ 1.43 per kilogram – source indexmundi) driven by oversupply and low oil prices (Anon, 2016).

Where smallholders rely primarily on income from monoculture rubber they are particularly vulnerable to these fluctuations in price (Romyen *et al.*, 2018). On-farm diversification strategies, such as growing other cash crops with rubber, provide a potential strategy for these farmers to mitigate this risk (McNamara and Weiss, 2005; Stroesser *et al.*, 2018).

In addition to fluctuations in rubber price, smallholders wishing to grow rubber face the challenge that rubber trees have a long gestation period before becoming productive, which serves as another disincentive for investors in rubber farming. Tapping of rubber trees for latex usually starts in the fifth to seventh year after planting and then continues for 25 to 30 years (Balsiger *et al.*, 2000; Michels *et al.*, 2012; Hougni *et al.*, 2018; Liu *et al.*, 2018). After approximately 30 years a decline in latex production makes further tapping of the trees uneconomic (Balsiger *et al.*, 2000). The long immature period means that monocropping rubber represents a loss in income for smallholders in the first years. Growing other crops with rubber is a way of enhancing an early return on investment, as well as reducing vulnerability to fluctuations in rubber price in the mature period and potentially providing additional income when production starts to decline.

This study aimed to identify on-farm diversification practices adopted alongside rubber farming and what economic impact the practices have on rubber farmers.  The study used systematic mapping methodology (James *et al.*, 2016; Collaboration for Environmental Evidence, 2018), to gather published and grey literature relevant to all rubber producing countries around the world to provide an overview of the current evidence base to identify:

1. Farming diversification practices aimed at improving the overall economic sustainability of the rubber production.
2. Economic outcomes of the identified farming diversification practices in comparison with rubber monoculture. Barriers and/or facilitators to uptake of diversification practices.
3. Knowledge gaps that might benefit from future primary research

We anticipated that the broad topic we were addressing would capture highly heterogeneous studies including different methodologies, interventions and outcomes, a mixture of quantitative and qualitative research, and evidence not limited to primary research. Systematic mapping methodology is increasingly being used in these instances to address topics of environmental importance (Haddaway *et al.*, 2016; Haddaway *et al.*, 2019) to gain an overview of a broad topic, identify knowledge gaps (topics that are underrepresented in the literature that would benefit from primary research) and sub-sets of evidence that may be suitable for secondary synthesis or analysis (e.g. systematic review). Systematic mapping follows a rigorous, objective and transparent processes to capture and screen literature, with the aim of reducing reviewer selection bias and publication bias, associated with traditional literature reviews, and providing transparency regards decisions made for inclusion of evidence (James *et al.*, 2016).

## 2. Methods

The systematic map followed the widely used and established Collaboration for Environmental Evidence guidelines and standards for systematic reviews and maps (Collaboration for Environmental Evidence, 2018). We developed a pre-review protocol (James, *et al.*, 2019), detailing the scope of the review, the search strategy, the screening process, the pre-defined inclusion and exclusion criteria, and data extraction strategies and data management mechanisms. The protocol was thoroughly discussed within the multidisciplinary international research team, comprising expertise in natural rubber production, economics of tree crop farming in developing countries, ecology, farming diversifications, agribusiness management and systematic reviews. The methods presented here are largely similar to those outlined in the protocol (James *et al.*, 2019). Adjustments from the original protocol are noted.

*2.1 Scope of the review and inclusion criteria*

The primary question of this study was:

"What evidence is there for farming diversification practices aimed at improving the economic sustainability of rubber production?"

This question was framed using population, intervention, comparator, outcome (PICO) key elements:

- *Population*: rubber farms;
- *Intervention*: on-farm diversification practice;
- *Comparator*: Before and after diversification measure, no diversification (monoculture rubber farming); no comparator
- *Outcome*: Indicators of economic sustainability.

Using literature gathered for the primary question, two secondary questions were addressed:

- "What are the economic outcomes of farming diversification practices in comparison with monoculture rubber farming?

The scope of literature was restricted to those published in English and Thai language only (but searched in databases in English only). Other inclusion criteria (what the article must contain to be eligible) used include:

- All rubber farming systems at all farm sizes and ownership
- Any farming diversification practice undertaken with the aim to improve economic sustainability of rubber farms (e.g. intercropping, multi-cropping, livestock rearing).
- Any or no comparator (e.g. before and after diversification measure, different diversification practice, no comparator).
- The study must focus primarily on economic outcomes with measures of financial outcomes (e.g. costs, margins, profit, income or returns etc).
- No date restrictions for inclusion of literature.
- Any study type based on quantitative and/or qualitative data.
- Masters and undergraduate theses were ineligible but PhD theses were eligible.

*2.2 Search strategy*

A comprehensive search to capture an un-biased sample of published and grey literature was undertaken using multiple information sources including: (i) 12 bibliographic databases (ii) 22 grey literature sources including websites of relevant organisations (Additional File 1). Searches for published literature were performed using English language search terms. Searches for grey literature were conducted in both the English and Thai language, considering that Thailand is the biggest natural rubber producer and exporter in the world.

*2.3 Search terms and searches*

Search terms were formulated by the review team and a scoping search was performed to validate the methodology. Keywords were tested for specificity and sensitivity using the online database ISI Web of Knowledge (core collection). Search terms were initially developed based on the key elements of the research question.

Population terms for “rubber farmers”

> (rubber) AND NOT (tyre OR tire OR synthetic* OR man*made)) AND (Farm* OR plantation* OR tapp* OR agro*forest* OR rural OR smallholder*)

Intervention terms for “farming diversifications”

> (sustain* OR "best practice*" OR inter*crop* OR “mixed farm*” OR multi*crop* OR diversif* OR portfolio* OR variabilit* OR technolo* OR innovat*)

Outcome terms for “economic outcomes”

> (sustain* OR economic OR poverty OR poor OR inequal* OR income* OR livelihood* OR profit* OR risk* OR portfolio* OR variabilit* OR yield* OR productivity OR efficien* OR stability OR wealth OR optimi*ation* OR maximi*ation OR return* OR financ* OR benefit* OR gain*)

The terms for intervention and outcomes may overlap. To avoid missing anything relevant, we used OR rather than AND to combine the two strings. The following final search string was used to capture literature between February and April 2019.

> (rubber) AND NOT (tyre OR tire OR synthetic* OR man*made)) AND (Farm* OR plantation* OR tapp* OR agro*forest* OR rural OR smallholder*) AND (sustain* OR "best practice*" OR inter*crop* OR “mixed farm*” OR multi*crop* OR diversif* OR technolo* OR innovat* OR economic OR poverty OR poor OR inequal* OR income* OR livelihood* OR profit* OR risk* OR portfolio* OR variabilit* OR yield* OR productivity OR efficien*

OR stability OR wealth OR optimi*ation* OR maximi*ation OR return* OR financ* OR benefit* OR gain*)

The search string was adapted to the syntax of each source searched and a record of each search was recorded (Additional File 1). Where the search string could not be used, websites were 'hand searched' for relevant literature.

*2.4 Screening of literature*

All retrieved studies were screened (assessed) for relevance against the pre-defined inclusion criteria, using EPPI-Reviewer 4, an online specialised systematic review software appropriate for teamwork. Screening of articles was based on pre-defined inclusion criteria developed in the protocol (James, *et al.*, 2019). Two main criteria had to be met: 1) research had to be on rubber farms or plantations in any country with any type of farming diversification activities practiced alongside rubber farming; and 2) any form of economic outcomes had to be reported in the study.

The screening was conducted in two stages: (i) title and abstract (screened concurrently for efficiency) and (ii) full text. All articles appearing to meet the pre-defined criteria by screening title and abstract were recorded for full text screening. Great efforts were made to obtain those full text articles which were not published in channels normally accessible to the research team, including inter-library loan and extra paid services. However, there are still many articles that could not be located or accessed for full text screening. The list was recorded (Additional File 1). The number of articles included and excluded at each screening stage was recorded, and reasons for exclusion at full text were recorded (Additional File 1).

Screening by title and abstract was completed by the full team. Prior to commencing screening, consistency checking and a Cohen's Kappa analysis was calculated for a random subset (10%) of articles at title and abstract level to ensure that bias was reduced and inclusion criteria were being applied consistently between reviewers. A Cohen's Kappa statistic of 0.6 or higher was considered acceptable indicating substantial agreement (Landis and Koch, 1977). Where the level of agreement was low (below c. 0.6 agreement), in depth discussions about disagreements for inclusion and further consistency checking was performed. Each of the full text articles was screened and coded by at two team members. The lead reviewer also sample-checked all categories of screening results. Where there was uncertainty or disagreement about inclusion or exclusion of an article, another team member examined the text and a consensus agreement was made.

*2.5 Study coding strategy*

All eligible studies included for full text coding were examined and the data were coded using the online software EPPI Reviewer 4. This enables the review team to extract data consistently and systematically with the following pre-defined coding categories:

- Bibliographic information (e.g. author, title, year, publication type)
- Basic information about intervention (i.e farming diversification practices such as crops, intercropping or multi-cropping). Each intervention group is recorded as a unique instance.
- Basic information about study design (e.g. year data collected, experimental or commercial farms, farm size, location, age of rubber plantation)
- Details of economic outcomes reported for both control group (monocrop rubber) and intervention groups

Coding consistency checking was carried out on a parallel coding of all full texts, discussing all disagreements. Where meta-data were missing from articles this was stated as “not reported”/“unclear”, since making efforts to obtain these data was not possible within the resources allocated to this project. Meta-data were extracted from the licenced specialised systematic review software and presented in an Excel spreadsheet.

We encountered many challenges to identify economic outcomes of farming diversification activities. Not all studies had a comparative study design, i.e., compared the economic outcomes of monoculture rubber farming with those of diversification activities. Farm sizes were not always reported either. Some studies were lacking in detail regarding stage of rubber plantation. This is particularly relevant as rubber trees have a long gestation period before becoming productive (5- 7 years have been reported).

*2.6 Data analysis and synthesis*

Meta-analysis to determine the economic effect of intervention practices was deemed inappropriate due to the diverse range of economic indicators used and incompleteness of data reported in the studies examined. Three types of syntheses were conducted. First, to provide an overview of farming diversification practices reported in the studies examined, simple numerical accounts of frequencies of interventions were used against study context using structured matrices. Second, qualitative content analysis was used to interpret the barriers and facilitators for farming diversification as reported in the studies examined. Third, for the subset of studies which reported economic outcomes for both control and intervention groups and for each phase in the lifecycle of rubber (if reported), extracted raw data for each occurrence from each article were compiled into a database in both excel and SPSS formats. Differences of economic outcomes of each farming diversification occurrence in comparison with the same economic indicator reported for monocrop rubber were calculated. The actual percentages of changes were further categorised into 22 groups on a 10-point range group (ranging from -11 representing decreasing by more than 100 percent to 11 increase by more than 100 percent) and direction of change (i.e., positive, negative or no change) compared to monoculture rubber farming were used for further synthesis and comparison.

### *2.7 Quality assessment*

For articles selected to provide an overview of farming diversification practices, individual articles were not appraised for quality of research design. The pre-defined inclusion criteria for inclusion was mainly whether farming diversification activities (intervention) were reported. We then applied other criteria for the final selection of the studies which are used for synthesis of economic outcomes. For the subset 14 studies selected to assess economic outcomes, the initial assessment of quality was based on the inclusion criteria for economic outcomes assessment. This included the completeness of data including type of economic outcomes (productivity only would be excluded), whether the data were primary, whether economic outcomes were collected for both intervention and control group, and whether rubber plantation studied include mature (productive years). Studies which only included immature rubber (which are often experimental studies) were excluded.

## 3. Results

### *3.1 Overview of the evidence base*

Literature included and excluded at each stage of the review process is shown in Figure 1.  Following full text screening, 65 studies were eligible for thematic coding to identify on-farm diversification practices used in rubber farming and barriers and facilitators to diversification. Fourteen studies with comparators were identified from the systematic map to investigate the comparative economic outcomes of farming diversification for different phases of rubber cycle. Six modelling studies were identified that specifically investigated diversification to increase resistance to rubber price volatility.

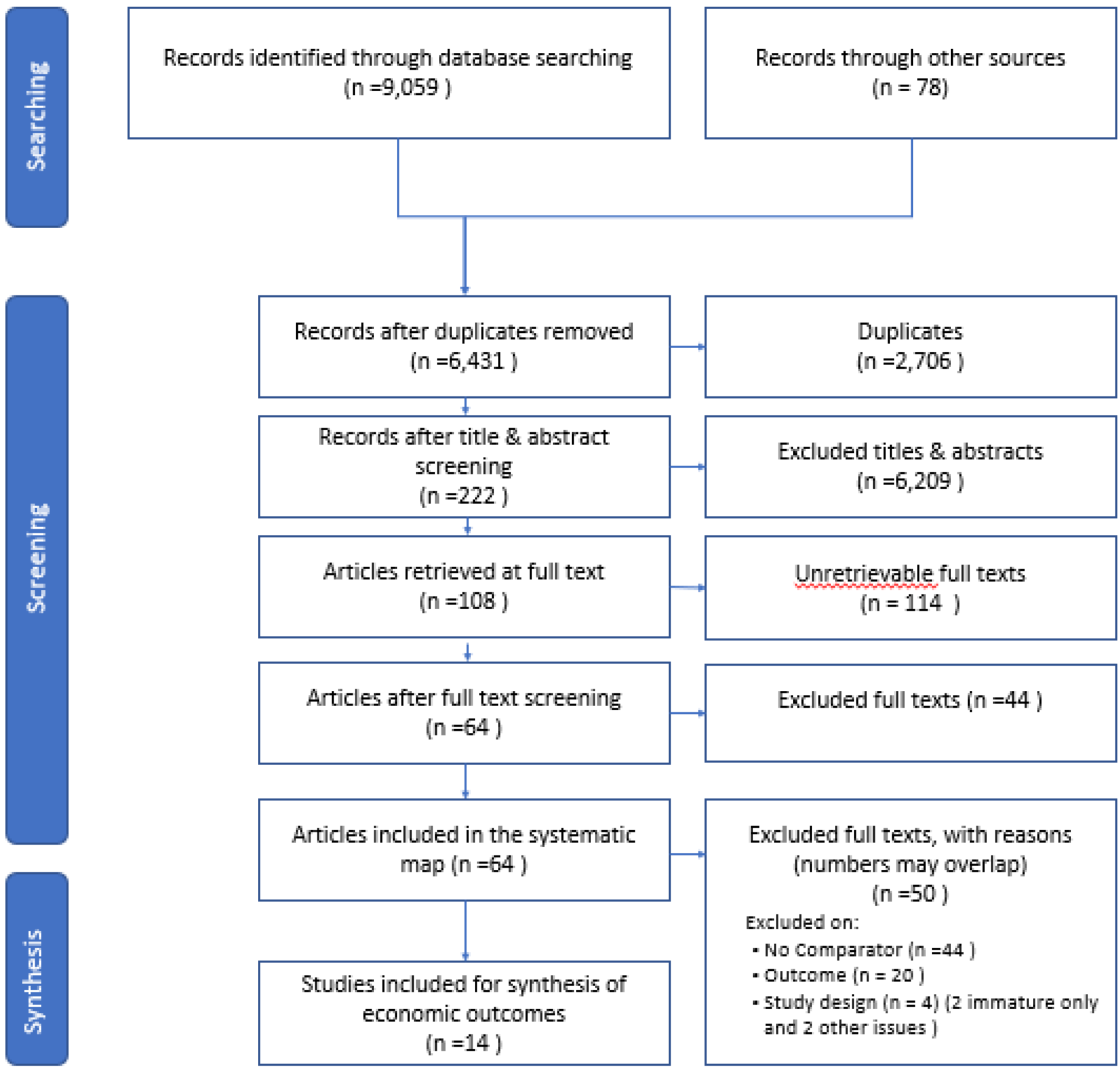


Figure 1: Flow chart illustrating the number of articles in the process of retrieving, screening and synthesis (diagram adapted from Haddaway *et al.*, 2017)

