Rubber Agroforestry Systems (RAS) strategies in Sri Lanka: the case of new rubber areas in eastern zone (Badalkumbura, Moneragala, Ampara)

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Summary

Rubber was then introduced in the 2000's into non-traditional areas Monaragala, Badulla and Ampara by the Smallholder Plantations Entrepreneurship Development Program (SPEnDP/IFAD/UN.ADB) to increase Sri Lanka's rubber production. To convince and help farmers to move on rubber cultivation, the government provided financial and technical support for development, planting materials and land preparation and a fertilizers supply. This new pioneer areas have with highly contrasting climates compared to the eastern traditional rubber area. Ampara is considered as an area with significative climatic constraints during dry season for rubber. Agroforestry patterns are considered as key to gene rate extra incomes during immature period as well as mature period. Most current RAS (Rubber Agroforestry Systems) have been identified and promoted by RRISL (Rubber Research Institute of Sri Lanka). If crop selected for immature period are relatively adapted, accorded to local markets, such as banana, maize, it seems that cocoa, the main crop proposed during mature period is definitely not adapted to high shading. Most cocoa intercropped with rubber do not produce at all. RRISL has tried, at very limited scale trough on station trials, cinnamon and some fruits trees. Farmers might be interested, with also timber species. The question of planting density and pattern remains as double-spacing systems with large inter-row seems to be more adapted for fruits for instance. Such double-spacing systems are completely new for local farmers. Eventually, agroforestry systems should take into account the potential water competition between rubber and associated crops, in particular in Ampara area. The question of planting density and pattern remains as double-spacing systems with large inter-row seems to be more adapted for fruits for instance. Such double-spacing systems are completely new for local farmers. The objective of the study is to provide reliable and adapted RAS recommendations for the RIVER project

Key words: RAS /rubber agroforestry systems, Sri Lanka, agroforestry patterns. Adaptation to climatic change.

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1 Introduction

1.1 Sri Lanka rapid overview

Formerly known as Ceylon, Sri Lanka is located to the southeast of India in the Indian Ocean, and covers an area of 65,610 km², with a population of 22,100,000. Its proximity to the Indian subcontinent encouraged numerous cultural exchanges with neighboring Asian countries. In the 80s, a social war broke out pitting the Tamil minority against the overwhelming Sinhalese majority in a confrontation that lasted until 2009. After the social conflict, Sri Lanka suffers from social upheaval and economic difficulties in particular for agriculture. In April 2022, inflation reached 54.6%, increase compared to 6% the previous year (BBC, 2022). The economic crisis is causing severe shortages of agricultural inputs, fuel and food. Paddy rice production, at 3 million tons, is at its lowest level since the drought-affected 2017 harvest. In addition, export prices for cash crops such as tea and rubber are well below average, leading to a significant reduction in farmers' income (Tanya Jansz et al, 2022). Income diversification became a priority for most farmers.

1.2 Context: the importance of rubber in Sri Lanka

Sri Lanka rubber producers is 82,600 for 136 300 ha in 2020 (Sankalpa et al., 2021) for 2% of the total land area (Sankalpa, 2020). Sri Lanka is the thirteenth largest producer of natural rubber in the world (WorldAtlas, 2017). According to the 2018 annual report, latex yield is declining year on year from 808 kg/ha/year in 2017 to 774 kg/ha/year in 2018. The latest RRISL report for 2020 announces an annual yield of 642 kg/ha/year, it could be due to several factors such as agronomic practices and intensification of diseases such as the White Root disease (fomes) and a new leaf disease named as "Pestalotiopsis" in wet regions of the country. In 1970, Sri Lanka had over 200,000 ha of rubber plantations (Dunuwila et al., 2018) located in the districts of Kegalle, Kalutara, Rathnapura, Colombo and Galle in the western part of the country. However, for various reasons (lack of labour force, pest and disease attacks and urbanization), the area under rubber cultivation has decreased to the 132,000 ha. (Chandrasiri and Gunarathna, 2022). (Figure 1: Map of area occupied by rubber cultivation in Sri Lanka).

