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CULTURES INTERCALAIRES À BASE D'HÉVÉA / RECHERCHE

Agronomic and socio-economic options for rubber intercropping in Sri Lanka: a forward analysis in the Moneragala and Ampara regions

Photo 1.
Rubber intercropping plantation (single row) with pineapple and banana in Ampara area.
Photo LOAM's officer.

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RÉSUMÉ

Options agronomiques et socio-économiques pour les cultures intercalaires à base d'hévéa au Sri Lanka : une analyse prospective dans les régions de Moneragala et d'Ampara

Le caoutchouc naturel est considéré comme une ressource stratégique pour le développement du Sri Lanka par le ministère des Plantations. En réponse au changement climatique, le pays a adopté une politique axée sur la résilience et le développement durable. C'est dans ce contexte que Ksapa a initié le projet RIVER en 2022, visant à développer un programme de renforcement des capacités agricoles du Sri Lanka. Pour mener à bien ce projet, l'entreprise a mandaté YAPI Expertise pour fournir des modèles de cultures intercalaires agroforestières à base d'hévéa présentant de bonnes performances agronomiques et économiquement intéressantes pour les producteurs en vue de diversifier leurs sources de revenus. Le projet RIVER est mis en œuvre dans deux districts du sud-est du Sri Lanka : Moneragala et Ampara. L'étude a débuté par une analyse de la littérature afin de sélectionner les cultures pouvant être associées à l'hévéa. En parallèle, 80 entretiens, préparés par YAPI Expertise, ont été réalisés sur le terrain par une organisation locale, LOAM. L'objectif de ces entretiens était d'identifier les modèles de cultures associées à l'hévéa déjà mis en œuvre dans les zones d'étude et de comprendre les raisons pour lesquelles les agriculteurs ont adopté ces modèles. Les entretiens ont fait l'objet d'une analyse statistique par analyse à correspondance multiple (ACM) et Chi². En les combinant avec la revue de la littérature, l'étude a permis d'établir cinq modèles (modèle ananas, modèle cacao, modèle banane, modèle fruit de la passion, modèle corossol) pour plusieurs cultures intercalaires pouvant être plantées avec de l'hévéa et ayant un potentiel d'adoption par les agriculteurs locaux. Enfin, des critères de sélection ont été élaborés pour chaque modèle. Ceux-ci présentent à la fois leurs points forts et leurs points faibles, car un modèle performant ne peut reposer sur la seule analyse agronomique et il sera essentiel d'adapter le choix des cultures au marché local et aux besoins des agriculteurs.

Mots-clés : hévéa, cultures intercalaires, analyse multicritère, analyse prospective, Sri Lanka.

ABSTRACT

Agronomic and socio-economic options for rubber intercropping in Sri Lanka: a forward analysis in the Moneragala and Ampara regions

Natural rubber is considered a strategic material for the development of Sri Lanka by the Ministry for Plantations. In response to climate change, the country has adopted a policy focusing on resilience and sustainable development. It is in this context that Ksapa initiated the RIVER project in 2022, aiming to develop a program to strengthen agricultural capacity in Sri Lanka. To carry out this project, the company commissioned YAPI Expertise to provide agroforestry intercropping models based on rubber trees with good agronomic performance and economically of interest to producers to diversify their sources of income. The RIVER project is implemented in two districts in south-eastern Sri Lanka: Moneragala and Ampara. This study began with an analysis of the literature in order to select crops that could be intercropped with rubber. In parallel, 80 interviews, prepared by YAPI Expertise, were conducted in the field by a local organisation, LOAM. The aim of these interviews was to identify rubber intercrop models already implemented in the study areas and to understand the reasons why farmers adopted these models. The interviews were analysed statistically by MCA and Chi². By combining these with the literature review, the study established 5 models (Pineapple model, Cocoa model, Banana model, Passion fruit model, Soursop model) for several intercrops that could be planted with rubber, with potential for adoption by local farmers. Finally, selection criteria were established for each model. Both their strong and weak points are presented, since an effective model cannot rely on agronomic analysis alone and it will be essential to adapt the choice of crops to the local market and to farmers' needs.

Keywords: rubber, intercropping, multi-criteria analysis, prospective analysis, Sri Lanka.

RESUMEN

Opciones agronómicas y socioeconómicas para los cultivos intercalados de caucho en Sri Lanka: un análisis prospectivo en las regiones de Moneragala y Ampara

El Ministerio de Plantaciones considera el caucho natural un material estratégico para el desarrollo de Sri Lanka. En respuesta al cambio climático, el país ha adoptado una política centrada en la resiliencia y el desarrollo sostenible. En este contexto, Ksapa inició el proyecto RIVER en 2022, con el objetivo de desarrollar un programa para reforzar la capacidad agrícola en Sri Lanka. Para llevar a cabo este proyecto, la empresa encargó a YAPI Expertise modelos de cultivos intercalados agroforestales basados en árboles de caucho con buen rendimiento agronómico y económicamente interesantes para que los productores diversifiquen sus fuentes de ingresos. El proyecto RIVER se implantó en dos distritos del sudeste de Sri Lanka: Moneragala y Ampara. Este estudio comenzó con un análisis de la bibliografía para seleccionar los cultivos que podrían intercalarse con el caucho. Paralelamente, una organización local, LOAM, realizó sobre el terreno 80 entrevistas, preparadas por YAPI Expertise. El objetivo de estas entrevistas era identificar los modelos de cultivos intercalados de caucho ya implantados en las zonas de estudio y comprender las razones por las que los agricultores adoptaron estos modelos. Las entrevistas se analizaron estadísticamente mediante análisis de correspondencias múltiples (MCA) y Chi². Combinándolos con la revisión bibliográfica, el estudio estableció cinco modelos (modelo de la piña, modelo del cacao, modelo del plátano, modelo de la fruta de la pasión, modelo de la guanábana) para varios cultivos intercalados que podrían plantarse con caucho, con potencial para ser adoptados por los campesinos locales. Por último, se establecieron criterios de selección para cada modelo. Se presentan tanto sus puntos fuertes como sus puntos débiles, ya que un modelo eficaz no puede basarse únicamente en el análisis agronómico y será esencial adaptar la elección de los cultivos al mercado local y a las necesidades de los agricultores.

Palabras clave: caucho, cultivos intercalados, análisis multicriterio, análisis prospectivo, Sri Lanka.

Introduction

The rubber sector of Sri Lanka and the RIVER project

The importance of Rubber in Sri Lanka

The economy of Sri Lanka is highly dependent on agriculture, both for food and cash crops. In response to the climate change that is particularly affecting Sri Lanka (drought, floods, soil erosion, etc.), the country has adopted a policy focused on enhancing the resilience and sustainability of agricultural productions. Therefore, in the context of the revitalisation of some agricultural export sectors, rubber is at the centre of governmental concerns. Rubber, as a major cash crop of this country, plays an important in the agricultural sector. In the recent years, the government of Sri Lanka has strongly encouraged the development of the rubber sector, with the help of scientific institutions and private companies such as "Camso Loadstar".

In 2017, the Sri Lankan government implemented the rubber master plan to promote this sector on a national level. The program consists of identifying the administrative and operational problems of the existing sector. The objective is to establish a sustainable industry in order to attract foreign investors. The benefits would accrue to the stakeholders in the rubber sector. The first results of the project are expected in 2025. In 2020, the export values of coffee, tea and spices accounted 15.6%, i.e., US$ 1,6 billion, of the country's total export value. Rubber by itself accounted for 8.1% (US$ 870 million) (Workman, 2022). The rubber industry accounts for around 10% of agricultural exports. In 2020, rubber represented 136 300 ha in Sri Lanka, which corresponds to 2% of the total land area (Sankalpa *et al.*, 2020) with an average yield of 642 kg/ha/year (Rubber Research Institute of Sri Lanka, 2020). 81% of rubber production comes from smallholders (Dissanayake *et al.*, 2016), and more than 80,000 of small-scale producers are involved in the rubber cultivation.

At the village scale, smallholders are organised in "*societies*" which can be compared to the functioning of agricultural cooperatives with the following features: i) Distribution of subsidies; ii) Developing marketing facilities; iii) Proposing training programs; and iv) Supporting processing facilities. Depending on the local conditions and territorial situations, these *societies* are more or less active in the villages. In Moneragala district, 43 *societies* out of 85 are considered as active. Altogether, 65% of the smallholders are members of a *society* in Moneragala (Gunarathne *et al.*, 2020).

The institutional context of the study

Ksapa is a French consulting company created in 2019. It provides services and assistance in the agricultural sector in order to promote a performant economic model of development. In collaboration with the government of Sri Lanka and with the objective to design solutions to reinforce the resilience for agricultural rubber systems, Ksapa initiated in 2022 the RIVER project based on a training program to strengthen agricultural capacity in South-East Sri Lanka with focus on rubber farming systems. The RIVER Project is funded by the French Ministry of Economy, Finance and Recovery and the Michelin Group. The main implementing organisations are Camso Loadstar (Michelin subsidiary in Sri Lanka) and LOAM (Lanka Organic Agriculture Movement), a local NGO promoting organic farming in Sri Lanka. Six thousand rubber smallholders are targeted by the RIVER project.

The present study has been commissioned by Ksapa for the initial diagnosis phase of the RIVER project. Intercropping and agroforestry being considered as levers for more resilient agricultural systems, the objective of this study is to identify potential intercrops in rubber cultivation systems, during the immature and mature phases of the tree, in the selected study areas (Moneragala and Ampara districts). Intercrops should allow farmers to have a higher income than in a monoculture system, allowing them to better cope with the very high volatility of natural rubber prices (Stroesser *et al.*, 2018) while having more environmentally friendly and productive production system. The final objective is to explore and provide "models of cultivation" based on intercropping during immature so far (and at least in the first place) that are agronomically "performant" and economically interesting for local farmers. These agroforestry systems should be adapted to local soils and climatic conditions as well as supported by local markets. This prospective study is partially based on some agroforestry practices used by local farmers. The prospective aspect concerns the search for best-bet potential agroforestry alternatives adapted to local conditions in an exploratory process.