*3.2. Evidence of farming diversification practices reported*

Evidence of farming diversification activities practiced alongside rubber farming were found from 65 included studies. The literature was dominated by studies published in peer-reviewed journals (n=53) with the remainder of the studies presented in conference papers (n=6), unpublished reports (n=3), published reports (n=1) and a thesis (n=1). Evidence was captured from 1985 until 2018. Figure 2 displays the number of relevant studies captured per year that were included in the review. Publication rate has been relatively low for the topic and have fluctuated from year to year although rates have generally been higher in the last twenty years.

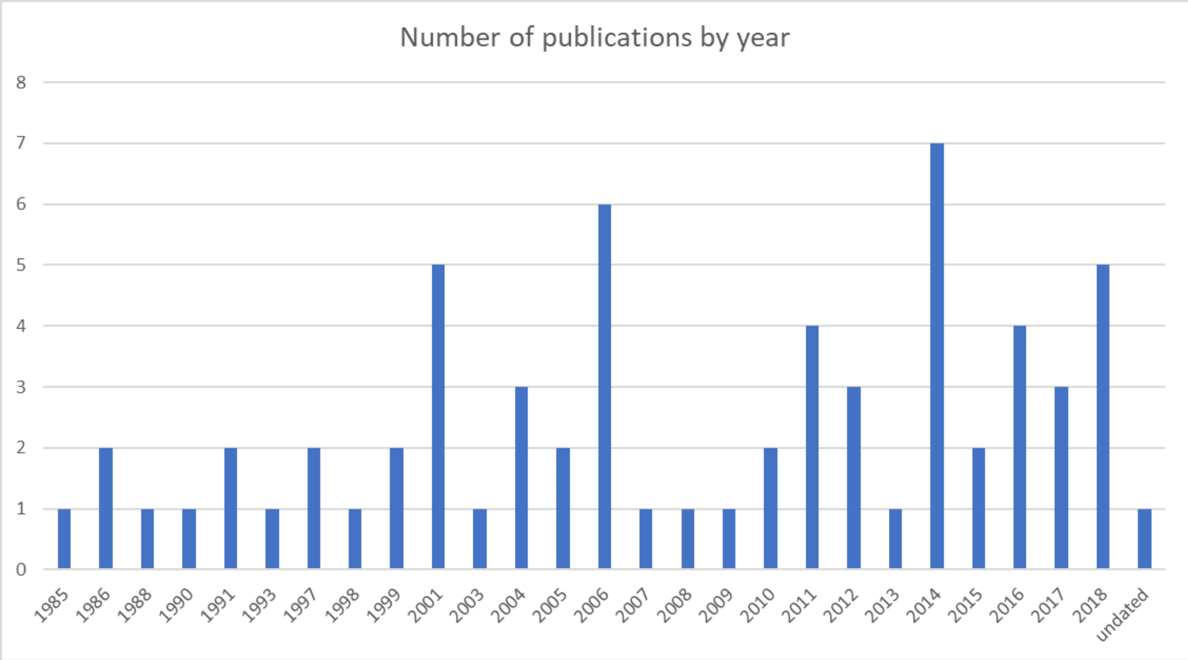


Figure 2: Number of publications per year eligible for systematic map of evidence of farming diversification activities

Ten countries were reported in the studies, within 5 geographic regions. The majority of studies were from South East Asia followed by South Asia (Figure 3a and b). Fewer studies were conducted in West Africa, East Asia and South America (Figure 3a and b.) Studies were mainly from upper-middle income group countries (Brazil, China, Malaysia, Thailand and Sri Lanka n=42), followed by lower-middle income group countries (Côte d'Ivoire, India, Indonesia, Nigeria and Philippines n=23) as classified by the World Bank 2019.

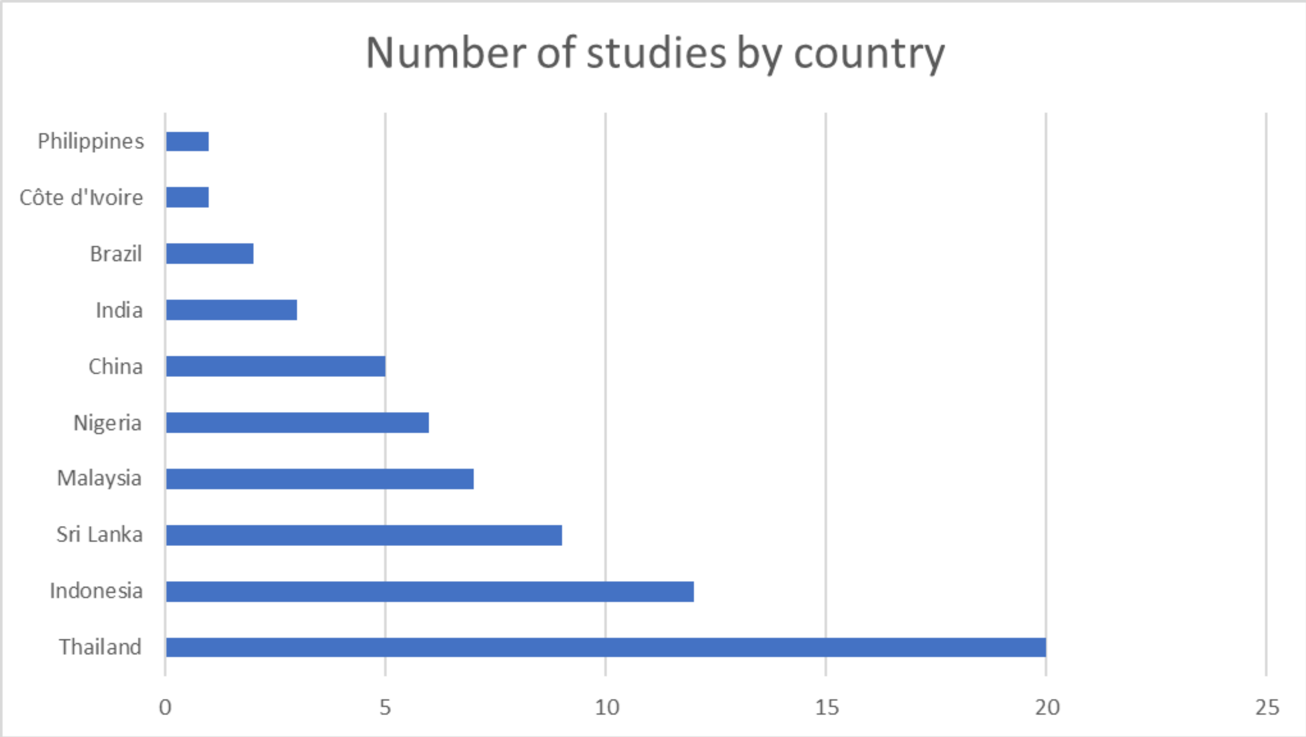


Figure 3a: Bar chart of number of studies captured by country

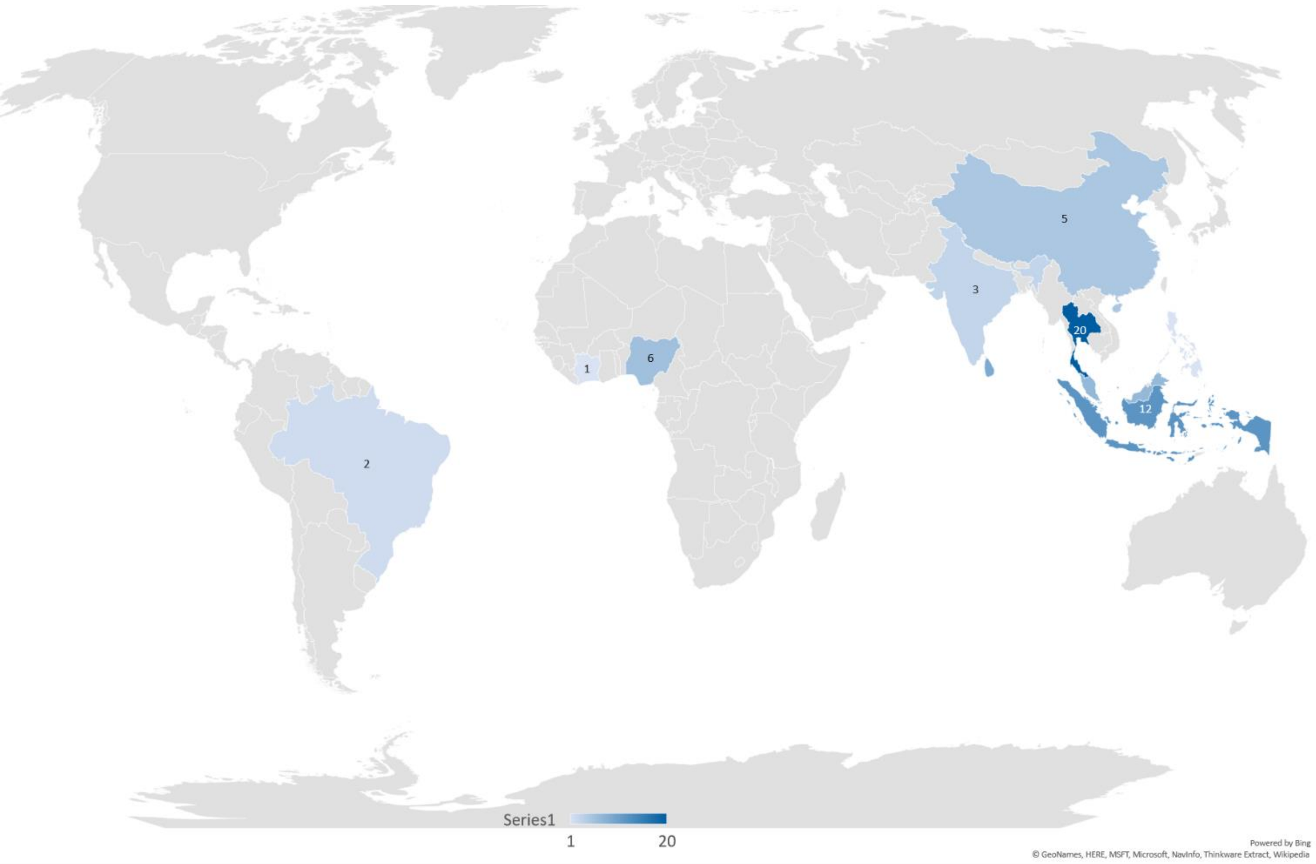


Figure 3b: Map of number of studies captured by country

The majority of studies were quantitative in design (n=28) consisting of modelling studies (n=6) and field trials (n=20), half of which were randomised, controlled trials. Twelve studies were qualitative case studies and twenty studies were of mixed qualitative and quantitative design. The remaining 4 studies were literature reviews. Twenty-six studies in total had a rubber monocrop control. Where length of study was reported 23 studies were of short duration lasting no more than one year and 18 lasted between 1.5 and 7 years, and 3 studies were of 10 years or more.

Over half of the studies investigated diversification measures that are already practiced by farmers (n=40) with the remainder being purely experimental (n=25). Average farm size was often unreported (n=19), or not applicable to the study because for example the study was conducted on experiment plots (n=27). Where average farm size was reported, 17 studies reported farm sizes from less than 1ha up to 7ha. Only 2 studies were based on larger plantations: Majid *et al.,* (1990) modelled sheep integrated with rubber based on plantation size of 28 ha but the focus of the study was smallholders, and Guo *et al.,* (2006) carried out an economic analysis of tea intercropped with rubber based on a state-farm 12,250ha in size comprising 333 ha of rubber plantation, 240 ha of tea plantation and 250 ha of rubber-tea cropping.

Over half of the studies reported that the farms under investigation were owned by smallholders (n=34), 15 were owned by research institutes and 2 were state or corporation owned. In the remainder of the studies farm ownership was unspecified.

The focus of the majority of studies was diversification in immature rubber plantations only (n=22), followed by studies that included both immature and mature rubber (n=14) and mature rubber only (n=10). Three studies modelled diversification throughout the life cycle of rubber, from the immature period to beyond 25 years (when production starts to decline), and 4 studies modelled diversification in the mature period to beyond 25 years. Eleven studies did not report rubber plantation age.

All the studies captured reported on-farm diversification in terms of cropping other plants or rearing livestock with rubber. Nineteen studies reported economic indicators related to productivity only, the remaining 44 studies also reported financial indicators of sustainability (Table 1). The most common economic indicators were productivity (n=39) followed by estimated returns (n=33). Out of the 44 studies that reported financial indicators, 6 studies modelled resilience of diversification practices against fluctuations in rubber price with the remainder of studies focussing on improving the overall economic sustainability of rubber production at different phases in the rubber life cycle.