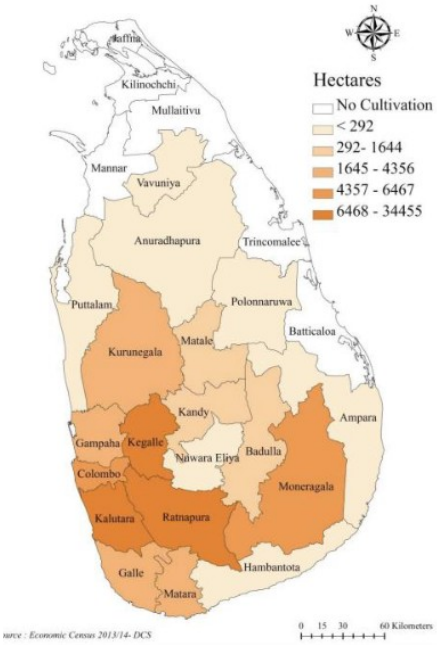


FIGURE 1: MAP OF AREA OCCUPIED BY RUBBER CULTIVATION IN SRI LANKA (SOURCE: STATISTICAL INFORMATION ON PLANTATION CROP 2018 - MINISTRY OF PLANTATION INDUSTRIES AND EXPORT AGRICULTURE)

Rubber was then introduced un the 2000's into non-traditional areas Monaragala, Badulla and Ampara by the Smallholder Plantations Entrepreneurship Development Program (SPEnDP) to increase Sri Lanka's production under the International Fund International for Agricultural Development (IFAD/UN.ADB) (Chandra Siri and Guna Rathna, 2022). To convince and help farmers to move on rubber cultivation, the government provides financial and technical support for development, planting materials and land preparation and a fertilizers supply. This new pioneer areas have with highly contrasting climates compared to the western traditional rubber area.

The new eastern region is very heterogeneous in terms of climatic and soil characteristics. The rainfall pattern is variable and create micro-conditions that will not allow to develop "one size fits all" technical recommendations. The dry season runs from June to mid-September, with rainfall ranging from 110-180 mm per month in Moneragala. In Ampara, we observed two dry season periods between February - March and May – Mid-September with precipitation rain lower than 50 mm per month (Figure 2: Moneragala and Ampara Rainfall pattern). Areas in the southern and eastern part of the district recorded a lower rainfall and thus consisting in marginal areas for rubber (Samarappuli et al., 2014). A clear gradient of rainfall from the North-West to the South-East can be highlighted (Figure 3: Maps of annual cumulative rainfall and land suitability for rubber cultivation in the eastern region). In the area, dry periods were identified as a problem by over 90% of the farmers either at medium or high level (Rodrigo et al., 2011). The distribution and yearly rainfall pattern are also very heterogeneous. This leads to located suitable land for rubber in the region (Karunaratne et al., 2011).