The research question

Given the favourable context of the rubber sector (supported by the rubber master plan previously mentioned), the national competent authorities of Sri Lanka identified new rubber growing areas. The two districts of Moneragala and Ampara appear as particularly interesting regarding their potential for rubber cultivation. This study aims to define several performant intercrops models in order to complete a training program that will be proposed to farmers of these two districts. The performant models consider the agronomic aspect and the socio-economic dimension.

More specifically, the aim of this paper is to establish a more agronomically, economically and socially sustainable cultivation system in order to raise incomes during rubber immature period in the short run. It has been shown in other countries that the implementation of intercropping is economically and agronomically interesting in rubber plots. Historically, many farmers in almost all rubber producing countries have adopted intercrops during immature period to raise an income before that of rubber (Langenberger *et al.*, 2016). In Indonesia and Thailand, inter-

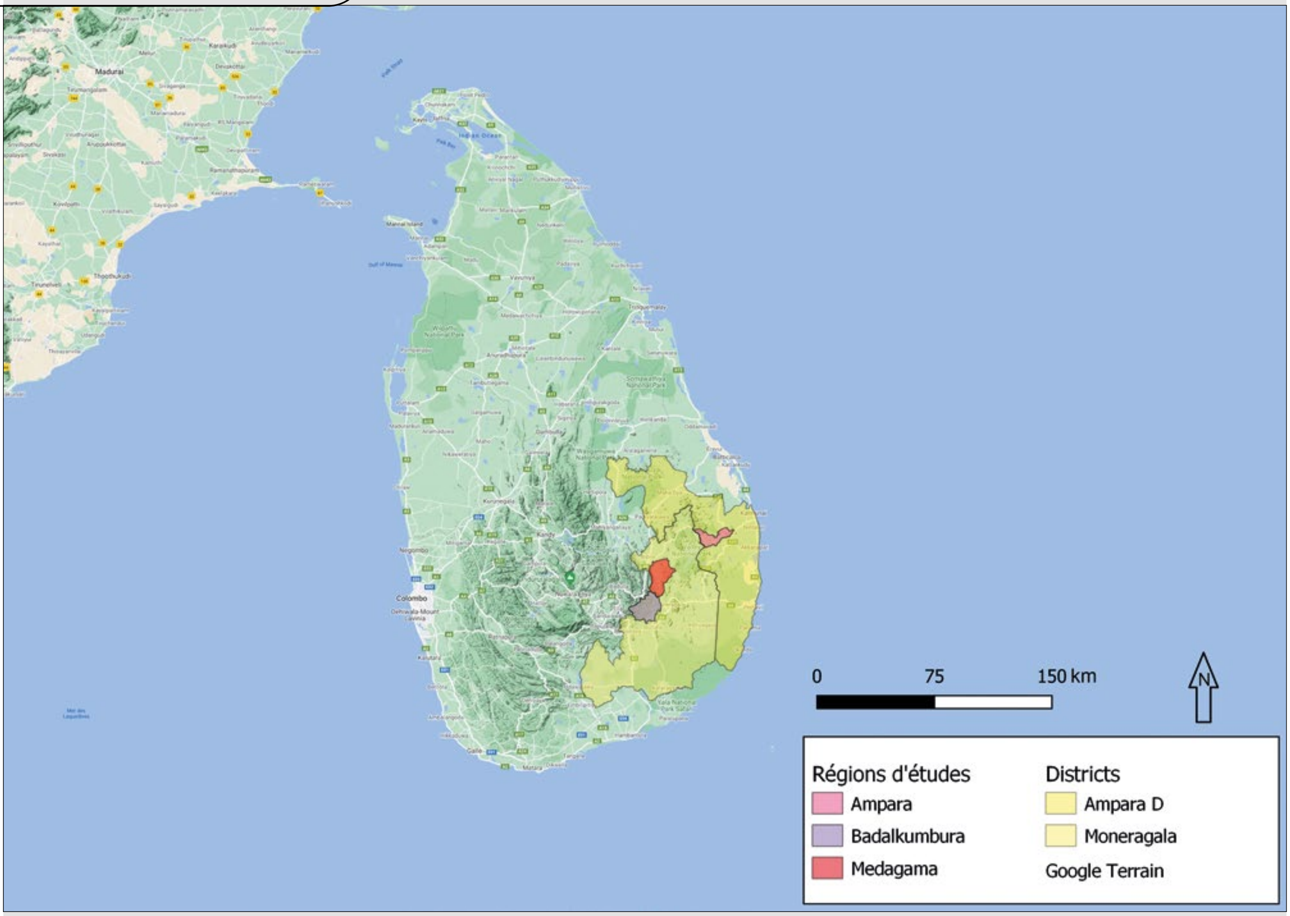

Figure 1.
Study area of YAPI Expertise's study areas.

cropping in mature period is also well developed (up to 15-20% of the total rubber area in Southern Thailand and Kalimantan) (Penot, 2001, 2004a, 2004b; Penot *et al.*, 2009; Jongrungrot *et al.*, 2014; Snoeck *et al.*, 2013; Somboonsuke *et al.*, 2011), Agroforestry practices display globaly an annual income increase from 20 to 40% in Southern Thailand (Stroesser *et al.*, 2018).

One of the hindrances to the development of intercropping is the difficulty of understanding potential interactions and implementing it by the rubber farmers. The survey conducted in the two selected districts helps to understand the limits of the implementation of these systems, and how to facilitate the development of these agroforestry practices.

The study areas

The study is conducted in two districts in the southeast of Sri Lanka (figure 1): Moneragala and Ampara. These two districts have been identified collectively with all partners of the RIVER project. This area is not an historical rubber cultivation zone. Indeed, they are: Kegalle, Rathnapura, Kalutara and Colombo. However, the government has decided to develop new rubber plantation areas in zone with a relative dry season due to the lack of available cultivable land in the historical rubber cultivation areas.

For this reason, the RIVER project decided to focus on these two districts nowadays considered as very promising areas for rubber cultivation in Sri Lanka.

Moneragala

Moneragala is located in the province of Uva (5,639 km²) and one of the least densely populated regions in the country with almost 90 inhabitants/km². Three different types of land can be identified within the district: i) The mountainous areas, rather located in the east of the district with altitudes between 550 m and 1,400 m above sea level; ii) The hilly areas, transition zones between the mountainous parts of the centre and the wide plains of the east. Their altitude ranges from 160 m to 550 m; and iii) The lowland areas are the most widespread zones in the district since they represent almost 75% of its area, generally below 160 m in altitude. 84% of the annual rainfall is concentrated in the seven months of the rainy seasons (Yasaratne *et al.*, 1992) with a relative 5 months dry season creating a situation of marginality for rubber.

Rice (*Oriza sativa*) is the most important crop of the district, covering almost 5.4% of the area, i.e., 30,450 ha. The second most common crop is sugar cane (*Saccharum officinarum).* Food crops are many and varied, including several types of fruit and vegetables, mostly grown in home gardens. Moneragala is the largest producer of Banana (*musa spp)* with nearly 8,000 ha. In addition, 2,000 ha are dedicated to mango cultivation (*Mandifera indica)* (Ministry of Agriculture of Sri Lanka, 2016). Papaya (*Carica papaya)*, rambutan (*Nephelium lappaceum),* orange (*Citrus* spp.*),* passion fruit (*Passiflora edulis*) and pineapple (*Ananas comosus*) are also produced in the district. Nowadays, Moneragala is the 5th most productive rubber region of Sri Lanka preceded by the 4 historical regions where rubber is cultivated. In the Moneragala district, 5,876 ha of rubber are cultivated by 7,800 producers in 2010 (last census), of which 7,250 had less than 2 ha, 4,808 less than 0.8 ha (Sri Lanka Export Development Board, 2022).

Ampara

Ampara is located at the east of Moneragala, with an area of 4,445 km². The population density is much higher than Moneragala and is 145 inhabitants/km² (Ampara District Secretariat, 2020). Ampara is the largest producer of rice in the country, estimated at over 25% of national production. There are also other widely grown crops such as corn, coconuts, cashew nuts and a wide variety of fruit trees (Ministry of Agriculture of Sri Lanka, 2019). Ampara is a recent rubber extension area, even more than Moneragala since almost no documentation do exist on the actual rubber cultivation practices in Ampara. In 2014 (last record), Ampara had 335 rubber smallholders, compared to 80,500 nationwide (Sri Lanka Export Development Board, 2022).

Methodology

Overall method of the study

The overall study consists in a multi-criteria approach to assess the agronomical and socio-economic performances and acceptability of intercropping in rubber farming systems. Based on these results, the RIVER project will assess the interest of supporting the introduction of intercropping practices in the two districts of Monaragala and Ampara. It is an agronomical study combined with a socio-economic approach of intercropping. The main objective is to compare the different intercrops and thus determine the most performant ones from an agronomic and socio-economic point of view.

The method is divided into three steps:

i) Literature review on intercropping systems with rubber. The literature will be analysed by multi-criteria analysis in order to produce a ranking of intercrop systems regarding their performance.

ii) Field survey of farmers in Sri Lanka. It consists in an assessment of existing intercrops in the study areas and an evaluation of the position of producers regarding these existing intercrops through adoption criteria.

iii) Focus groups: with all stakeholders of the rubber sector to discuss the results and foster dialogue on intercropping and sustainability of rubber cultivation.

The results of the three steps will be combined to determine the performance of intercropping models and identify the most performant models to be implemented in the study areas for the continuation of the RIVER project.

The study of potential associated plants to rubber

According to Rodrigo *et al.* (2004), rubber trees can be arranged in several ways on the plot depending on the type of cropping system, but the main special arrangements are: i) Single spacing, i.e., a single row of rubber trees with an inter-row distance of 6 to 8 m and ii) Double spacing, which consists of planting rubber trees in double rows with a spacing of 14.1 m between each double row. According to the literature review, double spacing would allow the inclusion of more intercropping. As stated by LOAM, single spacing is more frequent in Sri Lanka. In order to propose a model that is as faithful as possible to the realities of the ground, YAPI Expertise decided to base its study only on single spacing.