Table 1. Economic outcomes reported

| | Cost focused | Estimated returns | Equivalent ratios | Increments | Land focused | Marginal returns | Net present values | Non-NPV | Physical resources | Productivity | Return cost ratios |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Affendy *et al.*, 2011 | | | | | | | | | | X | |
| Aminuddin bin *et al.*, 1986 | | | | | | | | | | X | |
| Atia *et al.*, 2014 | | X | | | | | | | | | |
| Belcher *et al.*, 2004 | | | | | | | X | | | | X |
| Charernjiratragul *et al.*, 2014 | | | | | | | X | | | | X |
| Choengthong & Choengthong 2014 | X | | | | | | | | | X | X |
| Chong *et al.*, 1997 | | | | | | | | | | X | |
| Esekhade *et al.*, 2003 | | X | | | | X | | | | X | |
| Esekhade *et al.*, 2006 | | X | | | | | | | | | |
| Esekhade *et al.*, 2014 | X | X | | | | | | | X | X | X |
| Fu *et al.*, 2009 | | X | | | | | | | X | | |
| Giroh *et al.*, 2012 | X | X | | | | | | | | X | X |
| Gouyon *et al.*, 1993 | | X | | | | | | | | | |
| Guedes Pinto *et al.*, 2006 | | | | | | | | | | X | |
| Guo *et al.*, 2006 | X | | | | X | | | | | | |
| Hondrade *et al.*, 2017 | | | | | | | | | X | X | |
| Hougni *et al.*, 2018 | X | X | | | | | | | X | X | |
| Iniguez*et al.*, 1991 | | | | | | | | | | X | |
| Jongrungrot & Thungwa 2014a | | | | | | X | | | | | |
| Jongrungrot *et al.*, 2014b | | X | | | | | | | X | X | |
| Karim 2006 | | | X | | | | X | | | X | X |
| Lehebel-Peron *et al.*, 2010 | | | | | X | | X | | X | | |
| Li *et al.*, 2018 | | | | | | | | | | X | |
| Majid *et al.*, 1990 | | | | | | | X | X | | | X |
| Meng 2012 | | | | | | | | | | X | |
| Nayar *et al.*, 2004 | | X | | | | | | | | X | |
| Newman 1985 | | | | | | | | | | X | |
| Ogwuche *et al.*, 2012 | X | X | | | | | | | | X | |
| Pansak 2015 | | | | | | | | | | X | |
| Pathiratna & Perera 2006 | | | | | | | | | | X | |
| Penot 2004 | | X | | | | | | | | | |
| Polthanee *et al.*, 2016 | | X | | | | | | | | X | |
| Polthanee 2018 | X | X | | | | | | | X | X | |
| Prasong *et al.*, | X | X | | | | | | | | | |
| RAOT (not dated) 2016 | | | | | | | | | | X | |
| Rodgers 2010 | X | X | | | X | | | | | X | X |
| Rodrigo *et al.*, 1997 | | | | | | | | | | X | |
| Rodrigo *et al.*, 2001a | X | | | | | | X | | | | |
| Rodrigo *et al.*, 2001b | | | | | | | | | | X | |
| Rodrigo *et al.*, 2001c | | X | | | | | | | | | |
| Rodrigo *et al.*, 2005 | | | | | | | | | | X | |
| Saithanoo 1988 | | X | | | | | | | | | |
| San & Deaton 1999 | | X | | | | | X | | | | X |
| Santosa *et al.*, 2005 | | X | | | | | | | | X | |
| Sarkar *et al.*, 2011 | X | X | | | | | | | | | |
| Simien & Penot 2011 | | X | | | | | | | X | | |
| Snoeck *et al.*, 2013 | | X | | | | | | | X | X | |
| Somboonsuke 2001 | X | X | | | | | | | | | |
| Somboonsuke *et al.*, 2011 | | X | | | | | | | | | |
| Somboonsuke *et al.*, 2017 | X | X | | | | | | | | | |
| Stirling *et al.*, 1998 | X | | | | | | X | | | X | X |
| Stroesser *et al.*, 2018 | | X | | | | | | | X | | |
| Tajuddin 1986 | X | X | | | | | X | | X | X | |
| Tata *et al.*, 2015 | | | | | | | | | | X | |
| Thongyou 2014 | | | | | | | | | | X | |
| Tian *et al.*, 2016 | | X | | | | | | | | | |
| Treetaruyanont *et al.*, 2014 | | | | | | | | | | X | |
| Viswanathan 2008 | | X | | | | | | | | | |
| Wahab *et al.*, 2007 | | | | | | | | | | X | |
| Wijesuriya & Thattil 2001 | | X | X | | | | | | X | X | |
| Winarni *et al.*, 2017 | | | | X | | X | X | | X | X | |
| Winarni *et al.*, 2018 | | | | X | | X | X | | X | X | |
| Wojtkowski *et al.*, 1991 | | X | | | | | X | | X | X | |
| Wongsiri *et al.*, 1999 | | | | | | | | | | * | |
| Wulan *et al.*, 2006 | X | X | | | | | X | | X | | |
| Number of studies | 15 | 32 | 2 | 2 | 3 | 4 | 13 | 1 | 16 | 39 | 10 |

Notes for the table:

1. Wongsiri *et al.*, 1999 reported yields of honey only, but it was included as honey bee keeping can still be seen as an on-farm diversification practice
2. Economic outcomes categories
    - Cost focussed = Total cost; Variable cost
    - Estimated returns = Income; Net farm income; Monetary advantage; Total returns; Net returns; Gross margin or returns; Cumulative returns; Net benefit; Profit: Equivalent ratios = Annual equivalent return or ratio; Income equivalence ratio
    - Increments = Mean Annual Increment; Current Annual Increment
    - Land focussed = Returns to land; Land expectation value
    - Marginal returns = Marginal rate of return; Marginal annual production
    - Net Present Value (NPV) = Net present value; Internal rate of return:
    - Non NPV = Payback period
    - Physical resources = Labour; Return to Labour; Land equivalence ratio; Average Annual Production
    - Productivity = yield, biomass, growth, production rate or liveweight
    - Return costs ratios = Revenue/cost; Benefit/cost ratio; Economic ratio input/output

### *3.3 Farming diversification strategies*

With the exception of one study that described vertical diversification (adding value to rubber) through the creation of a rubber tree nursery in Nigeria (Atia *et al.*, 2014) all other studies described horizontal diversification (adding new products to the farming system that are unrelated to the current product, in this case, rubber).

Two types of cropping system were described: (i) non-intercropping, where crops or animals are grown/reared in rubber faming systems but on a separate parcel of land to the rubber (n=6) (ii) intercropping (n=61) where crops or livestock are grown/grazed between rows of rubber.

#### *3.3.1 Non-intercropping systems*

All six studies reported systems that are commercially practiced. Livestock reared using this spatial arrangement included rabbits and snails (Atia *et al.*, 2014), poultry (Viswanathan, 2008), fish (Somboonsuke, 2001; Viswanathan, 2008) and pigs (Viswanathan, 2008; Fu *et al.*, 2009). Crops grown in this spatial arrangement included: (i) fruit trees for example, bush mango and star apple (Atia *et al.*, 2014) and grapefruit (Fu *et al.*, 2009) (ii) perennial crops for example, passion fruit, Chinese cardamom, tea (Fu *et al.*, 2009), and oil palm (Penot 2004) and (iii) annual crops for example, soybean (San and Deaton, 1999); maize, capsicum (Fu *et al.*, 2009), and rice (Viswanathan, 2008; Somboonsuke, 2001).

### *3.3.2 Intercropping systems*

Intercropping practices could be categorised into eight main types: Tree food crop, small tree, shrub or palm food crops, root food crop, above-ground non-tree food crops, timber trees, non-food non-timber crops, livestock; and apiculture. (Figure 4).

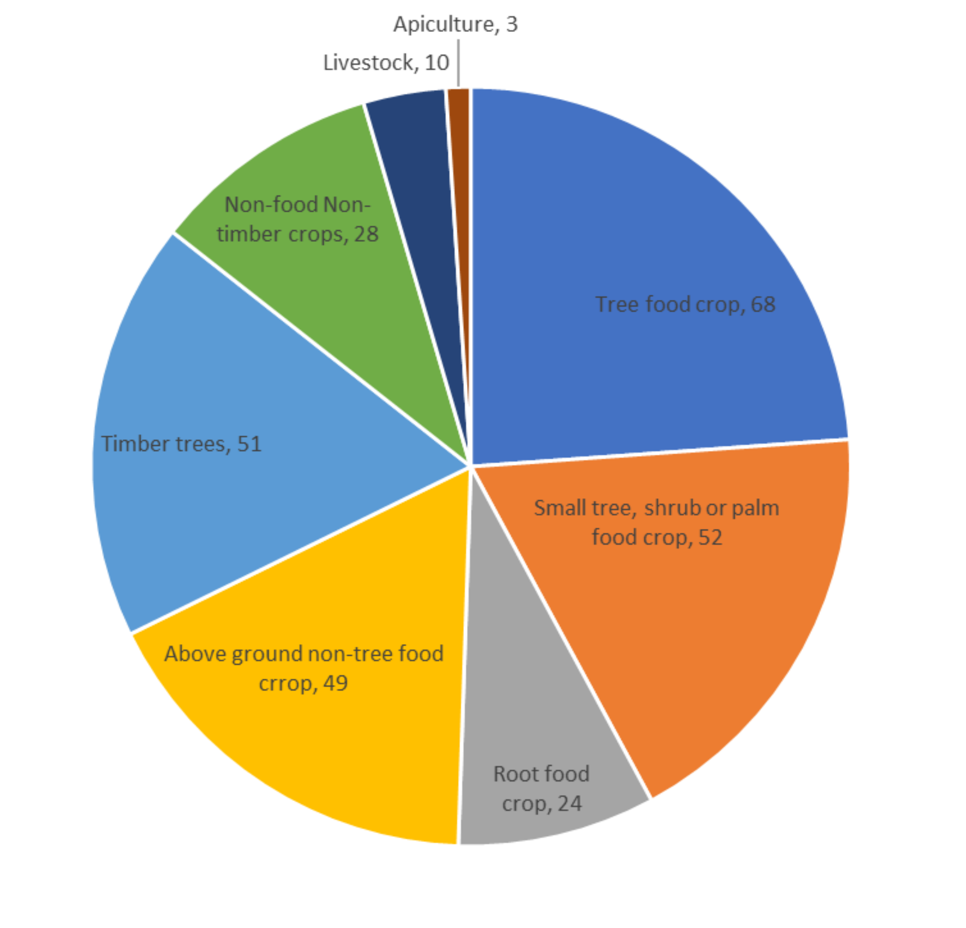


Figure 4: Number of intercropping systems reported

The most commonly studied intercrops with rubber were crops grown for food, including tree (e.g. fruit trees) and non-tree (e.g. cassava) crops. Table 2 summarises the main categories of intercropping plants by number of studies reported. Fewer studies investigated diversification through timber or livestock production and apiculture was seldom studied (Figure 4).

Table 2. Main categories of intercropping plants by number of studies reported

| Category | Scientific name | Common name | Number of studies |
|---|---|---|---|
| Tree food crop | Durio spp. | Durian | 11 |
| Tree food crop | Garcinia mangostana | Mangosteen | 6 |
| Tree food crop | Lansium domesticum Corr. | Lansium (Longkong) | 6 |
| Tree food crop | Parkia speciosa and timoriana | Bitter bean (Petai) | 6 |
| Tree food crop | Nephelium lappaceum | Rambutan | 5 |
| Tree food crop | Artocarpus integer | Champada | 4 |
| Tree food crop | Gnetum gnemon | Melinjo | 4 |
| Tree food crop | Archidendron jiringa | Jering | 3 |
| Tree food crop | Garcinia merguensis | Bastard garcinia (Mangosteen type) | 2 |
| Tree food crop | Shorea macrophylla | Tenkawang | 2 |
| Tree food crop | Theobroma cacao | Cocao | 2 |
| Tree food crop | Anacardium occidentale | Cashew | 1 |
| Tree food crop | Annona squamosa | Custard apple | 1 |
| Tree food crop | Archidendron microcarpum | Kabu | 1 |
| Tree food crop | Areca catechu | Areca nut | 1 |
| Tree food crop | Artocarpus heterophyllus | Jackfruit | 1 |
| Tree food crop | Asimina trilobal | Pawpaw | 1 |
| Tree food crop | Baccaurea ramiflora | Rambeh | 1 |
| Tree food crop | Bouea oppsitifolia | Plum mango | 1 |
| Tree food crop | Cinnamomum verum | Cinnamon | 1 |
| Tree food crop | Citrus limon | lemon | 1 |
| Tree food crop | Cola spp. | Cola | 1 |
| Tree food crop | Dimocarpus longan | Longan | 1 |
| Tree food crop | Garcinia spp. | brindleberry (Mangosteen type) | 1 |
| Tree food crop | Mangifera indica | Mango | 1 |
| Tree food crop | Rhus spp. | Sumac | 1 |
| Tree food crop | Sandoricum koetjape | Santol | 1 |
| Tree food crop | Syzygium aromaticum | Clove | 1 |
| Small tree, shrub or palm food crop | Musa spp. | Banana | 12 |
| Small tree, shrub or palm food crop | Ananas comosus | Pineapple | 11 |
| Small tree, shrub or palm food crop | Carica papaya | Papaya | 5 |
| Small tree, shrub or palm food crop | Salacca zalacca | salak | 5 |
| Small tree, shrub or palm food crop | Coffea spp. | Coffee | 4 |
| Small tree, shrub or palm food crop | Musa spp. | Plantain | 4 |
| Small tree, shrub or palm food crop | Cocos nucifera | Coconut | 3 |
| Small tree, shrub or palm food crop | Passiflora edulis | Passionfruit | 2 |
| Small tree, shrub or palm food crop | Elaeis guineensis | Oil palm | 1 |
| Small tree, shrub or palm food crop | Salacca wallichiana | Sweet salacca | 1 |
| Small tree, shrub or palm food crop | Vernonia amygdalina 1 | Bitter leaf | 1 |