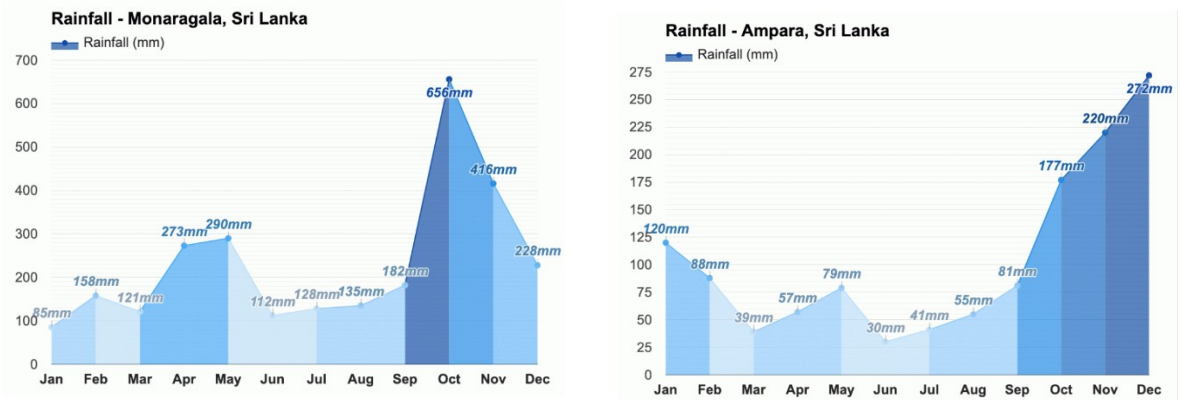


FIGURE 2 - RAINFALL PATTERN OF MONERAGALA (SOURCE: WEATHER ATLAS)

Despite the fact that the area from Badalkumbura to Bibile/Madulla seems suitable, other regions in the eastern part are rather marginal for rubber (Ampara). Rodrigo et al. (2011) stated that the province comprises two zones, the "Intermediate Zone" and "Dry Zone". The Intermediate Zone being much more adapted for rubber cultivation than the Dry Zone. Indeed, dry periods were identified as a problem by over 90% of the farmers either at medium or high level (Rodrigo et al., 2011).

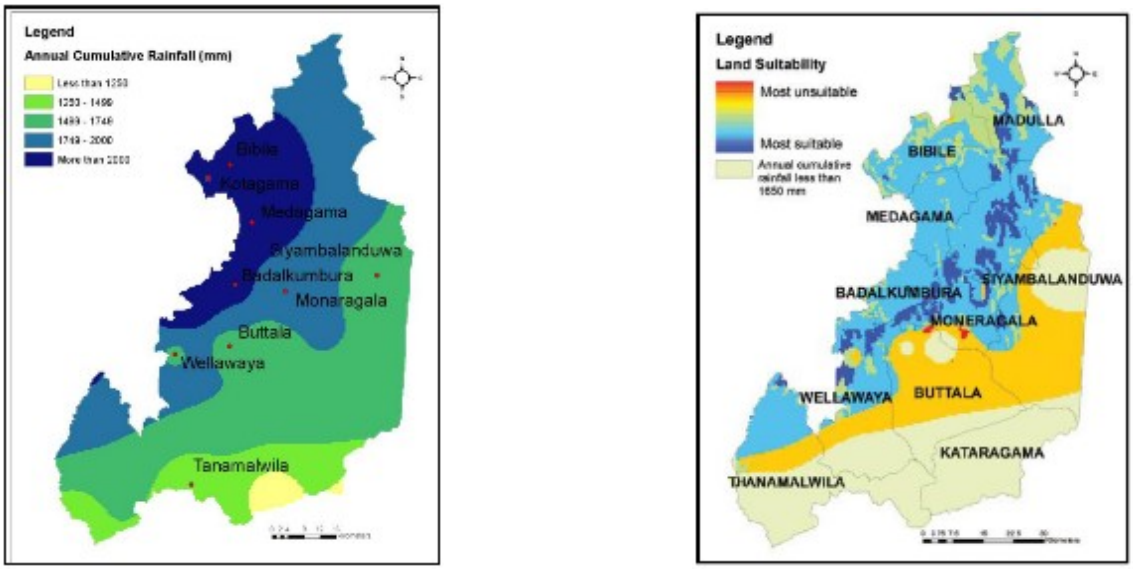


FIGURE 3 - MAPS OF ANNUAL CUMULATIVE RAINFALL AND LAND SUITABILITY FOR RUBBER CULTIVATION IN THE EASTERN REGION. MAPS COLLECTED FROM SAMARAPPULI ET AL., (2014) AND KARUNARATNE ET AL. (2011)

The understanding of climatic constraints is a key to understand local farmers' strategies and potentialities and release relevant further recommendations.