Literature review and intercrops ranking

This study began by completing the initial list of intercrops that have been made for the first deliverable. The literature review first aimed at establishing an extensive list of potential inter-crop for rubber cultivation systems. The list is mostly based on the one presented in the article "Rubber intercropping: a viable concept for the 21st century?" (Langenberger *et al.*, 2016). Thus, 80 crops have been identified. Only crops that are present in Sri Lanka have been retained, i.e., 70 crops. The literature review continued to address several criteria for each of the 70 crops selected. The following data are given for each crop in the list:

• Classification of the type of crop (fruit tree, medicinal plants, export commodity, etc.).
• Preferences of the crop regarding climate conditions.
• Preferences of the crop regarding soil conditions.
• Life cycle duration (annual, multiannual or perennial).
• Phase of the rubber tree in which the crop can be planted (mature and/or immature). It is based on the production period of the intercrop and its tolerance to shading.

The intercrops have been sorted in a second table according to the development phase of the rubber tree.

The potential crop candidates have been selected based on the following criteria:

• The "climate" category compares the needs and resistance of each crop studied with the climatic conditions (rainfall, temperature, etc.) of the study areas.
• The "soil" category, the criteria are based on the types of soil present in the two study areas.
• The criteria of the "crop" category based on the exchanges between the intercrop and the rubber tree, in particular the water competition, the light competition.

A colour scale has been used to determine whether the needs of the crop are compatible with the criteria. Green is "compatible", Orange is "moderately compatible"; and Red is "not compatible". As not all criteria have the same impact on the selection of the crop, degrees of impact have been established from 1 to 4. The aim is to assign a mark to each crop in order to be able to rank them. To do this, a numerical scoring system was set up. A preselection was carried out on the basis of the most important criteria, i.e., having a degree of impact of 4. As the pre-selection was not sufficient to reduce the number of crops on the list, a second and final selection was undertaken. This last selection was based on all the criteria, unlike the pre-selection, which was based only on the criteria having a degree of impact of 4.

Finally, from these two tables, the colour scale and the numerical scoring system, a final score could be assigned for each crop. Two ranking tables were constructed: one for the immature phase and one for the mature phase.

Table I.
Social performance criteria.

Criteria	Unity	Definition
Rubber yield (RubbTYield)	kg/year	The intercropping model studied should not have a negative impact on natural rubber yields.
Ecological performance (EcoLperf)	kg	One of the objectives of intercropping systems is to limit the addition of phytosanitary. inputs within the system, notably through the various ecosystem services (EcoSySryc). Models where phytosanitary inputs have disappeared are therefore more performant
Ecosystemic services (EcoSySrvc)		One of the most interesting aspects of setting up an intercropping plot is the ecosystem services the different species within the system can provide to each other (CIRAD, 2019). A performant intercropping system is therefore logically one in which each species maximises the benefits of the ecosystem services provided by the various crops.

Table II.
Economic performance criteria.

Criteria	Unity	Definition
Income from intercropping (IncoInterCrop)	LKR	The crop association must be a good source of income or food resources. As studied in Thailand by Stroesser L., income from intercrop production can make smallholder rubber farmers more resilient to the volatility of natural rubber prices. Nonetheless, the work mobilised for the intercrops should not have a negative impact.
Production cost of the plot (ProdCost)	LKR	Smallholders, especially in Moneragala district, have limited income (Sankalpa *et al.*, 2020). Introduction of inter-row cultivation should not increase significantly production costs.
Initial investment (IniInvst)	LKR	Smallholders in the Moneragala district have a very low monthly income and low capacity to invest. The initial investment in establishing a large intercrop is a major constraint.

Table III.
Adoption criteria.

Criteria	Unity	Definition
Labour required (InterCropLab)	Day/month or Hour/day or Unity of Human work	The availability of labour is one of the potential limiting factors for the implementation of such complex agronomic models. Moreover, as detailed by Rodrigo *et al.* (2011) and Karunaratne *et al.* (2011), the increase of the amount of labour force may be one of the major reasons for not implementing these practices.
Geographical access to the market (GeoMrkt)	km	Distance.

Field survey

The second step of the methodology is a socio-economic survey of the existing intercropping with rubber farming systems in Moneragala and Ampara. The objective is to analyse the actual practices of intercropping in the areas and collect qualitative data on the positions of farmers and the acceptability of increasing the intercropping in rubber systems. The method used is based on the publication about the evaluation of the overall performance of a farm (Zahm *et al.*, 2013) to determine agronomic, economic and adoption criteria. The objective of the field survey was to collect data regarding two categories of criteria: performance criteria and adoption criteria for intercropping.

Performance criteria

Most of the criteria defined refer to the scale of analysis of the cropping system, as the objective is to study the performance of intercrops models: Economic performance; Social performance; Agronomic performance (Zahm *et al.*, 2013). A model is called performant when it has the capacity to respond to the constraints of the context (both agronomic and socio-economic). The "agronomic" category is assessed by the first step of the methodology (table I). The tables II and III present all the "social" and "economic" performances criteria. It should be noted that each criterion was corrected and adjusted in collaboration with the Sri Lankan partners and CIRAD.

Adoption criteria

The intercropping models that will be designed following the analysis of the results can be considered agricultural innovations. An agricultural innovation is defined as a new idea, practice or technique that can sustainably increase agricultural productivity and income. Any innovation proposed to a population must be adopted by it. Adoption is defined as the decision to apply the innovation and to continue using it (Kam, 2013). Table VII presents the 2 criteria selected to assess the acceptability of an innovation consisting in the introduction of more intercropping in the actual rubber systems.

A survey with semi-structured interviews with farmers

The interview guides were constructed from the data needed to fulfil the performance and adoption criteria on intercropping. The questionnaire was tested during 5 interviews and then adapted to clarify misunderstandings and to prioritise the information requested by the multi-criteria study. The survey has been conducted by the Sri Lankan team of the RIVER project (mainly staff from LOAM), since the country was not accessible anymore due to a national crisis in Sri Lanka in July and August 2022. Sampling was based on LOAM's deployment capacity, considering the local situation of Sri Lanka during the national crisis. In total, 80 interviews were carried out, including 61 in Moneragala and 19 in Ampara (figure 2).

Farmers were interviewed as required by Sri Lankan regulations. Farmers were contacted according to their location and their motivation to become involved in a project like the RIVER project. These same farmers are currently still in contact with LOAM and are taking part in the pilot phase of the agricultural training provided by Ksapa.

As regards the people invited to take part in the focus group discussion, each person was informed that their participation would be considered in the diagnosis of the RIVER project. Each stakeholder has been made aware that their response will add value to the study and will therefore be analyzed.

Data analysis with MCA

The data are both quantitative or qualitative variables. The variables and their modalities are presented and organized into categories. The Multiple Correspondence Analysis (MCA) method is chosen by YAPI Expertise because it allows the analysis of the association between several qualitative variables. It should be noted that the answers

Table IV.
Economic performance variables.

Economic performance		
Variable category	**Qualitative variable**	**Modalities**
Crop	Cocoa	COCOA; NO.COCOA ; NG[1]
	Banana	BANANA; NO.BANANA; NG
	Pineapple	PINEAPPLE; NO.PINEAPPLE; NG
	Corn	CORN; NO.CORN; NG
	Cowpea	COWPEA; NO.COWPEA; NG
	Mungbean	MUNGBEAN; NO.MUNGBEAN; NG
	Pepper	PEPPER; NO.PEPPER; NG
	Sugarcane	SUGARCANE; NO.SUGARCANE; NG
Crop yield	Yield of each intercrop	high; medium; low; NG
Seed cost	Seed cost of each intercrop	high; medium; low; NG
Initial investment	Initial investment of each intercrop	high; medium; low; NG
Rubber yield	Rubber yield	high; medium; low; NG
Cost input[2]	Cost input	high; medium; low; NG
People household	People household	high; medium; low; NG
Extra people[3]	Extra people	high; medium; low; NG
Salary	Salary	high; medium; low; NG
Use of intercrop	Use of intercrop	AUTOCONSUMPTION; SELL; NG

[1] NG: when the data is not given. [2] Cost input: sum of fertiliser, herbicide and pesticide costs. [3] Extra people: labour force employed by the household.

Table V.
Socio-agronomic performance variables.

Socio-agronomic performance		
Variable category	**Qualitative variable**	**Modalities**
Major issues	Pest attack	PEST.ATTACK; NO.PEST.ATTACK; NG
	Lack of water	LACK.OF.WATER; NO.LACK.WATER; NG
	Lack of input	LACK.OF.WATER; NO.LACK.WATER; NG
	Wild animal attack	WILD.ANIMAL.ATTACK; NO.WILD.ANIMAL.ATTACK; NG
	Lack of labour	LACK.OF.LABOUR; NO.LACK.OF.LABOUR; NG
	Erosion	EROSION; NO.EROSION; NG
	Marketing problems	MARKETING.PROBLEMS; NO.MARKETING.PROBLEM; NG
	High cost of irrigation	HIGH.COST.IRRIGATION; NO.HIGH.COST.IRRIGATION; NG
	Drought	DROUGHT; NO.DROUGHT; NG
	Fuel crisis	FUEL.CRISIS; NO.FUEL.CRISIS; NG
	Expensive input	EXPENSIVE.INPUT; NO.EXPENSIVE.INPUT; NG
	High labour cost	HIGH.LABOUR.COST; NO.HIGH.LABOUR.COST; NG
	Lack of harvest	LACK.HARVEST; NO.LACK.HARVEST; NG
	Transportation problems	TRANSPORTATION.PROBLEMS; NO.TRANSPORTATION.PROBLEMS; NG
	Poor soil condition	POOR.SOIL.CONDITION; NO.POOR.CONDITION; NG
	Lack of technical knowledge	LACK OF TECHNICAL KNOWLEDGE; NO.LACK OF TECHNICAL KNOWLEDGE; NG
	Processing issues	PROCESSING.ISSUES; NO.PROCESSING.ISSUES; NG