Table 2. Main categories of intercropping plants by number of studies reported (continued)

| Category | Scientific name | Common name | Number of studies |
|---|---|---|---|
| Root food crop | Manihot sculenta | Cassava | 11 |
| Root food crop | Dioscorea spp. | Yam | 4 |
| Root food crop | Arachis hypogaea | Groundnut | 3 |
| Root food crop | Colocasia spp. | Cocoyam (Taro) | 2 |
| Root food crop | Pachyrhizus erosus | Yam bean (Jicama) | 1 |
| Root food crop | Xanthosoma sagittifolium | Tannia (Taro) | 1 |
| Root food crop | Zingiber cassumunar | Phlai | 1 |
| Root food crop | Zingiber officinale | Ginger | 1 |
| Above ground non-tree food | Oryza sativac | Rice | 13 |
| Above ground non-tree food | Zea mays | Maize | 10 |
| Above ground non-tree food | Camellia sinensis | Tea | 3 |
| Above ground non-tree food | Melon unspecified3 | Melon | 3 |
| Above ground non-tree food | Piper nigrum | Black pepper | 3 |
| Above ground non-tree food | Saccharum officinarum | Sugarcane | 3 |
| Above ground non-tree food | Capsicum annuum | Chili | 2 |
| Above ground non-tree food | Cucumis melo | Watermelon | 2 |
| Above ground non-tree food | Panicum miliaceum | Millet | 2 |
| Above ground non-tree food | Vigna radiata | Mung bean | 2 |
| Above ground non-tree food | Abelmoschus esculentus | Okra | 1 |
| Above ground non-tree food | Elettaria cardamomum | Cardamon | 1 |
| Above ground non-tree food | Glycine max | Soybean | 1 |
| Above ground non-tree food | Orthosiphon stamineus | Java tea | 1 |
| Above ground non-tree food | Pandanus amaryllifolius | Pandan | 1 |
| Above ground non-tree food | Piper sarmentosum | Pak mieng (Kaduk, or wild pepper) | 1 |
| Above ground non-tree food | Telfairia occidentalis | Telfera | 1 |
| Above ground non-tree food | Vigna unguiculate | Cowpea | 1 |
| Above ground non-tree food | Vigna unguiculate | Yard long bean | 1 |
| Timber trees | Azadirachta excelsa | Neem | 4 |
| Timber trees | Hopea odorata | Ironwood | 4 |
| Timber trees | Michelia champaca | Champaka | 4 |
| Timber trees | Aquilaria crassna | Eaglewood | 3 |
| Timber trees | Litsea grandis | Tung | 3 |
| Timber trees | Shorea roxburghii | White meranti | 3 |
| Timber trees | Acacia mangium | Mangium | 2 |
| Timber trees | Anthocepalus chinensis | Bur-flower | 2 |
| Timber trees | Dipterocarpus alatus | Yang | 2 |
| Timber trees | Lumnitzera littorea | Black mangrove | 2 |
| Timber trees | Shorea spp. Unspecified | | 2 |
| Timber trees | Swietenia macrophylla | Mahogany | 2 |
| Timber trees | Syzygium cumini | Jambolan Plum | 2 |
| Timber trees | Toona ciliate | Mouimein Cear | 2 |

Table 2. Main categories of intercropping plants by number of studies reported (continued)

| Category | Scientific name | Common name | Number of studies |
|---|---|---|---|
| Timber trees | Albizia Falcataria | Moluccan albizzia | 1 |
| Timber trees | Alstonia macrophylla | Hard alstonia | 1 |
| Timber trees | Cordia globifera | Suk-hin | 1 |
| Timber trees | Dyera polyphylla | Jelutong | 1 |
| Timber trees | Eugenia grandis | Sea apple | 1 |
| Timber trees | Gmelina arborea | Gamhar | 1 |
| Timber trees | Ilex cymose | Bangkulat | 1 |
| Timber trees | Intsia palembanica | Malacca teak | 1 |
| Timber trees | Justicia gendarussa | Gendarussa | 1 |
| Timber trees | Mesua ferrea | Sri Lankan Ironwood | 1 |
| Timber trees | Microcos tomentosa | Cenderai | 1 |
| Timber trees | Paramichelia baillonii | Magnolia | 1 |
| Timber trees | Schima wallichii | Needle wood | 1 |
| Timber trees | Swietenia mahagoni | American mahogany | 1 |
| Non-food Non-timber crops | Arecaceae family | Rattan | 4 |
| Non-food Non-timber crops | Bambusoideae | Bamboo | 3 |
| Non-food Non-timber crops | Cyrtostachys renda | Sealing wax palm | 2 |
| Non-food Non-timber crops | Johannesteijsmannia altifrons | Litter collecting palm | 2 |
| Non-food Non-timber crops | Licuala paludosa | Miang Ka Pho | 2 |
| Non-food Non-timber crops | Alpinia purpurata | Red ginger | 1 |
| Non-food Non-timber crops | Anthurium spp. | Flamingo flower | 1 |
| Non-food Non-timber crops | Calopogonium caeruleum | Legume type (cover crop) | 1 |
| Non-food Non-timber crops | Chrysalidocarpus lutescens | Yellow palm | 1 |
| Non-food Non-timber crops | Cinnamomum camphora | Camphor | 1 |
| Non-food Non-timber crops | Dimorphotheca spp. | Cape marigold | 1 |
| Non-food Non-timber crops | Flemingia spp. | Flemingia | 1 |
| Non-food Non-timber crops | Flowers and ornamentals | unspecified | 1 |
| Non-food Non-timber crops | Gossypium spp. | Cotton | 1 |
| Non-food Non-timber crops | Grass unspecified | Grass | 1 |
| Non-food Non-timber crops | Livistona speciosa | Livistona | 1 |
| Non-food Non-timber crops | Mucuna spp. | Veelvet bean (Cover crop) | 1 |
| Non-food Non-timber crops | Myristica yunnaensis | Nutmeg | 1 |
| Non-food Non-timber crops | Pueraria spp. | Kudzu | 1 |
| Non-food Non-timber crops | Zantedeschia spp. | Cala Lily | 1 |

Tree food-crops

Twenty-two studies originating mainly from South East or South Asia reported tree-food crops (fruit, nut, spice and legume trees) intercropped with rubber. Nineteen of these studies specified tree species.

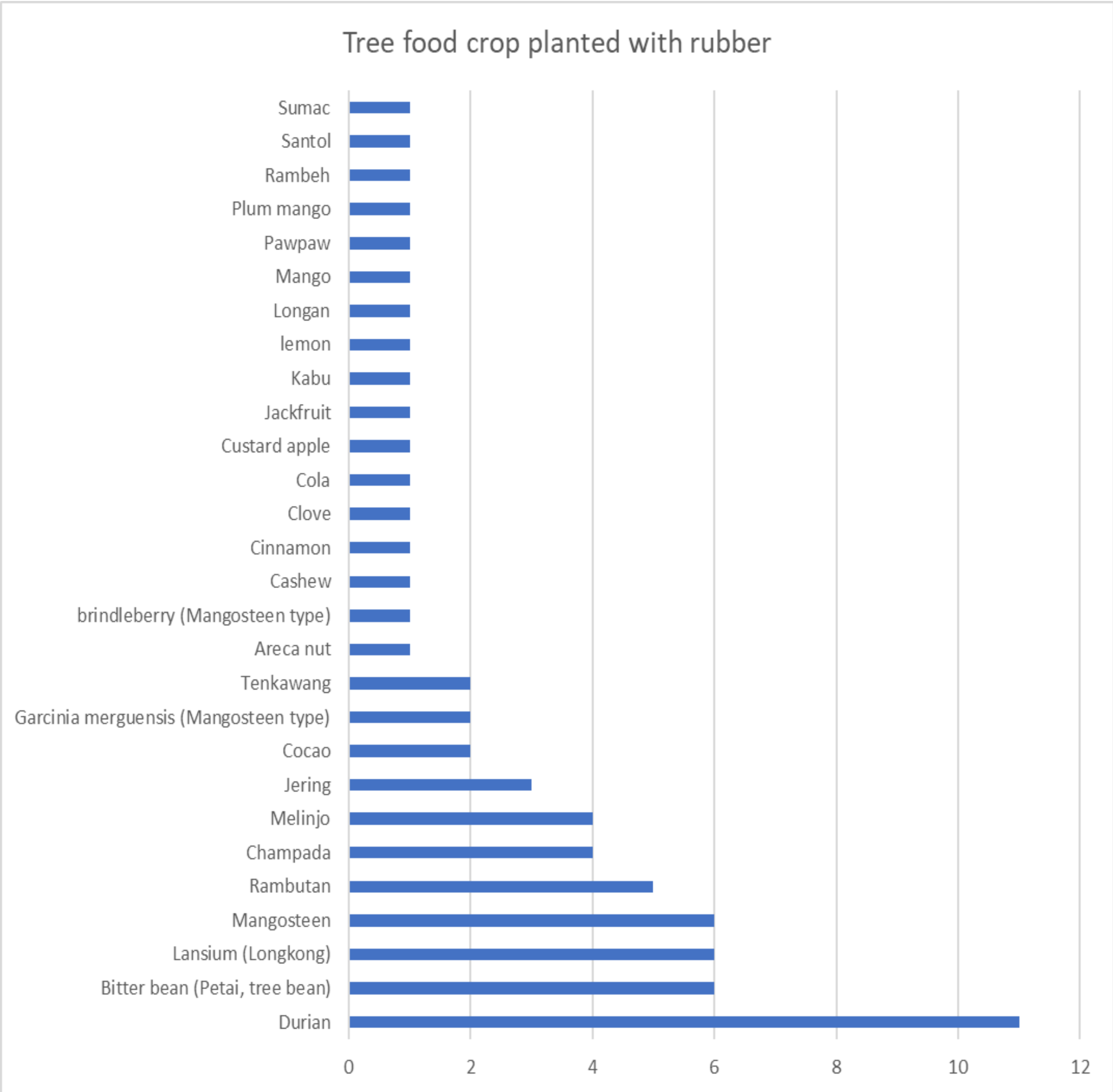


Figure 5. Number of studies reported tree food crops intercropped with rubber

A total of 28 types of trees were identified with fruit trees being most commonly intercropped with rubber, and Durian (*Durio* spp.) was most frequently studied (Figure 5 and Table 2). Other commonly studied tree crops were mangosteen (*Garcinia mangostana*), Lansium (Longkong), bitter bean (*Parkia speciosa*), and rambutan (*Nephelium lappaceum*). All of the tree-crops studied were reported to be commercially practiced with the exception of Cinnamon and Cola which were from experimental studies.

Non-tree food crops

Forty-three studies reported non-tree food crops intercropped with rubber of which 43 specified the type of food crop (Table 2). There are three sub-categories: small tree, shrub or palm food crops, root food crops and above-ground non-tree food crops.

Small tree, shrub or palm food crops include 11 crops, of which banana, pineapple, papaya and salak were some of the most commonly reported crops. Other crops included coffee, plantain, tea, coconut, passionfruit, oil palm and bitter leaf (Figure 6).

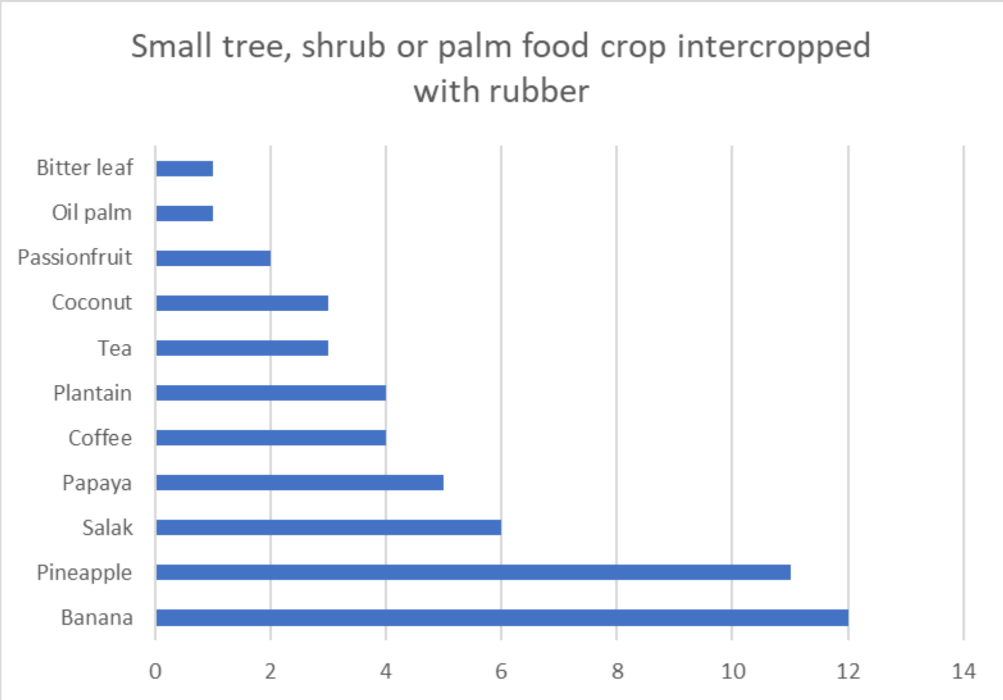


Figure 6. Number of studies reported small tree, shrubs or palm food crops intercropped with rubber

Seven crops were identified as root food crops are shown in figure 7. Cassava and yam were most reported crops. Other crops include groundnut, taro, jicama (yam bean), phlai and ginger.