1.3 Agroforestry practices importance in Sri Lanka

To compensate the lack of rubber production during the immature period, farmers develop agroforestry strategies with intercropping to diversify their income. We identified 2 main periods: i) The intercropping system in the rubber immature phase with annual and pluri-annual crops. The main benefits of intercropping are increased crop production rates and weed control (Liebman and Dyck, 1993), and ii) Rubber

agroforestry systems (RAS) during mature period with permanent association (Penot, 2001). De Foresta (2014) identified two main agroforestry systems: i) Simple system with one or two species like rubber/cocoa and ii) “Complex system” refers to the multi-strata morphology as a forest system (with many fruits and timber trees).
Rodrigo et al. (2001), found that 25-50% of farmers in traditional rubber cultivation areas are practicing RAS which includes mainly tea, banana, cinnamon, pepper and pineapple. In eastern area, RAS and intercropping systems are reducing poverty in rural areas for example in Moneragala where households were the poorest in the country (Sankalpa, 2020; Douangsavanth et al., 2008). There are real evidences that when rubber integrated with other crops, it can result in significant increases in household wealth and greater resilience in face of unpredictable market (Viswanathan and Shivakoti, 2008). The reduction in poverty in Moneragala is not the fact of a single factor (Sankalpa , 2020). Indeed, it could depend on the labor force and the farmland size. The aim of this study is to understand and identify the factors influencing the economic performance of diversified rubber-growing systems in order to make farming households self-sufficient and resilient in the face of market variability.

A preliminary overview on diversified system

As part of the RIVER project with YAPI expertise[1], a corpus of 21 Sri Lankan research articles were analyzed and discussed with farmers trough field observations in 2021. Table 1 displays the diversity of rubber-growing systems in the eastern part of the country:

Type of crops		Crops name	References
Livestock		Dairy Cattle	Sankalpa et al. (2020)
Annual	Leguminous	Ground nut *(Arachis hypogaea)*	Sankalpa et al. (2020); Rodrigo et al. (2009); Ishani et al. (2018)
		Pueraria phaseoloides	Senevirathna et al. (2010)
		Calopo *(Calopogonium muconoides)*	Senevirathna et al. (2010)
		Cowpea *(Vigna unguiculata)*	Rodrigo et al. (2009); Ishani et al. (2018)
	Non-leguminous	Maize *(Zea Mays)*	Sankalpa et al. (2020); Rodrigo et al., (2009); Ishani et al. (2018)
Semi-perennial		Passion fruit *(Passiflora edulis)*	Sankalpa et al. (2020); Herath and Takeya (2003); Senevirathna et al. (2010); Ishani et al. (2018)
		Banana *(Musa)*	Sankalpa et al. (2020); Herath and Takeya (2003); Rodrigo et al. (2001); Rodrigo et al. (2000a); Senevirathna et al. (2010); Ishani et al. (2018)
		Pineapple *(Ananas)*	Ishani et al., (2018); Herath and Takeya (2003); Ishani et al. (2018)
		Sugarcane *(Saccharum officinarum)*	Rodrigo et al. (2000b)
		Cirtonella *(Cymbopogon nardus)*	Senevirathna et al. (2010)
Perennial		Coffee *(Coffea canephora)*	Herath and Takeya (2003)
		Tea *(Camellia sinensis)*	Iqbal et al. (2006); Herath and Takeya (2003)
		Cinnamon *(Cinnamomum verum)*	Ishani et al. (2018); Herath and Takeya (2003); Senevirathna et al. (2010); Ishani et al. (2018)
		Pepper *(Piper nigrum)*	Sankalpa et al. (2020); Ishani et al. (2018)
		Cocoa *(Theobroma cacao)*	Sankalpa et al. (2020); Herath and Takeya (2003); Ishani et al. (2018)

TABLE 1 - LIST OF SPECIES INTERCROPPED WITH RUBBER IN SRI LANKA FROM LITERATURE (SOURCE: CIRAD)

Intercrops recommendations by RRISL

The Rubber Research Institute of Sri Lanka (RRISL) is the oldest rubber research institute of the world and advice among others topics on intercrops association with rubber. Main of the recommendations can be resume in the table 2 in annex.