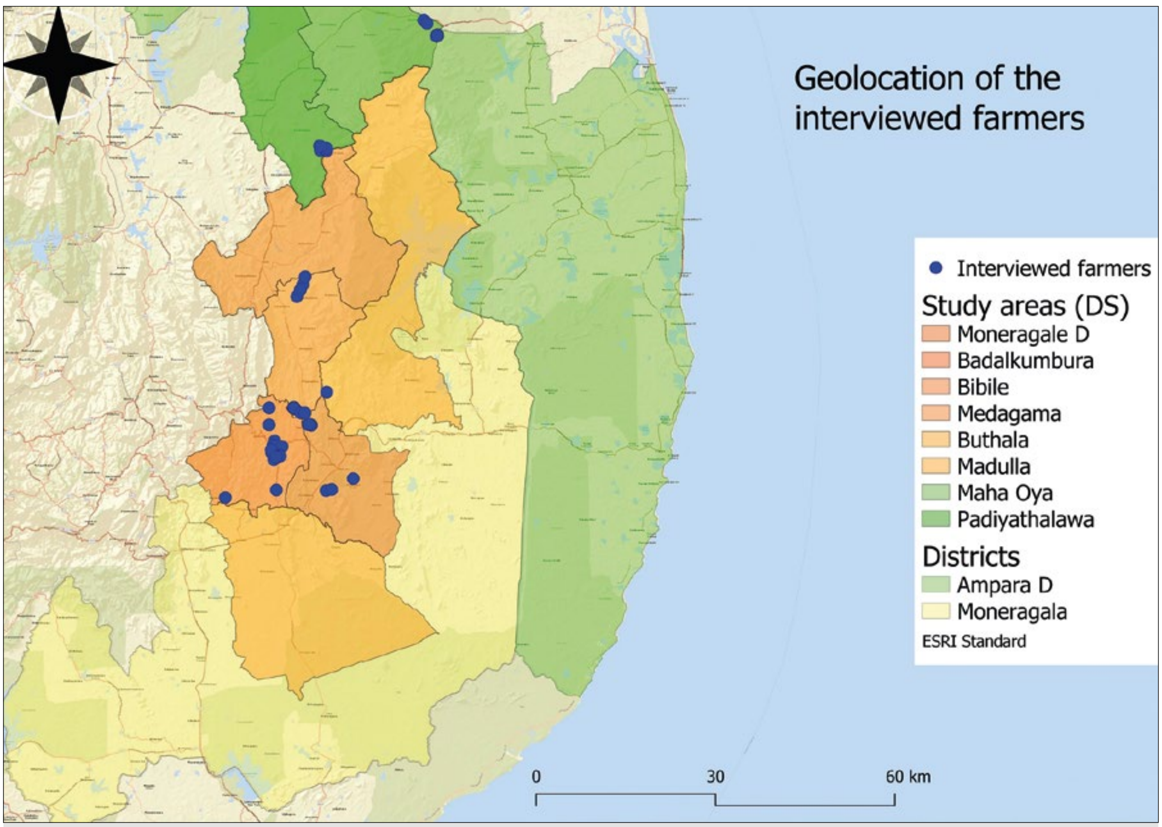

Figure 2.
Geolocation of the surveyed farmers.

related to economic performance were obtained through precise and closed questions. Whereas those related to socio-agronomic performance or adoption criteria were asked through open questions. They also complement the performance criteria (tables IV, V and VI). For the implementation of the MCA, all modalities, even quantitative, were discretized. Variables were also selected according to their relevance or according to the quality of the results obtained. Indeed, some questions were almost never answered or could not be used. For instance, a few intercrops were only grown by a very small number of farmers and the variable "Use of intercrop" did not obtain a good quality of responses. A range of values was defined using Box Plots (quartile, median): i) "Low" corresponds to values below the first quartile; ii) "Medium" corresponds to values between the first and third quartiles; and iii) "High" corresponds to values above the third quartile. The correspondences identified through the graphical projection of the ACM results were highlighted through a clustering performed using a Hierarchical Clustering on Principal Components (HCPC). Finally, Chi² tests were conducted to significantly associate each response to the variables with an intercrop or group of intercrops. For economic performance, the interdependence between all the variables was verified through this test (see figure 4).

Table VI.
Adoption variables.

Adoption criteria		
Variable category	**Qualitative variable**	**Modalities**
Reasons[1]	Moisture	MOISTURE.CONSERVATION; NO.MOISTURE.CONSERVATION
	Soil erosion	SOIL.EROSION; NO.SOIL.EROSION
	Extra income	EXTRA.INCOME; NO.EXTRA.INCOME
	Society	SOCIETY.CHOICE; NO.SOCIETY.CHOICE
	Less maintenance cost for rubber	LESS.MAINTENANCE.COST.FOR.RUBBER; NO.LESS.MAINTENANCE.COST.FOR.RUBBER
	Availability of planting material	AVAILABILITY.OF.PLANTING.MATERIAL; NO.AVAILABILITY.OF.PLANTING.MATERIAL
	Land preparation	LAND.PREPARATION; NO.LAND.PREPARATION
	Adapted to climate	ADAPTED.TO.CLIMATE; NO.ADAPTED TO.CLIMATE
	Easy maintenance	EASY.MAINTENANCE; NO.EASY.MAINTENANCE
	Support rubber growth	SUPPORT.RUBBER.GROWTH; NO.SUPPORT.RUBBER.GROWTH
	Use available space[2]	USE.AVAILABLE.SPACE; NO.USE.AVAILABLE.SPACE
	Soil nutrition	SOIL.NUTRITION; NO.SOIL.NUTRITION
	Shade	SHADE; NO.SHADE

[1] Reasons why farmers choose intercropping; [2] The farmer wanted to use the space left in the rubber plot.

Focus groups with stakeholders of the rubber sector

The focus groups are intended to discuss the processed data from smallholders and stimulates dialogue among the stakeholders of the rubber sector. It also seemed interesting for the study to obtain a global overview of the political, social, and economic dimensions of the rubber sector and its main intercrop. An open-ended interview guide was drafted for LOAM's interviewers, along with a facilitation note. The focus groups were set up in such a way that experts from research, the field actors and the economic environment met to discuss rubber cultivation in intercropping systems. The objective was the validation of results and more information on farmers strategies concerning intercropping. Based on LOAM's capacity, it was agreed to organise 3 focus group sessions. The three focus groups are composed of several key persons which are all linked with rubber cultivation but with different objectives and divergent visions. The focus groups have reunited, respectively, 8, 9 and 11 people in the Districts of Moneragala, Badalkumbura and Bibila. The composition of the different focus groups is relatively similar:

• One or two farmers, who are the first to be impacted by the establishment of intercropping plots.

• A farmer inspector and a representative of the *societies* (Thurusaviya). These two actors have an overall vision of the rubber industry in the region and are aware of the main issues the rubber farmers face.

• The District Director of Agriculture provides a government perspective on rubber cultivation in the region.

• Entities linked to research, such as the Rubber Research Institute and the Rubber Development Department, were present only in the first focus group in Moneragala. The presence of these actors provides a scientific opinion on the development of intercrops among smallholders.

• Private sector (mainly buyers): Camso Loadstar's participated to all the focus groups. Indeed, as the main actor of the project and the main buyer of rubber from the smallholders, their point of view is important. The main buyers of intercrop products are also represented.

• The Export Agriculture Department, which is linked to the marketing of cash crop products (cocoa, cinnamon, etc.). Both will provide an opinion on the economic aspect of the establishment of a particular crop and the economic issues that may be linked to it.

Table VII.
Results of the intercrops compatible with the immature phase. Right column: green is highly suitable, red is not suitable; yellow in between. Left column: light yellow is for immature period, purple is immature and mature periods.

Mature phase: results	
Crops	**Mark**
Azadirachta indica - neem	49
Centrosema pubescens - butterfly pea	47
Pterocarpus sp. - padouk, narra	47
Arachis pintoï	46
Aquilaria sp. - eaglewood	45
Fagraea fragrans - iron wood	45
Cocos nucifera - coconut	44.5
Gmelina arborea - gmelina	43
Pueraria phaseoloides - tropical kudzu	43
Ammonum villosum - medicinal cardamom	42
Nephelium lappaceum L. - rambutan	42
Piper nigrum L. - pepper	41.5
Mangifera indica L. - mango	41.5
Tectona grandis L. - teak	41.5
Calopogonium caeruleum	41
Parkia speciosa - stink bean	41
Stylosanthes guianensis - common stylo	41
Paraserianthes falcataria (L.) - white albizia	41
Passiflora edulis Silms - passion fruit	41
Artocarpus altilis - breadfruit	40.5
Cinamomum verum - cinnamon	40.5
Shorea macrophylla - light red meranti	40.5
Garcinia mangostana L. - mangosteen	40
Morinda officinalis - morinda	40
Annona reticulata L. - custard-apple	39.5
Artocarpus heterophyllus - jackfruit	39
Salacca zalacca - snake fruit	39
Vanilla fragrans - vanilla	38.5
Anacardium occidentale L. - cashew nut	38
Areca catechu - betel nut tree	37.5
Citrus x paradisi - grapefruit	37
Citrus reticulata - tangerine	37
Citrus x sinensis - orange	37
Durio zibethinus - durian	36
Carica papaya L. - papaya	35
Citrus aurantiifolia - lime	35
Macadamia sp. - macadamia nut	35

Table VIII.
Results of the intercrops compatible with the mature phase. Right column: green is highly suitable, red is not suitable, yellow in between. Left column: light yellow is for immature period, purple is immature and mature periods.