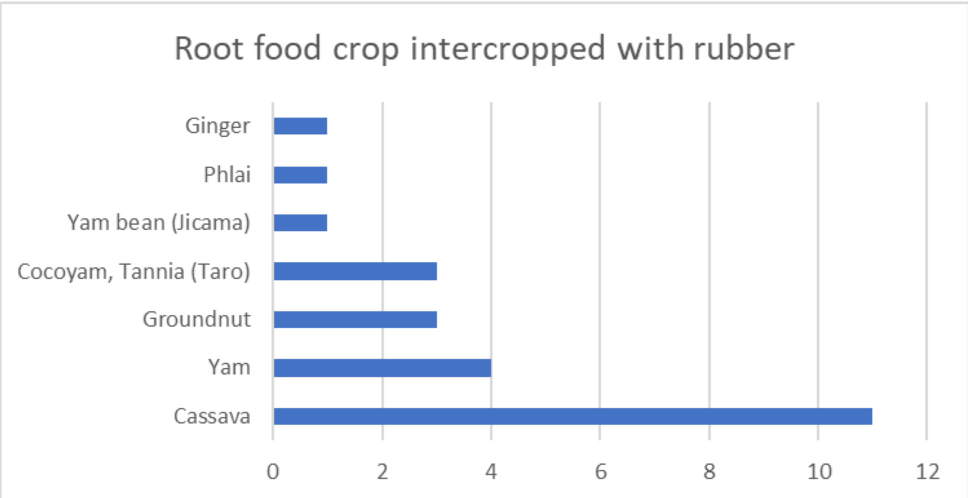


Figure 7. Number of studies reported root food crops intercropped with rubber

Eighteen food crops are above-ground non-tree type, most of which tend to be grain and vegetables. As shown in figure 8, rice (n=13) and maize (n=10) were the most reported, followed by melon, black pepper and sugarcane. Other crops reported were chili, millet, mungbean, watermelon, Cowpea, Java tea, Okra, Pak mieng (Kaduk, or wild pepper), Pandan, Soybean, Telfera and Yard long bean.

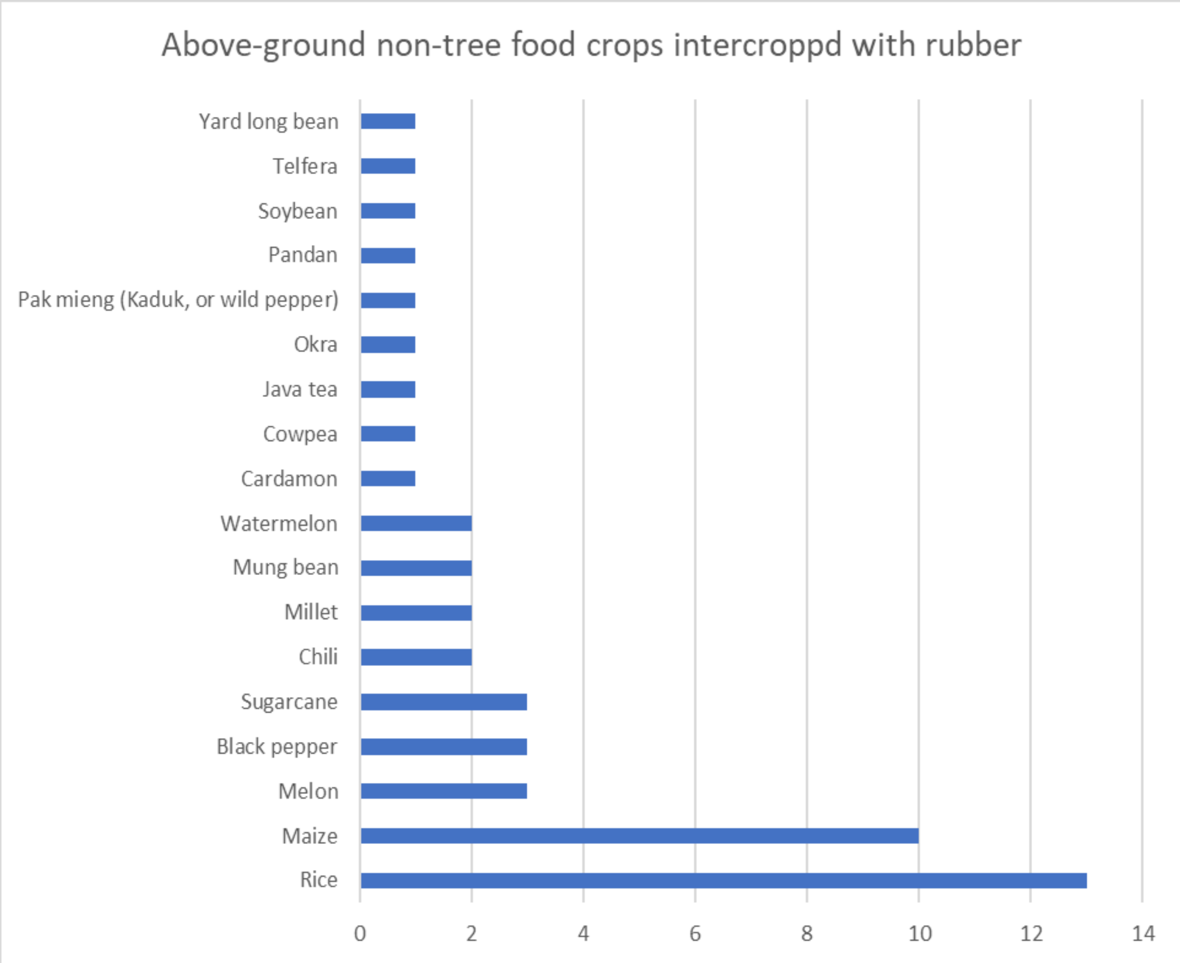


Figure 8. Number of studies reported above-ground non-tree food crops intercropped with rubber

Of all non-tree crops, cowpea (*Vigna unguiculate*), Java tea (*Orthosiphon stamineus*), Phlai (*Zingiber cassumunar*) and Soybean (*Glycine max*) were experimentally intercropped with rubber. The remainder of the food crops were commercially practiced. Banana (*Musa* spp.), maize (*Zea mays*), cassava (*Manihot sculenta*), rice (*Oryza sativa*) and pineapple (*Ananas comosus*) were some of the most commonly studied crops. The majority of these crops were intercropped with immature rubber (n=35 studies).

Timber

Twelve studies reported timber being intercropped with rubber of which 9 specified the species/genus of tree (Table 2 and Figure 9).

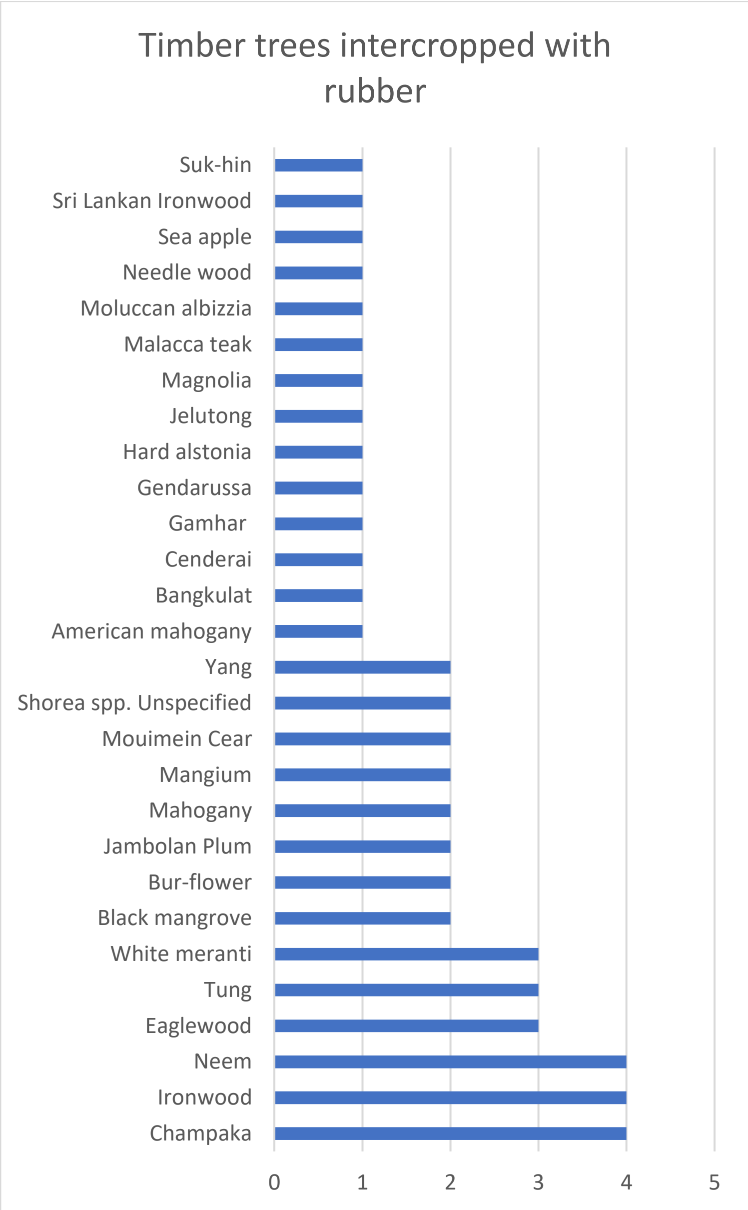


Figure 9. Number of studies reported timber trees intercropped with rubber

Twenty-eight timber trees were identified, with neem, ironwood and Champaka being the most commonly studied. American mahogany (*Swietenia mahagoni*), Gamhar (*Gmelina arborea*), Jelutong (*Dyera polyphylla*), Magnolia (*Paramichelia baillonii*), Mangium (*Acacia mangium*), Moluccan albizzia (*Albizia Falcataria*), *Shorea* spp. (unspecified species) and Sri Lankan Ironwood (*Mesua ferrea*) were experimentally intercropped with rubber. The remainder of the tree species were reported to be commercially practiced.

Non-food crops other than timber

Thirteen studies reported non-food crops other than timber being intercropped with rubber. Twenty non-food non-timber crops, including ornamental flowers, palms and cover crops were identified (Figure 10).

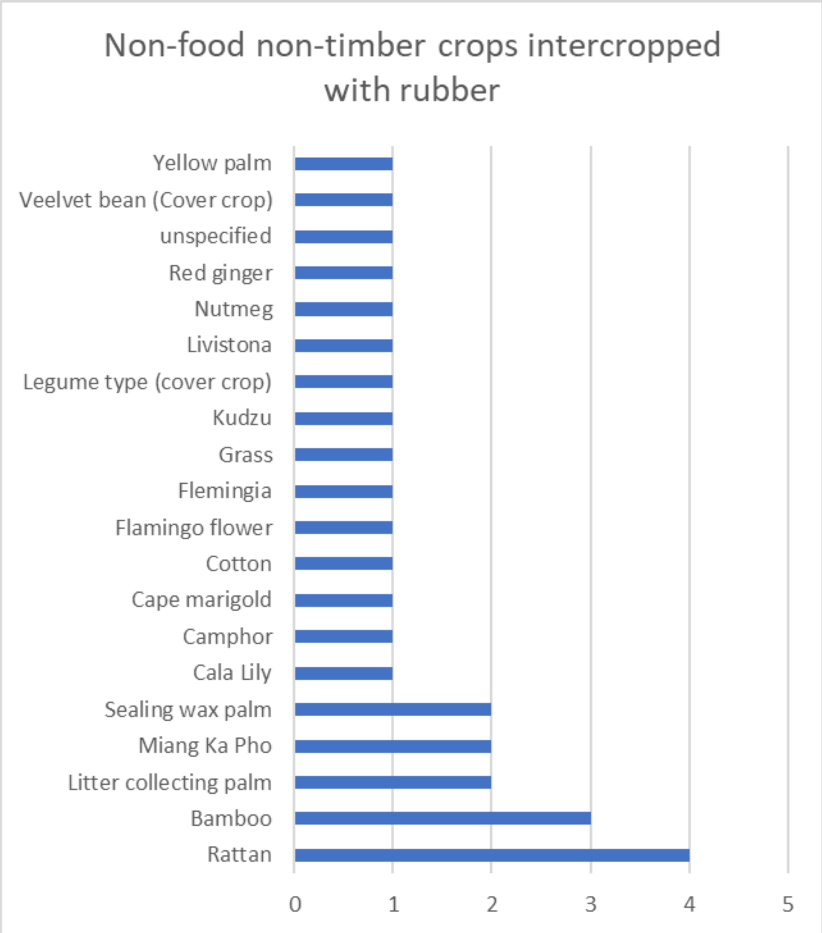


Figure 10. Number of studies reported non-food and non-timber crops intercropped with rubber

Rattan (Arecaceae family) and bamboo (subfamily Bambusoideae) were most commonly reported. Calla lily (*Zantedeschia* spp.), *Flemingia* spp., *Mucuna* spp. and *Myristica yunnaensis* were experimentally intercropped with rubber, the remaining crops were commercially practiced.

Livestock

A total of 10 studies reported rearing livestock under rubber, with sheep being most commonly reported (Majid *et al.*, 1990; Iniguez *et al.*, 1991; Tajuddin 1996; Chong *et al.*, 1997; San and Deaton, 1999), followed by goats (Saithanoo 1998; Stroesser *et al.*, 2018), broiler chickens (Tajuddin 1996; Meng *et al.*, 2012) and cattle (Somboonsuke *et al.*, 2011). One study did not specify livestock type (Somboosuke, 2001). All studies reported activities that are commercially practiced with the exception of three research studies reported for sheep and poultry (Chong *et al.*, 1997; Iniguez *et al.*, 1991; Tajuddin 1996). Livestock were reared in both immature and mature rubber. Authors noted however, that rubber trees must be tall enough before integrating certain livestock to avoid animals feeding and damaging rubber plants (e.g. Tajuddin 1986).

Apiculture

Commercial honey production in rubber plantations was reported in 3 studies (Tajuddin, 1986; Wongsiri *et al.*, 1999; Atia *et al.*, 2014), in both immature and mature rubber.

### *3.3.3 Summary*

Due to the majority of studies were from South Asia and Southeast Asia, it is unsurprising to see that most crops intercropped with rubber are normally found in Asia. Brazilian studies used cacao and sugarcane. Studies from Côte d'Ivoire used cacao, cola, lemon, and coffee, and studies from Nigeria reported mainly non-tree food crops such as cassava, melon, plantain, maize, pineapple and yam.

The above mapping showed what farming diversification systems were reported in the identified studies. Of all farming diversification systems for rubber farming, rice (n=13), cassava (n= 12), and maize (n=10) were the most common crops used in both Asia and Africa. The most common fruit crops were banana (n=12), durian (n=11) and pineapple (n=11). The next section looks at whether the identified farming diversification systems work for rubber farmers financially.