[1] Entitled *Study on intercropping rubber cultivation in Ampara and Moneragala regions in Sri Lanka*, the report was based on a RAS literature analysis and a limited field survey implemented by the NGO Lanka Organic Agriculture Movement (LOAM), the local partner of the project

1.4 Objectives and problematic

Our study aimed at better understanding the economic performance of diversified rubber farmer in the new planted area, and proposing adapted RAS prototype considering the climatic variability and constraints of the zone

2 Methodology

Twenty farmers were interviewed in three zones. Those three zones were Ampara, Moneragala and Badalkumbura. They were selected to represent a West-East gradient to cover the region spatial heterogeneity. A total of 60 farmers were randomly selected. The table 3 shows the distribution of the 60 farmers interviewed, the stage of rubber stand and the number of intercrops encountered, according to their category (perennial, semi-perennial, seasonal).

	Distribution of intercrops visited		Distribution of RAS visited		Number of farmers interviewed
Badalkumbura	Perennial	18	Mature	17	20
	Semi-perennial	3	Immature	3	
	Seasonal	1			
Ampara	Perennial	0	Mature	0	20
	Semi-perenial	13	Immature	20	
	Seasonal	33			
Moneragala	Perennial	14	Mature	14	20
	Semi-perennial	9	Immature	9	
	Seasonal	1			

Total distribution				
Total perennial	32	Total mature	31	Total Farmers
Total semi-perennial	25	Total immature	32	60
Total seasonal	35			

TABLE 2 - STUDY SAMPLING DISTRIBUTION

The questionnaire includes 2 scales: the plot scale and the activity system (a farm + an household). In the case of a mature plantation, these data provide a static image of the farms. In the case of an immature plantation, where farmers are in the investment period, data relating to the first 4 years have been recorded and standardized for a 4 years period. The aim was to measure the real economic impact of intercropping during the immature period. A farm typology and a behavioral typology were built. Results were discussed and validated through focus group restitution sessions at the end of the study.

3 The main results

Ampara, Moneragala and Badalkumbura have clearly different climatic patterns.

3.1. Description of the context of the studied regions

3.1.1 Badalkumbura: The old rubber plantation area

Thirty years ago, sugar cane was mainly cultivated. Nowadays, most of the farmers turn into rubber, pepper and home garden cultivations. Indeed, in Badalkumbura, the most westerly region, the rubber plots are the eldest plantations aged between 20 and 30 years old, it is very difficult to find immature plot. The RRISL tried to diversify the rubber farmers income with cocoa but, due to a lack of sunlight and management, cocoa trees do not produce. Badalkumbura area is very favorable to rubber due to the continue rainfall (2200 mm of rain), (figure 4) however changes are currentlyobserved by local farmers. For instance, for pepper (one of the main crops in Badalkumbura), the variety is no more adapted to the new rainfall pattern and do not produce any more for the last four years.