Immature phase: results	
Crops	**Mark**
Centrosema pubescens - butterfly pea	47
Arachis pintoï	46
Mucuna bracteata	45
Mucuna cochinchinensis	45
Manihot esculenta - cassava (culture < 12 months)	44.5
Vigna unguiculata - cow pea	44
Flemingia macrophylla	43
Pueraria phaseoloides - tropical kudzu	43
Noicotiana spp. - tobacco	42.5
Alpinia oxiphylla - black cardamom	42
Arachis hypogaea L. - groundnut	42
Cajanus cajan (L.) - pigeon pea	42
Ananas comosus (L.) - pineapple	42
Ammonum villosum - medicinal cardamom	42
Capsicum annuum L. - chili pepper	41.5
Cymbopogon citratus (DC.) - lemon grass	41.5
Calopogonium caeruleum	41
Stylosanthes guianensis - common stylo	41
Citrullus colocynthis - bitter cucumber	40.5
Sorghum bicolor (L.) - sorghum	40.5
Musa acuminata - banana	40
Crotalaria spp. - rattlepods	40
Glycine max (L.) - soybean	40
Morinda officinalis - morinda	40
Theobroma cacao L. - cocoa	40
Ipomoea batatas L. - sweet potato	39.5
Psophocarpus tetragonolobus (L.)	39.5
Luffa acutangulas - angled Loofah	39.5
Vigna radiata (L.) - mung bean	39
Pogostemon cablin (Blanco) - patchouly	39
Curcuma domestica - turmeric	37.5
Coffea canephora - coffea robusta	37.5
Citrullus lanatus - watermelon	34
Saccharum officinarum L. - sugar cane	33
Oryza sativa L. - upland rice	32

Results

Ranking of intercrops

The literature review of the selected crops in Sri Lanka and in other countries led to the creation of a rating of rubber tree, through a scoring system according to the mature and immature phases. A solid agronomic analysis led to such scoring considering as well potential adoption by local people. The maximum score that can be assigned to the crops is 49. As shown in the tables bellow, the selected crops were classified according to the methodology presented previously. The gradient is represented by colours from green (the best) to red (the worst or less adapted). The higher score corresponds to the crops which fits the most with the soil and climate conditions of the study areas and can be planted with rubber tree. Conversely, a low score is represented by a red colour and indicates that the crop does not correspond to the soil and climate conditions of the study areas and is not recommended as an intercrop with rubber (tables VII and VIII).

Results of the field survey

Figure 3 highlights the difference in intercrops cultivated between the two study areas. Intercrops in Ampara are more diversified than in Moneragala. The most common intercrops grown in Ampara are cover and food crops with cowpea (21.2%), mungbean (13.5%) and corn (13.5%) while in Moneragala there is a large majority of cash crops with cocoa (42.6%), banana (21.3%) and pepper (16.7%).

The projection of the points on the two factorial axes shows that some modalities are gathered, and form clusters highlighted by the red circles. Note that the modalities followed by the letter NG correspond to answers not given by the surveyed for this variable. The size of the dots depends on their contribution to the factorial axis. The hierarchy presented in figure 5 just below highlights these clusters more clearly and precisely.

These results associate the establishment of intercrops with specific economic characteristics: i) sugar cane and pineapple require much more field work than other crops; ii) pepper requires moderately more field work than other crops; iii) cowpea, corn and mungbean lower input costs; Iv) cocoa is highly related to wild animal attacks (giant squirrel and monkey); v) banana and pepper imply high workforce costs and resist very badly to drought periods; vi) pepper cultivation is strongly linked to pest attacks; and vii) there is a global market issue for each intercrop.

The projection of the MCA for the adoption criteria forms very few clusters. It should be noted that the modality "other" refers to intercrops that were identified very few times and are therefore not significant to analyse. On the other hand, the clusters are more visible on the dendrogram as follows: i) farmers choose sugarcane as an intercrop because it is adapted to the pedo-climatic conditions of the study areas; Ii) farmers choose pineapple as an intercrop because it would help to prevent soil erosion and would also reduce the cost of the rubber plot's maintenance; and iii) cowpea, mungbean and corn provide soil nutrition and support rubber tree's growth. It is the main reasons why farmers use them as intercrops.

Finally, the histogram highlights that *societies* encourage producers to grow cash crops for the market. It shows that the main reasons why farmers decided to add intercrops to their rubber plots was to bring in extra income. In order to further analyse the links

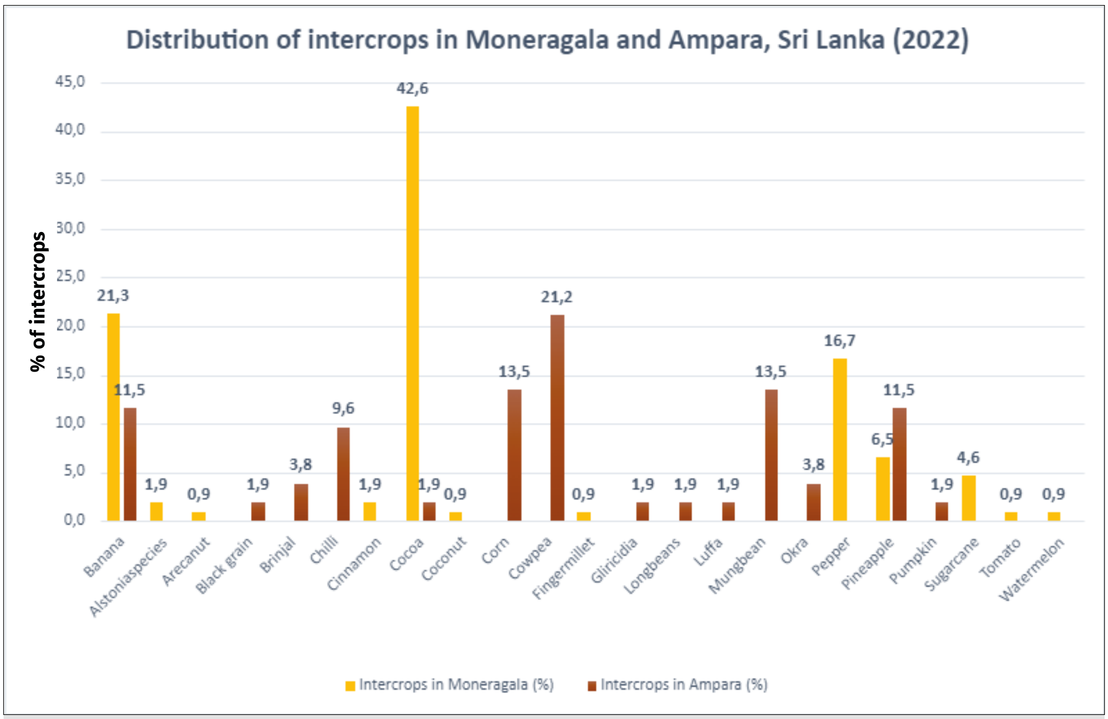

Figure 3.
Distribution of rubber tree intercrops in Moneragala and Ampara.

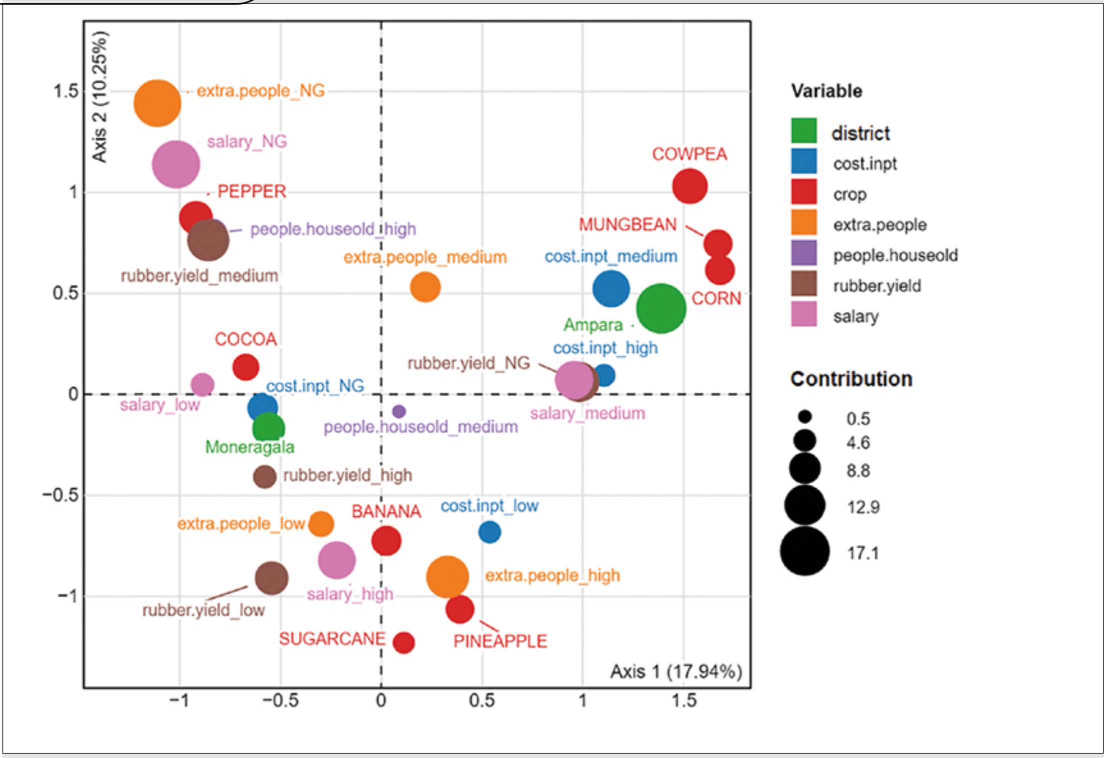

Figure 4.
MCA of economic performance data.

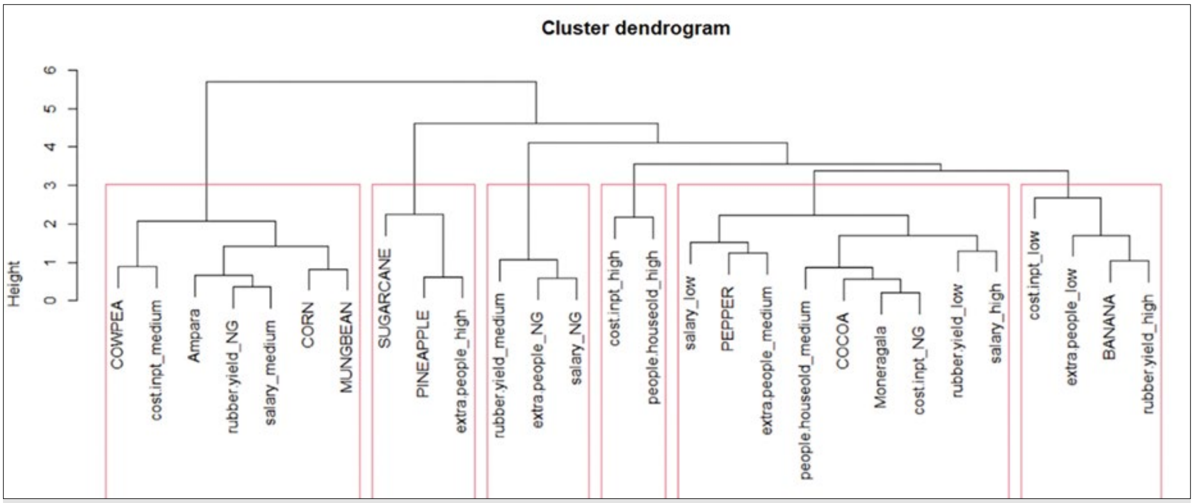

Figure 5.
Cluster dendrogram of economic performance data.