## *3.4 Impacts of on-farm diversification on financial outcomes of rubber-based farming systems*

### *3.4.1 Study selection and profiles of studies selected*

As explained in the methods section, the 65 articles identified provided evidence of farming diversification systems practiced alongside rubber farming. However, not all of those articles included complete information to enable a robust synthesis of the economic outcomes in comparison with monoculture rubber farming system. To be eligible for this type of analysis, each article had to meet the following additional criteria:

- The study should have reported one or more economic outcomes (e.g. Benefit cost ratio; Net Present Value; Return to land; Return to Labour; Income; Cumulative return; Net farm income; Gross margin; Net benefit and Net profit). Productivity related indicators such as yield alone was not eligible.
- Economic outcomes should be reported for both intervention group (diversification) and control group (monoculture rubber).
- Data used should be primary rather than secondary.
- Rubber plantation studied should include productive stage. If only immature stage was included, the economic outcomes would be limited (often costs only).

After applying those additional criteria, 14 studies were found to be eligible. Details of the 14 studies are presented in Tables 3 and 4. Of the 14 articles, seven used net present value, four used net farm income, one used cumulative return, one used income and one used gross margin. As noted by Mallett *et al.,* (2012), there are many practical challenges in reviewing literature in international development field. Due to the range and inconsistency of methodological approaches adopted, "meta-analysis is rarely possible (p. 449). After assessing all the information available from the 14 studies, the research team came to the conclusion that a conventional meta-analysis of the economic impact of farming diversification in rubber farming was not possible. Information on statistical significance of comparisons, standard errors and confidence intervals were not available. Therefore, we adopted a qualitative synthesis approach.

Of the 14 articles, 12 were published in peer-reviewed journals, one was presented to a conference and one was unpublished report. Twelve articles were in English and two were in Thai (with key information translated by the team members who were native Thai). The majority of the farms studied were commercial private-owned small-scale farms with two exceptions. Guo *et al.,* (2006) used data from a state-owned large commercial farm with 333 ha for mono rubber plantation and 250 ha for rubber-tea intercropping. Snoeck *et al.,* (2013) collected data from a 17-year experimental farm. Table 3 shows the profile of the studies with seven studies collected data from Thailand, four from Indonesia, one from China, one from Malaysia, one from Côte d'Ivoire and one from India (which also included Thailand).

Table 3. Profiles of the studies selected for synthesis of economic outcomes

| Author | Publication type and language | Country of studies | Year of studies | Sample size (number of farms) | Average farm size (ha) | Rubber age |
|---|---|---|---|---|---|---|
| Charernjiratragul *et al.*, 2015 | Unpublished Thai | Thailand | 2011 | 23 | 3.2 (all inclusive) | unclear[a] |
| Guo *et al.*, 2006 | Peer-reviewed English | China | 2001-2004 | 1 | Large[b] | Mature, |
| Lehebel-Peron *et al.*, 2010 | Peer-reviewed English | Indonesia | 2008 | 26 | 2 | Immature, Mature, |
| Majid *et al.*, 1990 | Peer-reviewed English | Malaysia | 1987-88 | 51 | 28 | Immature, Mature |
| San & Deaton, 1999 | Peer-reviewed English | Indonesia | 1995-2011 (1993) | 85 | 3 | Mature |
| Simien & Penot, 2011 | Peer-reviewed Thai | Thailand | 2005 | 20 | 1.5-17[c] | Immature, Mature |
| Snoeck *et al.*, 2013 [f] | Peer-reviewed English | Côte d'Ivoire | 1989-2005 | 1 | 6 | Immature, Mature |
| Somboonsuke, 2001 | Peer-reviewed English | Thailand | 1999-2001 | 26 | 1.92 | Immature, Mature |
| Somboonsuke *et al.*, 2011 | Peer-reviewed English | Thailand | 2007 | 300 | 2.5 | Immature, Mature |
| Somboonsuke *et al.*, 2007 | Peer-reviewed Thai | Thailand | 2010-2019 | 109 | 2.6 | unclear |
| Stroesser *et al.*, 2018 | Peer-reviewed English | Thailand | 2014-2015 | 32 | 3.48[d] | Immature, Mature |
| Viswanathan, 2008 | Peer-reviewed English | India, Thailand | 2005 | 309 106 | 2.39 | unclear |
| Winarni *et al.*, 2018 | Peer-reviewed English | Indonesia | 2000-2016 | Unclear | 5.6-14.7 [e] | Mature, |
| Wulan *et al.*, 2006 [f] | Conference English | Indonesia | 2005-2006 | 80 | 4.8 | Immature, Mature |

Notes:

a. Unclear - Due to the data suggest income from rubber farming, it was assumed that mature rubber was considered in the study.

b. state-owned farm with 12,250ha (333 ha of rubber plantation, 240 ha of tea plantation and 250 ha of rubber-tea cropping)

c. 3ha for monorubber, 1.5-3.2 ha for rubber and rice. Three were less than 8 and one 17 ha for rubber and fruit trees

d. calculated by the authors Sum of (6*3.9, 3*1.2, 6*1.4, 3*3.6, 5*1.9, 1*2.1, 4*10.5, 4*2.9)/32

e. 10.1 for mono rubber, 14.7 for rubber and camphor and 5.6 for rubber and Durian

f. Snoeck *et al.,* (2013) study was based on an experimental farm and Wulan *et al.,* (2006) used commercial farms who participated in a development project.

Table 4 shows the crops of diversification systems reported in the 14 studies. However, not all the crops reported were specifically matched for economic outcomes. For example, Lehebel-Peron *et al.*, (2010) used the generic term agroforest 9 types as one category and singled out petai (bitter bean) for comparison. Specific diversification farming system matching against economics outcomes for synthesis is presented in tables a – c.

Table 4. Farming diversification systems reported in the studies selected for synthesis of economic outcomes

| **Author** | **Diversification practice type** | **Crop/Livestock reported (if specified)** |
|---|---|---|
| Charernjiratragul *et al.*, 2015 | Tree-food crop, Timber, Non-food crop other than timber | Bitter bean, durian, champada, longkong, mangosteen, plum mango, rambeh, santol, tree bean, bamboo |
| Guo *et al.*, 2006 | Non-tree food crop | Tea |
| Lehebel-Peron *et al.*, 2010 | Tree-food crop, Timber, Non-food crop other than timber | Bitter bean, champada, durian, jerin, kabu, longan, rattan |
| Majid *et al.*, 1990 | Livestock | Sheep |
| San & Deaton, 1999 | Livestock, Non-tree food crop | Soybean, sheep |
| Simien & Penot, 2011 | Tree-food crop, Non-tree food crop, Timber | Durian, longkong, mangosteen, rambutan, ginger, maize, pak mieng, pineapple, rice |
| Snoeck *et al.*, 2013 | Tree-food crop, Non-tree food crop | Cocao, cola, lemon, coffee |
| Somboonsuke, 2001 | Livestock, Tree-food crop, Non-tree food crop, Aquaforestry | Fish, maize, pineapple, rice |
| Somboonsuke *et al.*, 2011 | Livestock, Tree-food crop, Non-tree food crop, Non-food crop other than timber | Cattle, cashew, custard apple, durian, jackfruit, mango, mangosteen, papaya, sumac, banana, cassava, chilli, maize, pineapple, rice, salacca, cape marigold, cotton |
| Somboonsuke *et al.*, 2007 | Tree-food crop, Non-tree food crop | Oil palm |
| Stroesser *et al.*, 2018 | Livestock, Tree-food crop, Non-tree food crop, Timber | Goats, bitter bean, durian, mangosteen, malinjo, salacca, champaka, ironwood, longkong, neem, Shorea roxburghii, tung, |
| Viswanathan, 2008 | Livestock, Tree-food crop, Non-tree food crop, Aquaforestry | Poultry, fish, pigs, rice |
| Winarni *et al.*, 2018 | Tree-food crop, Non-food crop other than timber | Camphor, durian |
| Wulan *et al.*, 2006 | Tree-food crop, Non-tree food crop, Timber, Non-food crop other than timber | Bitter bean, durian, rambutan, tengkawang, rice, gambar, mangium, Moluccan albizia, shorea, Flemingia, Mucuna, Pueraria |

Economic outcomes used by the studies vary greatly as shown in Table 5. To maximise the convergence and consistency of comparison, only one indicator was chosen from each study for synthesis. Net present value (NPV) was the preferred option if available. This was followed by cumulative return, net farm income, return to labour, land expectation value (LEV) and income. Table 5 shows which indicator was chosen for each study.

Table 5: Economic outcomes reported in each study

| **Author** | **Main economic outcome chosen for comparison** | **Other economic outcomes reported in the study** |
|---|---|---|
| Charernjiratragul *et al.*, 2015 | net present value (NPV) | benefit cost ratio, |
| Guo *et al.*, 2006 | net present value | land expectation value (LEV), variable cost, |
| Lehebel-Peron *et al.*, 2010 | net present value | return to labour, return to land |
| Majid *et al.*, 1990 | net present value | benefit cost ratio, internal rate of return, payback period |
| San & Deaton, 1999 | net present value | revenue/cost, income |
| Winarni *et al.*, 2018 | net present value | marginal annual production, mean annual increment, current annual increment, internal rate of return, average annual production, yield |
| Wulan *et al.*, 2006 | net present value | internal rate of return, total cost, labour, income, profit |
| Simien & Penot, 2011 | net farm income | labour, income, |
| Somboonsuke, 2001 | net farm income | total cost, income, |
| Somboonsuke *et al.*, 2011 | net farm income | |
| Somboonsuke *et al.*, 2007 | net farm income | income, net profit, costs |
| Snoeck *et al.*, 2013 | cumulative return | labour, yield, gross margin, |
| Stroesser *et al.*, 2018 | return to labour | gross margin |
| Viswanathan, 2008 | income | |

Due to the heterogeneity of reporting and study context, it was impossible to combine the economic impact. Synthesises of the research findings were carried out in a qualitative descriptive approach in three sections below based on data extracted for 1) net present value, 2) net farm income, and 3) other indicators (cumulative return, return to labour and income). Only data for productive stage of rubber were used. Where multiple diversification systems were reported, they were presented separately. Where multiple years of data were available, mean score of the years were used. Percentage of changes of economic outcomes (EO) was calculated with this formula:

% change of EO = (EO of diversification – EO of mono rubber)/EO of mono rubber x 100

The changes are presented in both table and bar chart formats.

*3.4.2 Net Present Value comparison*

Net Present Value was used in seven studies as shown in the table below. Due to the heterogeneity of the context such as the farming diversification systems practiced, the years of rubber plantation, discount rate used, it was impossible to conduct a meaningful meta-analysis of the outcomes. To enable synthesis of the economic outcomes, percentages of increase or decrease of NPVs of diversified framing systems compared to the NPVs of mono rubber system were calculated using the reported figures from six studies. San and Deaton (1999) did not provide the original data, but reported percentage of changes.

Table 6 and Figure 11 show that the outcomes are mixed. Negative changes (i.e., decrease in NPV) were reported by Lehebel-Peron et al. (2010), Winarni *et al.,* (2018) and Wulan *et al.,* (2006) all from Indonesia.  Lehebel-Peron *et al.,*'s (2010) study looked at petai (bitter beans) and 9 types of agroforestry trees (unspecified species) intercropping with rubber and modelled the economic performance across different scenarios. They found that mono rubber farming system performs better than all types of agroforestry systems. Of all the scenarios, Petai intercropped with rubber trees performed better than other 9 types of agroforest trees, although it's still worse than rubber monocropping. Winarni *et al.,* (2018) and Wulan *et al.,* (2006) both found that rubber intercropped with food crops (unspecified), tree crops such as camphor and fast-growing trees did not perform as well as monocrops. On the other hand, they found positive changes for Durian (Winarni *et al.,* 2018) and timber trees associated with rubber (Wulan *et al.,* 2006). Studies by Charenjiratragul *et al.,* (2014), Guo *et al.,* (2006) and Majid *et al.,* (1990) all found that farming diversification systems performed better than rubber monocropping system. Of all the types of intercrops looked at by the seven studies, Durian was found to be the best performing crop with an increase of 144.4%, followed by associated timber trees (46.3% to 127% increase). Sheep grazing seemed to moderately enhance the economic performance (Majid *et al.,* 1990) and Sand & Deaton, 1999).

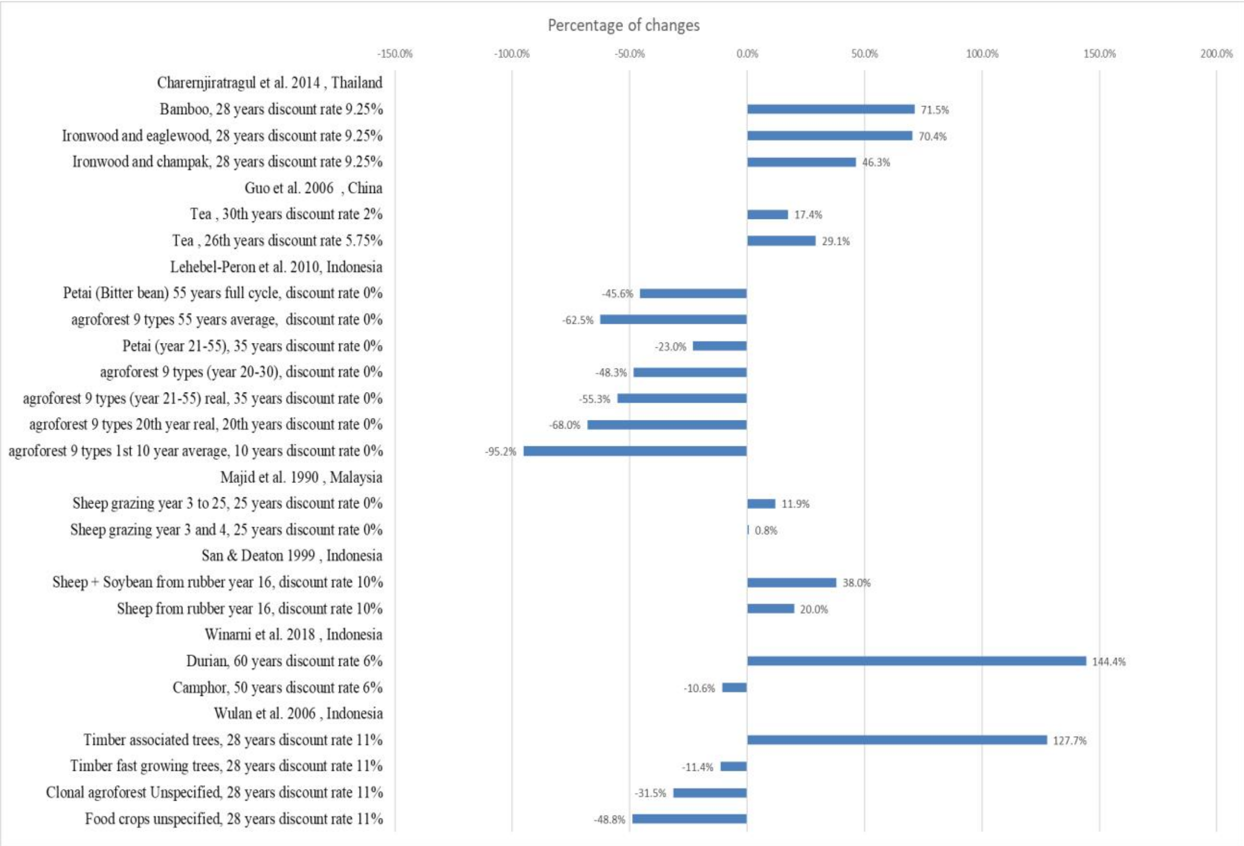


Figure 6. Percentage of changes of net present value compared to mono rubber farming