Table IX.
P-value of the «major issues». P-values less than 0.05 indicate independent variables in green.

	Pest attack	Lack of water	Lack of input	Wild animal attack	Lack of labour	Drought marketing	Fuel crisis	High labour cost	Lack of harvest
Crop	0.04993	0.5604	0.03587	0.02741	0.1415	0.4578	0.03018	0.6523	0.2675

between the variables, Chi² tests have been carried out. The null hypothesis of this test is "there is no interdependence between the variables". Only Chi² test with a p-value lower than 0.05 are interdependent. The p-values of the performance variables, the main issues variables and the adoption variables have been reported in tables IX, X and XI. Below are the p-values of the variables related to economic performance, the main issues encountered by farmers and the reasons for adopting intercrops; p-values below 0.05, i.e., the variables are interdependent, are in green.

Global interpretation

The statistical results of the interviews with farmers reveal that the main reason why farmers have chosen to grow intercrops in rubber cultivation is to earn extra income. A variety of intercrop choices are available, but *societies* encourage to grow cash crops such as cocoa, banana and pepper. However, banana, pepper and sugar cane are labour intensive crops and require producers to hire employees. This is a fact which needs to be taken into consideration as there is a relatively high labour deficit in Moneragala and Ampara. On the other hand, cocoa is subject to recurrent attacks by wild animals. However, some crops have a positive impact on the soil, such as cowpea, mungbean and corn, while banana increases the rubber growth. Finally, markets seem to be poorly developed in the study areas, which may justify the lack of interest of all farmers for intercropping.

Results of the focus groups

Each focus groups' feedback has been drawn up by LOAM as summarized in tables XII and XIII. The objective is to establish intercrop models with rubber trees adapted to the study areas. Based on the literature review and on the field surveys' analysis, YAPI Expertise was able to select a final list of interesting crops (and potentially adopted by local smallholders) for the modeling of intercropping systems. The list of the final selected crops is based on the performance and adoption criteria of the field surveys combined with the results of the bibliographic study (in annexes 1 & 2).

LOAM and YAPI Expertise made together the final choice of the crops which would be part of the models in order to fullfil the demand from surveyed farmers. Banana, pineapple, cocoa and mung-bean are crops that already exist as intercrops in the study areas, as the field survey showed, and they have been selected. However, sugarcane, corn and pepper were not efficient enough. Indeed, sugarcane and corn are very low in the ranking of the literature search. From an agronomic point of view, they need a lot of water to develop, a need that can hinder rubber trees' growth. From a socio-economic point of view, their maintenance costs (chemical inputs, seed costs and workforce) are high, and therefore, less attractive for producers to implement. Regarding pepper, the cultivation calendar does not correspond to the climatic conditions of the study areas because of global warming. The changing of seasons does not allow the flowering of pepper. Cowpea was also not included in the final list because the corn-cowpea association is already widespread and does not correspond to an agronomic innovation in the study areas. On the other hand, groundnut, *Mucuna* sp., butterfly pea and neem are crops not identified in the field surveys. However, LOAM found it interesting to include them in the models because they are already well-established crops in the study areas. All these models have been discussed in focus groups with local communities.

Five models have been identified along three axes, spatial, temporal and functional: i) the pineapple model, ii) the cocoa model, iii) the banana model, iv) the passion fruit model and v) the soursop model (annex 3). The time of cultivation on the plot, the periods of sowing, growth, maintenance and harvesting are explained for each model. The models are built over the first ten years of the rubber tree. It might be different during mature phase (after 7 years when rubber canopy is closed) as shadow might not be compatible in particular in normal spacing system. The cropping association would be different during mature

Table X.
P-values of the economic performance. P-values less than 0.05 indicate independent variables in green.

	District	Rubber yield	Cost input	People household	Extra people	Salary
Crop	8,62E-16	0,2098	0,7923	0.4163	7.25E-06	6.93E-06

Table XI.
P-values of the «adoption». P-values less than 0.05 indicate independent variables in green.

	Moisture conservation	Soil erosion	Extra income	Society choice	Less maintenance cost for rubber	Adapted to climate	Easy maintenance	Support rubber growth	Soil nutrition	Shade
Crop	0.000003614	0.6306	0.9706	0.1776	0.09223	0.00000000002119	0.01297	0.0001769	1.923E-07	0.5242

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Table XII.
Summary of the focus groups.

Subject	Comments
	Agronomic part
General trends of intercrops	There are many annual plants in the immature phase (mungbean, finger millet, corn, cowpea) . and cocoa in the mature phase
Most wanted intercrops	Cocoa and pineapple: they have positive impacts on the plot environment / Moisture conservation and climate. Corns, mungbean, finger millet, cowpea: well-known crops to producers and used for self-consumption /Safe annual crops.
Historical of the lands	The rubber lands were previously “chena”1 cultivated area where corn, pepper or sugar cane were cultivated, which became less fertile.
Origin of the seeds	Producers buy their seeds from private or government agencies. Prices fluctuate between sellers but remain similar from one area to another.
Rubber yield	Buyers indicate the same latex yields, which are around 1,000 kg/ha/year and do not differ between areas. However, producers report much higher yields. The yields are higher than average, suggesting that producers are exaggerating their yields.
Workforce and salary	It is difficult to analyse the workforce required by crop. Sugar cane cultivation requires a larger workforce. Salaries are the same in all areas.
Major issues faced by producers	Producers face the same issues in all three zones. They are the following: animals attacks, lack of knowledge and technical materials, expensive workforce, problem of producers’ behaviour.
	Economic part
Intercrop network	Not very common. Especially for cocoa and sugar cane crops.
Certification	Certifications are specific to the zones and to the cocoa crop.
Collection site	Only few existing sites in Moneragala, especially for cocoa and pepper.
Type de contract	Agreements between the producers and the societies.
Major downsides of the societies	Weak organisation is reported as well as internal conflicts within societies and with producers. Producers tend to sell their products outside the societies because the societies do not sell them at prices that are attractive to the producers. Societies are therefore very unstable, and producers have little hope for the future of these organisations.

[1] Slash-and-burn.

Table XIII.
Final selection of the intercrops for the models.

Types of crop	Crop species
Cash crop	*Annona muricata*
	Theobroma cacao
	Ananas comosus
	Passiflora edulis
Cover crop	*Vigna radiata*
	Arachis hypogeae
	Clitoria ternatea
	Mucuna pruriens
Timber crop	*Azadirachta indica*

phase Focus has been put on cropping models for the first ten years in that case for that particular study Finally, the spatial and functional axes are represented in the diagrams below. Each model represents different intercrop combinations according to the farmers’ cropping patterns. The study also proposes different intercrop’s possibility according to the plots’ profile. In addition, the following criteria have been assessed for each model: the study area, the soil, the surface of the plot, the workforce, the initial investment and the risk of wild animal attacks.

These 5 models are those selected by farmers in the current conditions of existing markets and prices system. They represent the type of systems that would probably be most adopted by local farmers in the second phase of the project with focus on rubber-based agroforestry systems development. The next step of the RIVER project is to promote trough extension activities the recommended systems for the period 2023-2024. The prospective analysis is intended to gain time through the participatory approach for further development.

Conclusion and recommendation

YAPI Expertise's study was conducted as a desk study due to social unrest in the country but was completed by a local survey implemented by partner NGO. Firstly, the literature review on intercropping provided a high amount of data on each crop showing a relatively high level of knowledge and know-how on intercropping. These data were obtained from scientific as well as grey literature (not included in the bibliography of this publication). The data have been verified and sometimes adapted by experts to profit from experience and reliability. Such analysis should be later on counter-verified by local visits, the data needed to define the criteria for intercrop selection were sometimes difficult to find and to adapt to different soils or rainfall conditions. Data were provided to local stakeholders for analysis. Furthermore, for certain reasons, some of the data provided during the interviews had outliers and were not considered in the analysis. Finally, the intercropping models were mainly based on agronomic data. The lack of information on social categories (labor availability, labor requirement, etc.) and economic categories (input costs, place of crops on the Sri Lankan market, selling costs of crops, etc.) led to the construction of models based on a questionable database.

Indeed, a performant model cannot rely only on agronomic analysis. In order to adapt these models to the reality of the country, it will be essential to budget inputs and adapt the choice of crops to the local market (consumer demand, presence of collection and resale centers, etc.) and above all to the farmers' needs. Most of the current proposal has been discussed in focus groups with local communities but further monitoring should be done when development phase will be launched in 2023-2024 in order to ensure the best possible adaptability to local conditions. This exploratory research activity enables the RIVER project to move rapidly to extension.

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Photo 2.
Focus group discussion with LOAM's officer, Michelin Lanka experts, society farmers' representatives and export company's representatives.
Photo LOAM's officer.

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Annex 1.
Final selection of potential intercrops for the immature phase of rubber tree. Green is suitable, red is not suitable, yellow in between.

Final crop selection table - Immature phase of rubber tree

Crops	Climate						
	Rainfall during the dry season (600-1,200 mm/year)	Rainfall during the wet season (1,200-3,000 mm/year)	Temperature (15-30 °C)	Altitude (< 600 m)	Resistance to high heat	Resistance to wind	Resistance to heavy rain
Degree of impact	4	4	4	3	3	2	2
Alpinia oxiphylla - black cardamom	4	4	4	3	1,5	2	2
Ammonum villosum - medicinal cardamom	2	4	4	1.5	1.5	2	2
Arachis hypogaea L. - groundnut	4	4	4	3	3	1	0
Cajanus cajan (L.) - pigeon pea	4	4	4	3	3	2	0
Calopogonium caeruleum	2	4	4	3	3	2	2
Citrullus colocynthis - bitter cucumber	0	4	4	3	3	2	0
Citrullus lanatus - watermelon	0	4	4	3	1.5	2	1
Ipomoea batatas L. - sweet potato	2	4	4	3	3	1	2
Manihot esculenta - cassava (culture < 12 months)	4	4	4	3	3	2	2
Mucuna bracteata	4	4	4	3	3	2	2
Mucuna cochinchinensis	4	4	4	3	3	2	2
Noicotiana spp. - tobacco	0	4	4	3	3	2	2
Oryza sativa L. - upland rice	0	4	2	3	1.5	2	2
Psophocarpus tetragonolobus (L.)	4	4	4	3	3	2	1
Sorghum bicolor (L.) - sorghum	4	2	4	3	3	1	1
Vigna radiata (L.) - mung bean	4	0	4	3	3	2	2
Vigna unguiculata - cow pea	4	4	4	3	3	1	2
Ananas comosus (L.) - pineapple	4	4	4	3	3	2	2
Capsicum annuum L. - chili pepper	4	4	4	3	3	1	0
Luffa acutangulas - angled loofah	4	4	4	3	3	2	1
Musa acuminata - banana	2	4	4	3	1.5	0	1
Pogostemon cablin (Blanco) - patchouly	2	4	4	3	1.5	1	1
Saccharum officinarum L. - sugar cane	2	2	4	3	3	2	2
Arachis pintoï	2	4	4	3	3	2	1
Centrosema pubescens - butterfly pea	2	4	4	3	3	2	2
Coffea canephora - coffea robusta	0	4	4	3	3	2	2
Crotalaria spp. - rattlepods	2	4	4	3	3	2	1
Curcuma domestica - turmeric	2	4	4	3	3	2	2
Cymbopogon citratus (DC.) - lemon grass	2	4	4	3	3	2	1
Flemingia macrophylla	2	4	4	3	3	2	2
Glycine max (L.) - soybean	2	4	4	3	1.5	2	1
Morinda officinalis - morinda	4	4	4	1,5	3	1	2
Pueraria phaseoloides - tropical kudzu	2	4	4	3	3	2	2
Stylosanthes guianensis - common stylo	2	4	4	3	3	2	2
Theobroma cacao L. - cocoa	2	4	4	3	3	2	2

Key
Annual plants
Multiannual plants
Perennial plants
Refers to the criteria's definitions
Refers to the criteria's definitions
Refers to the criteria's definitions
Unknown information

Soil				Crop				
Adaptation to Reddish brown earth and Red yellow podzolic soil (pH = 4.5-6)	Adaptation to Vertisol (pH = 7-7.5)	Adaptation to feralitic soil (pH = 5-6.5)	Biomass to be returned to the soil	Water competition with rubber trees	Light competition from rubber trees	Required space between crops and rubber trees	Need of mechanisation	Mark
4	4	4	1	4	4	4	2	49
4	4	4	1	2	2	4	2	42
4	4	2	1	4	4	4	2	42
4	0	4	1	4	4	4	2	42
2	2	4	1	4	4	4	1	42
4	2	4	1	4	2	4	2	41
4	4	4	0.5	2	4	4	2	40.5
2	0	4	0.5	4	2	4	2	34
4	0	4	0.5	4	2	4	2	39.5
4	2	2	0.5	4	4	4	2	44.5
4	2	4	1	4	2	4	2	45
4	2	4	1	4	2	4	2	45
4	4	4	0.5	4	2	4	2	42.5
2	2	4	0.5	2	2	4	1	32
4	2	2	0.5	2	2	4	2	39.5
2	4	4	0.5	4	2	4	2	40.5
2	2	2	1	4	4	4	2	39
2	4	4	1	4	2	4	2	44
4	0	4	1	2	4	4	2	42
4	0	4	0.5	4	4	4	2	41.5
0	2	4	0.5	4	2	4	2	39.5
4	4	4	0.5	2	4	4	2	40
4	2	4	0.5	2	4	4	2	39
2	0	4	1	0	2	4	2	33
4	4	4	1	4	4	4	2	46
4	4	4	1	4	4	4	2	47
4	4	4	0.5	2	2	2	1	37.5
2	4	2	1	2	4	4	2	40
2	0	4	0.5	4	2	4	1	37.5
2	4	4	0.5	4	2	4	2	41.5
4	4	4	1	4	2	4	2	43
2	2	4	0.5	4	4	4	2	40
4	2	4	0,5	4	4	4	2	40
4	2	4	1	4	2	4	2	43
4	0	4	1	2	4	4	2	41
4	4	4	1	2	2	2	1	40

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Annex 2.
Final selection of potential intercrops for the mature phase of rubber tree. Green is suitable, red is not suitable, yellow in between.

Final crop selection table - Mature phase of rubber tree

Crops	Climate						
	Rainfall during the dry season (600-1,200 mm/year)	Rainfall during the wet season (1,200-3,000 mm/year)	Temperature (15-30 °C)	Altitude (< 600 m)	Resistance to high heat	Resistance to wind	Resistance to heavy rain
Degree of impact	4	4	4	3	3	2	2
Ammonum villosum - medicinal cardamom	2	4	4	1.5	1.5	2	2
Calopogonium caeruleum	2	4	4	3	3	2	2
Piper nigrum L. - pepper	4	4	4	3	0	2	0
Carica papaya L. - papaya	4	4	4	3	1.5	0	2
Vanilla fragrans - vanilla	4	4	4	3	0	1	2
Anacardium occidentale L. - cashew nut	4	4	4	3	3	2	1
Annona reticulata L. - custard-apple	4	4	4	3	3	0	1
Aquilaria sp. - eaglewood	4	4	2	3	3	1	1
Arachis pintoï	2	4	4	3	3	2	1
Areca catechu - betel nut tree	2	4	4	3	3	1	2
Artocarpus altilis - breadfruit	2	4	4	3	3	2	2
Artocarpus heterophyllus - jackfruit	2	4	4	3	1.5	2	2
Azadirachta indica - neem	4	4	4	3	3	2	2
Centrosema pubescens - butterfly pea	2	4	4	3	3	2	2
Cinamomum verum - cinnamon	2	4	4	3	3	2	2
Citrus aurantiifolia - lime	2	4	4	3	1.5	1	1
Citrus x paradisi - grapefruit	2	4	4	3	1.5	1	1
Citrus reticulata - tangerine	2	4	4	3	1.5	1	1
Citrus x sinensis - orange	2	4	4	3	1.5	1	1
Cocos nucifera - coconut	2	4	4	3	3	2	2
Durio zibethinus - durian	2	4	2	3	3	1	2
Fagraea fragrans - iron wood	4	4	4	3	3	2	2
Garcinia mangostana L. - mangosteen	2	4	4	3	3	1	2
Gmelina arborea - gmelina	4	4	4	3	3	2	2
Macadamia sp. - macadamia nut	4	4	4	3	3	0	2
Mangifera indica L. - mango	4	4	4	3	1.5	1	1
Morinda officinalis - morinda	4	4	4	1,5	3	1	2
Nephelium lappaceum L. - rambutan	4	4	4	3	3	1	2
Paraserianthes falcataria (L.) - white albizia	2	4	4	3	3	2	2
Parkia speciosa - stink bean	4	4	4	3	3	2	2
Passiflora edulis Silms - passion fruit	4	4	4	3	1.5	1	1
Pterocarpus sp. - padouk, narra	2	4	4	3	3	2	2
Pueraria phaseoloides - tropical kudzu	2	4	4	3	3	2	2
Salacca zalacca - snake fruit	4	4	4	3	1.5	1	1
Shorea macrophylla - light red meranti	4	4	4	3	3	2	2
Stylosanthes guianensis - common stylo	2	4	4	3	3	2	2
Tectona grandis L. - teak	2	4	4	3	1.5	1	2

Key
Annual plants
Multiannual plants
Perennial plants
Refers to the criteria's definitions
Refers to the criteria's definitions
Refers to the criteria's definitions
Unknown information

Soil				Crop				
Adaptation to Reddish brown earth and Red yellow podzolic soil (pH = 4.5-6)	Adaptation to Vertisol (pH = 7-7.5)	Adaptation to feralitic soil (pH = 5-6.5)	Biomass to be returned to the soil	Water competition with rubber trees	Light competition from rubber trees	Required space between crops and rubber trees	Need of mechanisation	Mark
4	4	4	1	4	4	4	2	49
4	4	2	1	4	4	4	2	42
4	2	4	1	4	2	4	2	41
2	4	4	0.5	4	4	4	2	41.5
2	2	2	0.5	2	2	4	2	35
2	2	4	0.5	2	4	4	2	38.5
4	2	2	1	2	2	2	2	38
4	2	2	0.5	2	4	4	2	39.5
4	4	4	1	4	4	4	2	45
4	4	4	1	4	4	4	2	46
4	2	2	0.5	2	2	4	2	37.5
4	4	4	0.5	2	2	2	2	40.5
4	4	4	0.5	2	2	2	2	39
4	4	4	1	4	4	4	2	49
4	4	4	1	4	4	4	2	47
4	2	2	0.5	4	2	4	2	40.5
2	2	4	0.5	2	2	4	2	35
2	4	4	0.5	2	2	4	2	37
4	2	4	0.5	2	2	4	2	37
4	2	4	0.5	2	2	4	2	37
4	4	4	0.5	2	4	4	2	44.5
4	2	4	1	2	2	2	2	36
4	2	4	1	4	2	4	2	45
2	2	4	1	2	4	4	2	40
2	2	4	1	4	2	4	2	43
4	0	2	1	2	2	2	2	35
4	4	4	1	2	2	4	2	41.5
4	2	4	0,5	4	4	4	2	40
4	2	4	1	2	2	4	2	42
2	4	2	1	4	2	4	2	41
0	2	4	1	4	2	4	2	41
2	4	4	0.5	2	4	4	2	41
4	4	4	1	4	4	4	2	47
4	2	4	1	4	2	4	2	43
4	0	4	0.5	4	2	4	2	39
4	0	4	0.5	4	2	2	2	40.5
4	0	4	1	2	4	4	2	41
4	4	4	1	4	2	4	1	41.5

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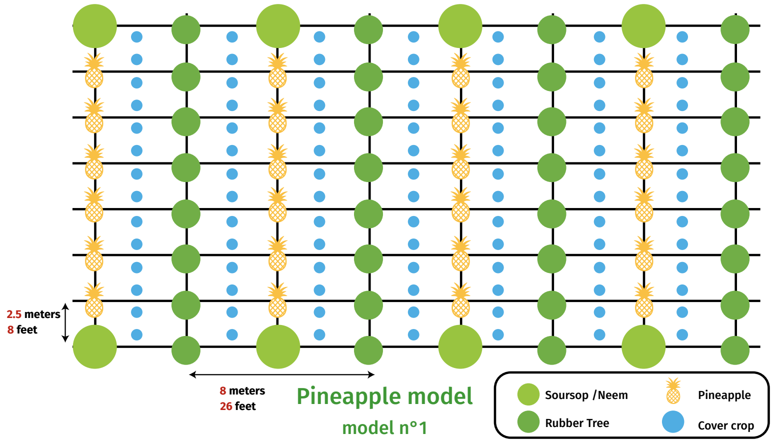
Annex 3.