Table 6. Net present value and percentage of changes compared to mono rubber farming

| Author (year) (country of study) / Farming systems | Rubber years | Discount rate | NPV | Percentage of changes compared to mono rubber |
|---|---|---|---|---|
| Charernjiratragul *et al.*, 2014 (Thailand) | | | (THB/rai) | |
| Bamboo | 28 | 9.25 | 75603 | 71.5% |
| Timber Ironwood and eaglewood | 28 | 9.25 | 75118 | 70.4% |
| Timber Ironwood and champak | 28 | 9.25 | 64510 | 46.3% |
| Mono rubber | 28 | 9.25 | 44092 | |
| Guo *et al.*, 2006 (China) | | | (RMB/ha) | |
| Tea | 30th | 2 | 271030 | 17.4% |
| Tea | 26th | 5.75 | 50717 | 29.1% |
| Mono rubber | 29th | 2 | 230829 | |
| Mono rubber | 29th | 5.75 | 39286 | |
| Lehebel-Peron *et al.*, 2010 (Indonesia) | | | (Euro/ha) | |
| Petai (Bitter bean) 55 years | 55 | 0 | 2332 | -45.6%[a] |
| agroforest 9 types 55 yrs average | 55 | 0 | 1608 | -62.5%[a] |
| Petai 35 years (21-55) | 35 | 0 | 3300 | -23.0%[a] |
| agroforest 9 types (21-55) real | 35 | | 1916 | -55.3%[a] |
| agroforest 9 types years 20-30 | 20th - 30th | 0 | 2216 | -48.3% |
| agroforest 9 types 20th year real | 20th | 0 | 1370 | -68.0%[a] |
| agroforest 9 types 1st 10 year average | 10 | 0 | 205 | -95.2%[a] |
| Mono rubber (traditional) years 20-30 | 20th - 30th | | 4286 | |
| Majid *et al.*, 1990 (Malaysia) | | | (MYR/ha) | |
| Sheep grazing year 3 to 25 | 25 | 0 | 496181 | 11.9% |
| Sheep grazing year 3 and 4 | 25 | 0 | 446818 | 0.8% |
| Mono rubber | 25 | 0 | 443351 | |
| San & Deaton 1999 (Indonesia) | | | | |
| Sheep + Soybean from rubber year 16 | from year 16 | 10 | | 38.0%[b] |
| Sheep from rubber year 16 | from year 16 | 10 | | 20.0%[b] |
| Mono rubber from year 16 | from year 16 | 10 | | |
| Winarni *et al.*, 2018 (Indonesia) | | | (IDR/ha) | |
| Durian | 60 | 6 | 22832400 | 144.4% |
| Camphor | 50 | 6 | 8348200 | -10.6% |
| mono rubber (25 years) | 25 | | 9341900 | |
| Wulan *et al.*, 2006 (Indonesia) | | | (IDR/ha) | |
| Timber associated trees | 28 | 11 | 18316000 | 127.7% |
| Timber fast growing trees | 28 | 11 | 7127000 | -11.4% |
| Clonal agroforest Unspecified | 28 | 11 | 5514000 | -31.5% |
| Food crops unspecified | 28 | 11 | 4116000 | -48.8% |
| Mono rubber SRDP | 30 | 11 | 8045000 | |

Notes: No direct comparison (compared with mono rubber years 20-30 figure)

a. No original data available. Percentage of changes was provided in the report.

### *3.4.3 Net farm income*

Four studies reported net farm income for both mono rubber and farming diversification systems, all based on data from Thailand (Figure 12 and Table 7). Simien and Penot (2011) studied five rubber-based production systems in Phatthalung and Songkhla provinces of Thailand: rubber with durian, rubber with rice, rubber with other veg and fruit crops, jungle rubber and conventional mono rubber systems. Jungle rubber was excluded from our synthesis as there was no comparable interventions. They modelled three scenarios of rubber price fluctuations (increase to the ceiling price US$2/kg, decrease and then rise to current price and current price). Therefore, seven years (2005-2011) of data for mono rubber and rubber-based durian, rice, veg and fruit crops were extracted for each price scenario and mean score were used for comparison. Somboonsuke *et al.,* (2011), Somboonsuke *et al.,* (2017) and Somboonsuke (2001) all used one year of data. Somboonsuke *et al.,* (2011) reported net farm income for specific crops in food crops, small fruit trees or bush, fruit trees and livestock (cattle) whilst the other two used generic categories only. Somboonsuke *et al.,* (2017) didn't include livestock.

Of the four studies, all farming diversification systems reported in Somboonsuke (2001) and Somboonsuke *et al.,* (2017) performed better than monocrop rubber production. Fruit trees or bushes in general generated better income than mono rubber system as shown in Simien and Penot (2011), Somboonsuke *et al.,* (2011) and Somboonsuke (2001), whilst food crops intercropped with rubber were found to be worse off than mono rubber system.

Mixed results for rice and durian were found. Rubber intercropped with rice were found to perform worse than mono rubber with a decrease of 75 to 80% in all three price scenarios reported by Simien and Penot (2011). However, rice intercropped in rubber were reported to increase income by 95% in Somboonsuke *et al.,*'s (2011) and by 410% in Somboonsuke's (2001) study. Durian intercropped with rubber were found to increase income by 96% in current price scenario and by 84% in decreased rubber price scenario as shown in Simiem and Penot's (2011) report. Somboonsuke *et al.,*'s (2011) study found that income from rubber intercropped with durian was 40% worse off than income from mono rubber.

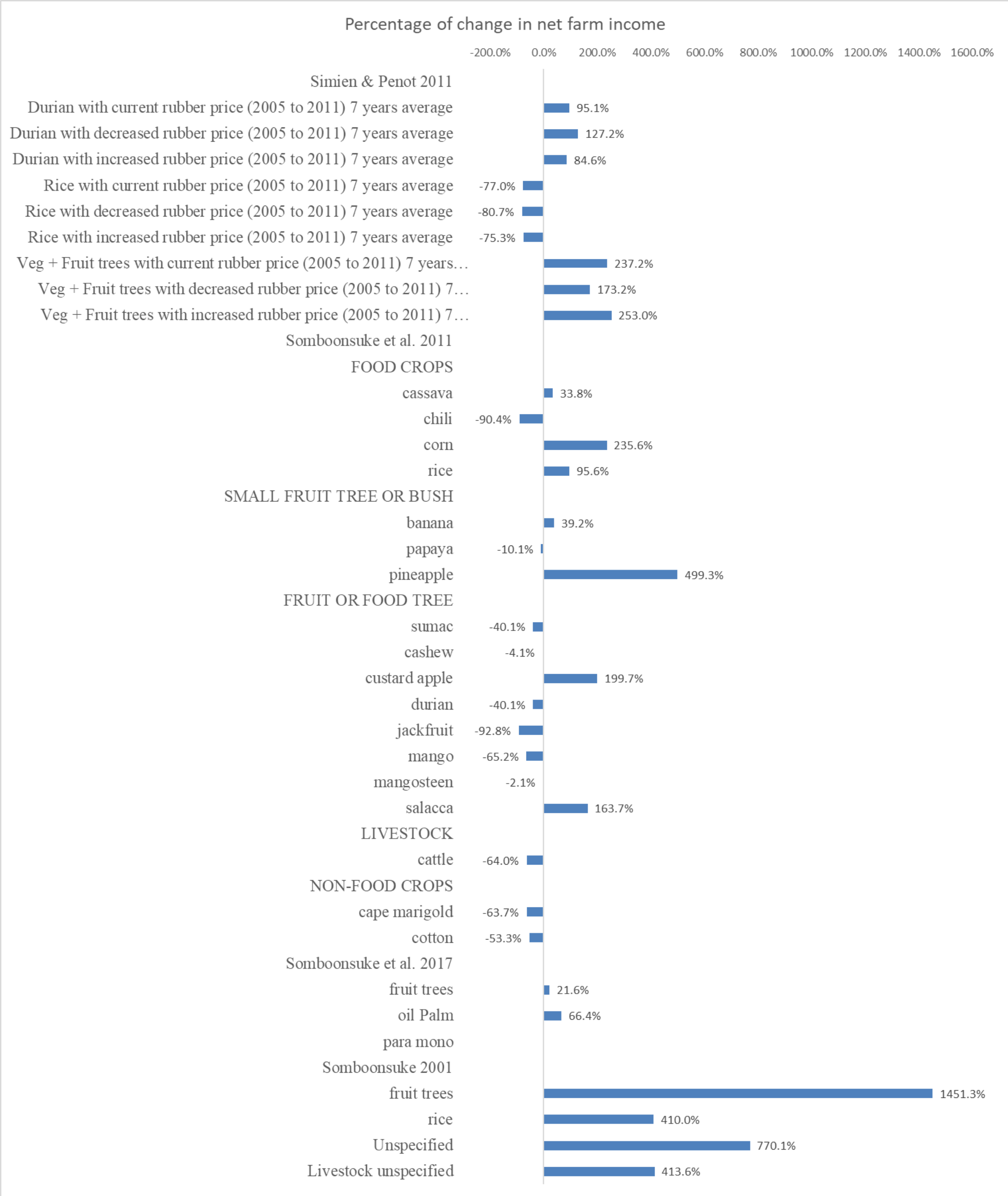


Figure 12. Percentage of changes of net farm income

Table 7. Net farm income and percentage of changes

| Author (year) (country of study) | Farming systems | Net farm income | Percentage of change |
|---|---|---|---|
| Simien & Penot 2011 (Thailand) | | THB/ha | |
| | Durian with current rubber price (2005 to 2011) 7 years average | 328685.7 | 95.1% |
| | Durian with decreased rubber price (2005 to 2011) 7 years average | 240501.7 | 127.2% |
| | Durian with increased rubber price (2005 to 2011) 7 years average | 376413.9 | 84.6% |
| | Rice with current rubber price (2005 to 2011) 7 years average | 38770.7 | -77.0% |
| | Rice with decreased rubber price (2005 to 2011) 7 years average | 20412.7 | -80.7% |
| | Rice with increased rubber price (2005 to 2011) 7 years average | 50313.3 | -75.3% |
| | Veg + Fruit trees with current rubber price (2005 to 2011) 7 years average | 568174.8 | 237.2% |
| | Veg + Fruit trees with decreased rubber price (2005 to 2011) 7 years average | 289150.4 | 173.2% |
| | Veg + Fruit trees with increased rubber price (2005 to 2011) 7 years average | 720014.9 | 253.0% |
| | Mono rubber with current rubber price (2005 to 2011) 7 years average | 168473.1 | |
| | Mono rubber with decreased rubber price (2005 to 2011) 7 years average | 105833.1 | |
| | Mono rubber with increased rubber price (2005 to 2011) 7 years average | 203958.9 | |
| Somboonsuke *et al.*, 2011 (Thailand) | | THB/ha | |
| FOOD CROPS | cassava | 111666.7 | 33.8% |
| | chili | 8000.0 | -90.4% |
| | corn | 280000.0 | 235.6% |
| | rice | 163200.0 | 95.6% |
| SMALL FRUIT TREE OR BUSH FOOD CROPS | banana | 116106.7 | 39.2% |
| | papaya | 75000.0 | -10.1% |
| | pineapple | 500000.0 | 499.3% |
| FRUIT OR FOOD TREE | sumac | 50000.0 | -40.1% |
| | cashew | 80000.0 | -4.1% |
| | custard apple | 250000.0 | 199.7% |
| | durian | 50000.0 | -40.1% |
| | jackfruit | 6000.0 | -92.8% |
| | mango | 29000.0 | -65.2% |
| | mangosteen | 81668.0 | -2.1% |
| | salacca | 220000.0 | 163.7% |
| LIVESTOCK | cattle | 30000.0 | -64.0% |
| NON-FOOD CROPS | cape marigold | 30250.0 | -63.7% |
| | cotton | 39000.0 | -53.3% |
| | mono rubber | 83428.6 | |
| Somboonsuke *et al.*, 2017 (Thailand) | | THB/ha | |
| | fruit trees | 14017.5 | 21.6% |
| | oil palm | 19183.2 | 66.4% |
| | para mono | 11525.5 | |
| Somboonsuke 2001 (Thailand) | | THB/ha | |
| | fruit trees | 4813.7 | 1451.3% |
| | rice | 1582.5 | 410.0% |
| | unspecified | 2700.0 | 770.1% |
| | livestock unspecified | 1593.8 | 413.6% |
| | mono rubber | 310.3 | |

### *3.4.4 Cumulative return, Return to labour and Income*

Three studies used different economic measures (Figure 13 and Table 8). Snoeck *et al.,* (2013) used cumulative return over 17 years. Data extracted from year 8 to year 17 were used to calculate the means score for each system for comparison with mono rubber system this is because rubber plantation hardly generates income during years 1 to 7. Data from this study were collected from an experimental farm in Cote d'Ivoire. They experimented five farming systems (mono rubber, cacao, coffee, cola, fruit trees (unspecified) and lemon). Stroesser et al (2018) collected data from Phatthalung province in Southern Thailand. Data for return to labour were extracted for seven farming systems. Viswanathan's study (2008) collected data from 3 villages in India and 1 in Thailand. Mean scores of data from the three villages from India were calculated. They looked at income from six farming diversification systems (fish, Pigs, poultry, Unspecified livestock, rice, Veg + fruit trees) in comparison with income from mono rubber production system. Of all the systems reported, Viswanathan (2000) reported increase of income from all diversified farming systems in both India and Thailand. Snoeck et al (2013) found that rubber-based fruit tree diversification systems were slightly worse than mono rubber (6.4% decrease of cumulative return) and nut trees (cacao, coffee and cola) all performed better than mono rubber with coffee being the best with an increase of 28%.