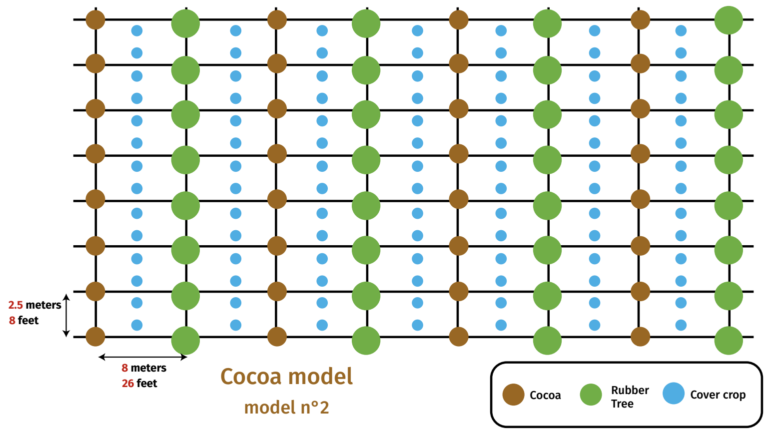


Criteria :

- Place : Moneragala and Ampara
- Field : 1ha+
- Labour force : ***
- Initial cost : ***
- Wild animals : **

Model 1: Pineapple Model

In this first model, there is a row of pineapples between two rows of rubber trees, that are surrounded by a cover crop. The choice of the cover crop is free. Finally, Neem trees frame the plot, as they are quite imposing and take a lot of space. The framing of the plot by these kind of trees limits attacks by fungi. Moreover, they do not require any maintenance work. When the rubber trees have reached the mature phase, the amount of light that filters through the canopy will be too low and the cover crops will disappear by themselves as well as pineapple. It means that during the mature phase of the rubber tree, only remain neem trees.

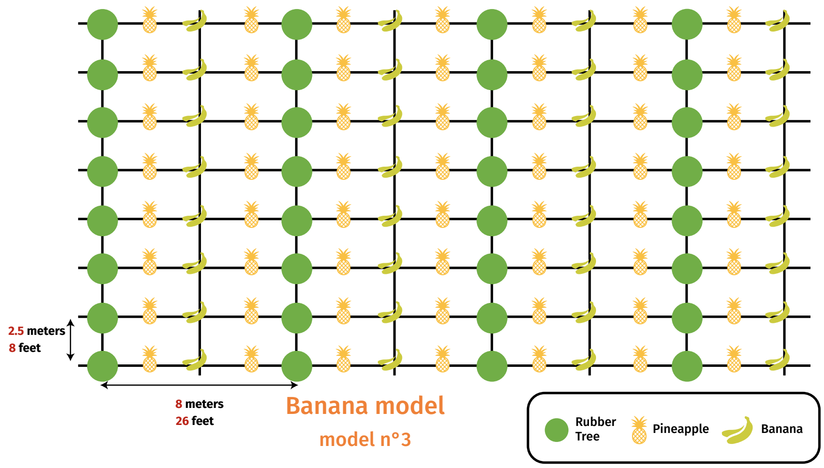


Criteria :

- Place : Moneragala and Ampara
- Field : 0,4 - 1ha
- Labour force : ****

Model 2: Cocoa Model

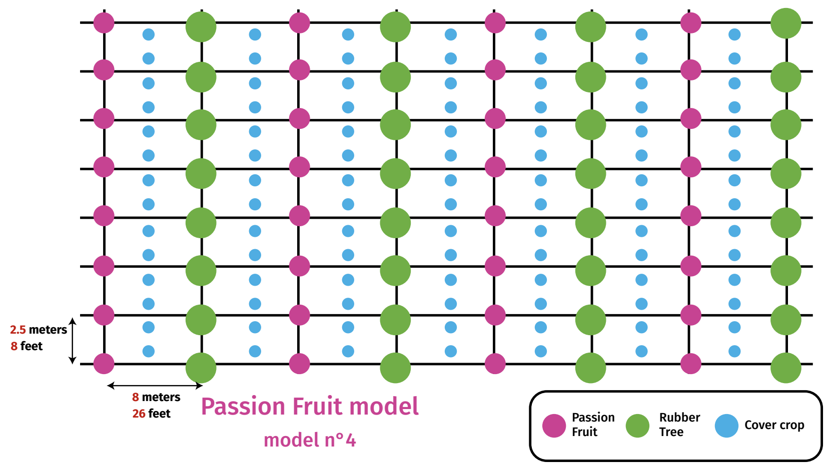
The second model is based on cocoa trees placed between rows of rubber trees. There are also cover crops between the rubber trees and the cocoa. They aim to limit weeds and fix nitrogen in the soil. Like the first model, the cover crops will disappear by themselves when the shade provided by the rubber trees is too important. However, the cocoa trees will still be present during the mature phase of the rubber trees, but a decrease in cocoa's yield is likely to be observed.



Criteria :

- Place : Moneragala and Ampara
- Field : 0,4 - 1ha
- Labour force : ***
- Initial cost : ***
- Wild animals : **

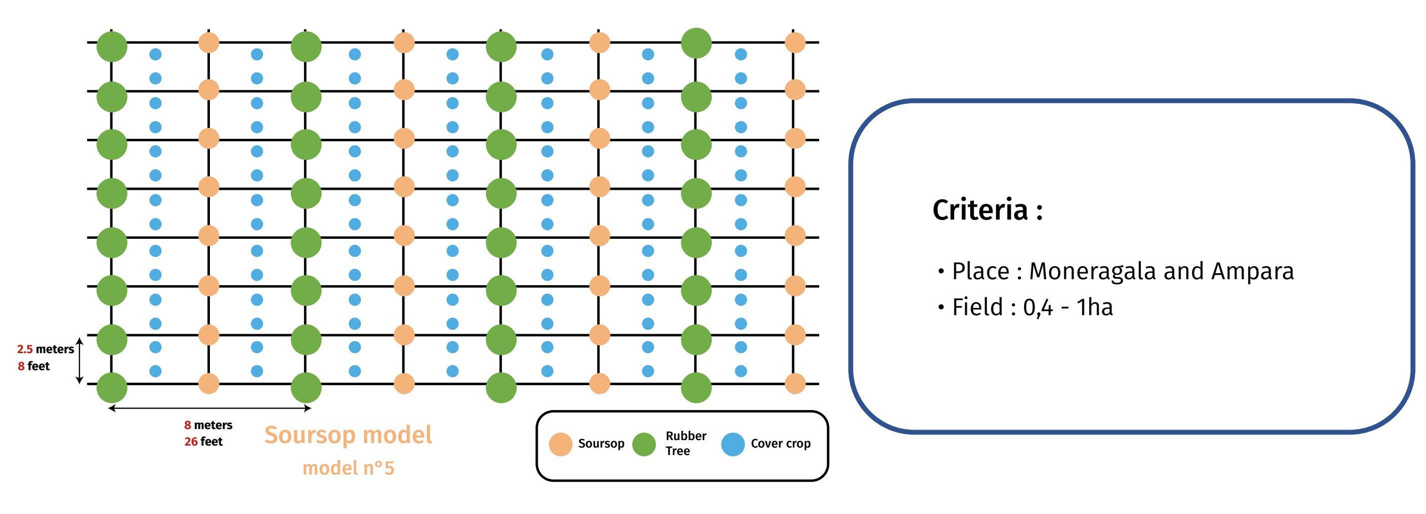
Model 3: Banana Model
Banana Model has been enthusiastically welcomed by LOAM, particularly because of the combination of rubber and banana. According to Rodrigo, the combination of rubber and banana allows for a better use of resources in the soil. A row of pineapple has also been added between the rubber and banana rows. These intercrops can be grown for the first 6 years of the rubber tree's life. After that the tree canopy will be too important and the amount of light too low to enable the bananas and pineapples to grow. From the 7th year onwards, the field will be a monoculture of rubber trees.



Criteria :

- Place : Ampara
- Field : 0,4 - 1ha

Model 4: Passion Fruit Model
This model is highly advised in Ampara and in the driest areas of Moneragala. Indeed, the passion fruit is a liana that needs sun and a dry climate to grow properly and produce fruit. Passion fruit should be planted during the immature period of the rubber tree and then removed during the mature period. A cover crop is planted between the rubber trees and the passion fruits like in the first two models. The cover crop will disappear during the mature phase of the rubber tree, leaving the plot in monoculture.



Model 5: Soursop Model
The last model is based on the recommendations of local stakeholders. Soursop is a fruit tree already present in Sri Lanka, in this model it is planted in the immature phase of the rubber tree and remains on the plot throughout the life of the rubber tree. Between the trees' rows, cover crops are planted, which will disappear during the mature phase of the rubber tree.

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