Stroesser et al (2013) found that timber trees intercropped with rubber or fruit and timber trees intercropped with rubber had worse return to labour than mono rubber (decrease of up to 28%). All other four farming diversification systems (Gnetum with or without fruit trees, goat plus fruit trees and goat plus timber) all showed increase of return to labour. The combination of goat, fruit trees and rubber performed the best with an increase of 105%.

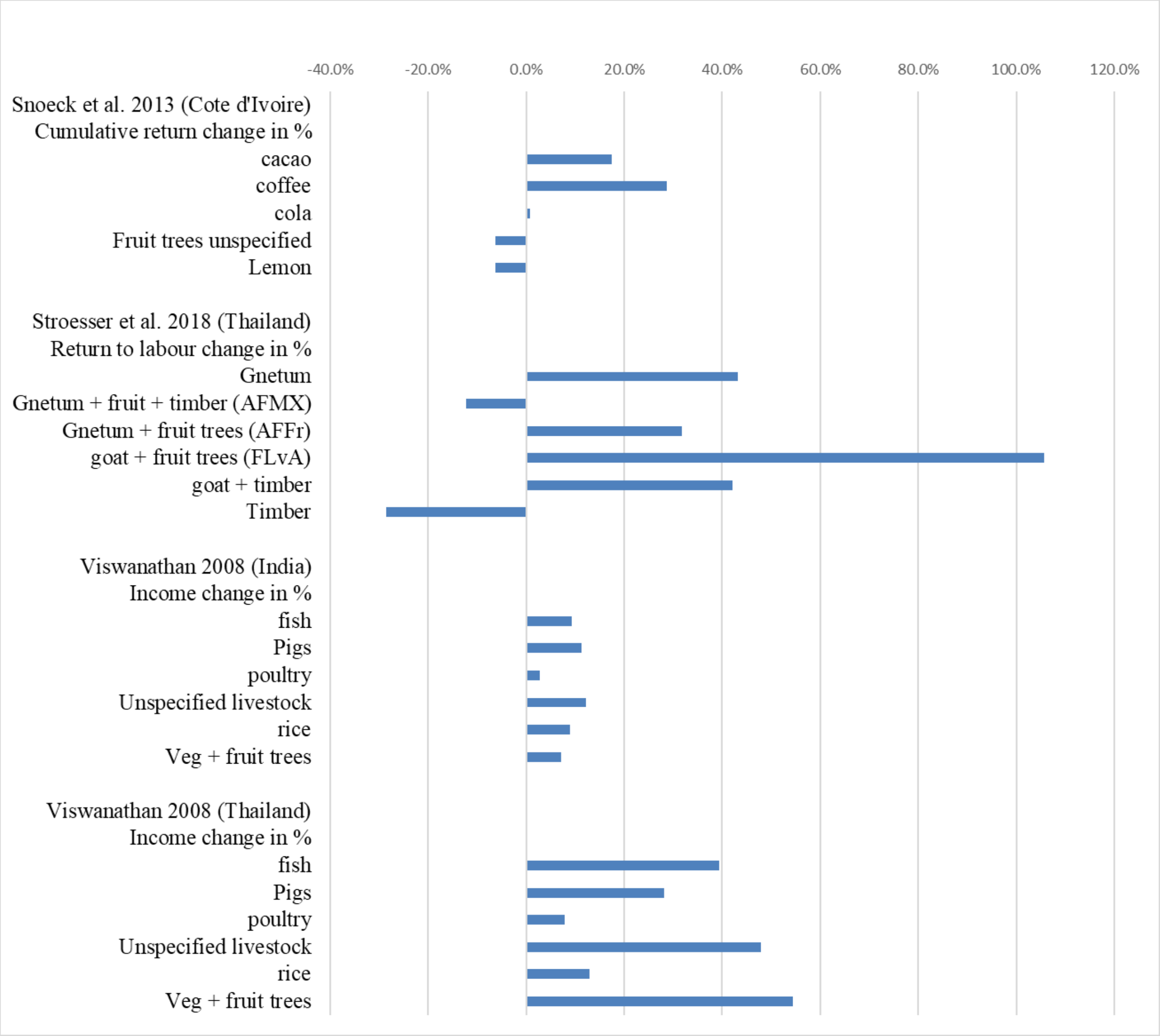


Figure 13 change of cumulative return or return to labour or Income

Table 8. Change of cumulative return or return to labour or Income

| Author (year) (country of study) | Economic outcome | change in % |
|---|---|---|
| Snoeck *et al.*, 2013 (Cote d'Ivoire) | Cumulative return (10 years) | |
| cacao | 19367600 | 17.4% |
| coffee | 21227200 | 28.7% |
| cola | 16622200 | 0.8% |
| Fruit trees unspecified | 15444700 | -6.4% |
| Lemon | 15444700 | -6.4% |
| Mono rubber | 16495600 | |
| Stroesser *et al.*, 2018 (Thailand) | Return to labour | |
| Gnetum | 76082 | 43.2% |
| Gnetum + fruit + timber (AFMX) | 46605 | -12.3% |
| Gnetum + fruit trees (AFFr) | 70020 | 31.8% |
| goat + fruit trees (FLvA) | 109329 | 105.7% |
| goat + timber | 75465 | 42.0% |
| Timber | 37904 | -28.7% |
| Mono rubber | 53145 | |
| Viswanathan 2008 (India) | Income | |
| fish | 52567 | 9.3% |
| Pigs | 53540 | 11.4% |
| poultry | 49429 | 2.8% |
| Unspecified livestock | 53976 | 12.3% |
| rice | 52362 | 8.9% |
| Veg + fruit trees | 51522 | 7.2% |
| Mono rubber | 48079 | |
| Viswanathan 2008 (Thailand) | Income | |
| fish | 40476 | 39.4% |
| Pigs | 37187 | 28.1% |
| poultry | 31314 | 7.9% |
| Unspecified livestock | 42948 | 48.0% |
| rice | 32775 | 12.9% |
| Veg + fruit trees | 44811 | 54.4% |
| Mono rubber | 29027 | |

*3.4.5 Impacts of on-farm diversification on resilience against fluctuation in rubber price*

Two studies directly investigated on-farm diversification to increase resilience against fluctuation in rubber price (Simien and Penot, 2011; Stroesser *et al.,* 2018). Both were prospective modelling studies, based on data from Southern Thailand and used the same software "Olympe" to simulate volatility of prices on financial indicators over time.

The studies reached the same conclusions that in general diversified rubber systems are more economically robust when rubber price is low, but when rubber prices are high whilst the economic advantage may still exist it is often less clear, depending on for example, returns to labour for the intercrop under these conditions (e.g. Stroesser *et al.,* 2018). These studies indicated that fruit trees (e.g. Durian and Mangosteen) and timber (e.g. profitable species such as Ironwood, Eagle Wood, Champaka, Neem and White Meranti) are two of the most potentially economically advantageous diversification strategies in the face of low rubber prices. Simien and Penot (2011) reported that the greater the share of income from the intercrops the more resilient the farmer is when rubber prices decline. These authors pointed out that resilience is, however, dependent on a wide variety of variables including off-farm income, labour availability, input costs, local markets for intercrop products, the quantities, species, age and productivity of intercrops (in particular for perennial crops such as timber and fruit trees), efficiency in management to increase yields, and adaption of other kinds of products from intercrops to increase household income, for example selling bamboo grafts instead of shoots.

## 4. Conclusion and discussion

This systematic map provides an overview of literature to date that seeks to identify what practices have been used to diversify smallholder rubber plantations to improve economic sustainability. Combined with the secondary analysis, a number of insights and evidence gaps regarding current research efforts were identified.

### *4.1 Insights*

Overall, the evidence analysed in this study suggests that on-farm diversification can provide smallholder rubber farmers with an opportunity to improve the sustainability of rubber, but this is dependent on crop and other variables such as rubber price fluctuation, off-farm income and labour availability etc.

On-farm diversification is also a strategy that has the potential to reduce the vulnerability of smallholders to volatile markets for rubber. Whilst profitability of intense monoculture rubber may be greater than that of diversified less-intensive systems particularly when rubber prices are high, diversified rubber reduces the vulnerability of smallholders' income from these external economic influences (e.g. Stroesser *et al.,* 2018). However, resilience is subject to a wide variety of other variables (e.g. availability of labour, off-farm income, input costs, local markets for intercrop products, quantities, species, age and productivity of intercrops, efficiency in management to increase yields, and adaption of other kinds of products from intercrops) and the evidence for what works in one region or country may differ considerably to that in another region country due to environmental (rainfall, climate, soil), political (crop subsidies) and economic and socio-economic (local markets) factors. This combined with the relatively few studies that compare diversification with monoculture rubber and had sufficient detail and raw data for any detailed quantitative analysis/synthesis make it difficult to make any specific recommendations about what type of diversification practice is most economically advantageous.

Unsurprisingly, the majority of studies were from South East Asia followed by South Asia. More than 90% percent of the world's total area under rubber cultivation and 80% of world's production is in Asia due to its favourable climate (Anon, 2016). Fewer studies were conducted in West Africa, East Asia and South America. Outside of Asia the most important producing countries are Ivory Coast, Nigeria, and Brazil but together these represent only a small fraction of global production (Anon, 2016).

The most commonly reported diversification practice was intercropping rubber, within the immature period. Fewer studies reported intercropping in mature rubber and diversification using other spatial arrangements.

The most common intercrops were crops grown for food, including tree (e.g. fruit trees) and non-tree (e.g. cassava) crops. Less research has been conducted on diversification through timber and livestock, and research for apiculture and aquaforestry is very scarce. Timber represents a long-term return strategy for smallholders converting from monocropping to diversified systems, many of which may instead be looking for quicker potentially higher returns and more regular income. However, systems that include highly valued timber which is ready for harvest, can help to increase resilience in the face of declining rubber prices, as trees can be harvested and sold when needed (Jongrungrot and Thungwa, 2014a). If properly selected and established, only little labour input might be required to maintain them (Langenberger *et al.*, 2016). There are a number of practical issues regards integrating some species of livestock into rubber, including limited browse under mature rubber, damage to the bark of young rubber (e.g. from goats), and livestock drinking and spilling latex from cups and causing root damage and soil compaction due to trampling (e.g. from cattle) (Tan *et al.*,1980; Tajuddin 1986). Nevertheless, livestock can also help reduce the fertilisation and weeding costs for rubber plantations (Tajuddin 1986; Stroesser *et al.*, 2018), and other animals are potentially less damaging to rubber, for example, chickens (broiler or layers) which can be farmed free-range or permanently housed (although the latter would require more capital for set up costs).

Despite the relatively large amount of research published indicating that intercropping can: have a positive impact on income; increase resilience to fluctuations in rubber price; and in some cases, have synergistic agronomic benefits for rubber, information about actual adoption rates (particularly beyond initial integration of crops in the first 2 years) in rubber producing countries is hard to find (Langenberger *et al.*, 2016). In Thailand, Delarue and Chambon 2012, reported that 10% of the overall plantation area in Thailand is intercropped and, Charernjiratragul *et al.*, 2015, reported that rubber-based intercropping systems are rare, with an estimated 2 percent of all rubber farmers in both Songkhla and Phattalung provinces (areas of high rubber production) practicing intercropping. In Xishuangbanna, southern Yunnan, China, a household survey indicated that only 14% of the assessed rubber plantation area was intercropped (Min *et al.*, 2015).

*4.2 Limitations of the methods used*

The strategy developed and used to conduct this systematic map was designed to be comprehensive but not exhaustive due to resource constraints. The following potential limitations and biases of this review have been identified. The first limitation is that the search was limited to English language search terms for bibliographic literature, and English and Thai language for grey literature. The scope of this review meant that literature published in other languages, for example, French, Spanish, Malay, Chinese, has not been search for and included. It may therefore be possible that considerably more research is done, for example in South America, West Africa and China than the identified literature suggests.

A second limitation of the review was that whilst the review team piloted and tested the search strategy to be inclusive, some literature may have been missed due to specific terms not being included (i.e. semantic challenges associated with interdisciplinary fields of research).

The full text of 21 articles, that had been identified as relevant on title/abstract level, were un-retrievable due to subscription limitations and were therefore not screened at full text for possible inclusion in the review.

Finally, the results presented in this study come with the caveat that no formal critical appraisal of studies was carried out either for the systematic map or secondary analysis, and only basic qualitative analysis of study results was possible in some of the secondary analysis. The studies collated were highly heterogenous and poor reporting and lack of suitable raw data made other methods of quantitative synthesis or analysis challenging (e.g. meta-analysis). The results of the secondary analysis are compounded by the wide range of variables that can affect the sustainability of rubber-based systems and their resilience, which vary not only between but also within countries.

*4.3 Limitations of the evidence base*

Missing meta-data was a consistent issue with the studies captured. Some did not report basic study design information, such as length of study (n =20) and age of rubber plantation (n=11), whilst for other studies outcome data was either poorly reported or missing, making extraction of raw data for secondary analysis challenging. Clarity of reporting to facilitate synthesis/analysis of studies and repeatability of experiments is an issue highlighted by reviewers carrying out systematic syntheses (e.g. Haddaway, 2015a; Haddaway *et al.*, 2015b).

There was also an issue with the way authors reported and defined financial outcomes. Better standardisation of reporting financial outcomes is needed in all studies of economic impact of any intervention activities.

*4.4 Implications for research*

This map identified a number of understudied subtopics that may correspond to knowledge gaps, which may benefit from primary research. Knowledge gaps were identified in the following areas:

- Rubber based systems that include, livestock, apiculture and aquaforestry
- Rubber systems that look beyond the immature period
- Prospective modelling studies that investigate fluctuating rubber price in combination with the agronomic impacts of intercropping (e.g. density of planting, age).
- Longer-term studies, for example, field experiments that investigate agronomic impacts and any potential fluctuations in price over study period
- Less research from China and smaller rubber producing countries in West Africa and South America

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