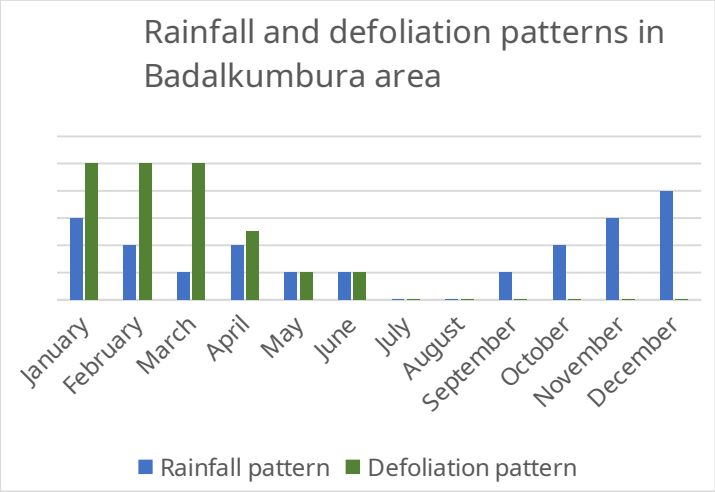


FIGURE 4- RAINFALL AND DEFOLIATION PATTERNS IN BADALKUMBURA AREA. BARS HGHLIGHTS THE PEAK SEASONS DESCRIBED THROUGH FARMER INTERVIEWS.

In Badalkumbura, the spacing between rubber rows is following the former recommendations of the RRI: 5x3.5 m. The land is very slopy making weeding or maintaining very difficult. the old plantations are no longer supplied with inputs, mainly because of the country's economic situation.

3.1.2 Moneragala: the intermediate climatic rubber area

As for the climatic description, Moneragala can be defined as the intermediate region for the rubber. Historically, the region is known for its high sugar cane production. Although it still well established, farmers are gradually turning to rubber production, a less costly and more resilient crop with a daily income. Currently, the main cultivated crops are sugar cane, rubber, teak and banana. Although the rainfall pattern in Moneragala seems to be very similar to that of Badalkumbura (up to 2300mm of rainfall per year), the rainfall distribution perceived by farmers is different (Figure 5). The dry period of May to Mid-September is more intense than in Badalkumbura. The rainfall can completely stop during 2 or 3 months. In Moneragala no any visible leaves diseases contamination has been observed. The defoliation period takes place at the same time than Badalkumbura, between January and March, but it lasts only 2.5 months.

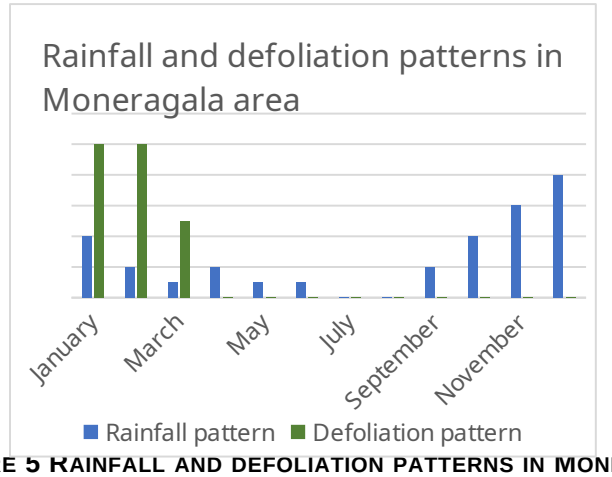


FIGURE 5 RAINFALL AND DEFOLIATION PATTERNS IN MONERAGALA AREA.

BARS HGHLIGHT THE PEAK SEASONS DESCRIBED THROUGH FARMER INTERVIEWS.

Unlike the Badalkumbura region, farmers in Moneragala were able to benefit from training from RRISL and RRD in good "rubber farming practices" before entering the production stage. As a result, the quality of the tapping is higher, and the plots are better maintained. The spacing between rubber rows is following the current recommendations: 2.5x7 m. The land topography is less slopy than Badalkumbura area that allows the use of tractors in the field. The government is still able to supply rubber fertilizer for plantations in the immature stage (i.e., under 6 years old). One of the most common intercrops in Moneragala is sugar cane. Fertilizers and herbicides are provided by the sugar cane factory. Farmers used to apply sugar cane fertilizer on young rubber plants to boost growth.

3.1.3 Ampara: a real new area with rubber still in immature period

The global market environment is different, closed and limited. Maize, sugarcane and paddy are the unique crops marketable. The main intercrop implemented by farmers is sugar cane. Rubber was recently introduced by RDD and it represents an opening gate to increase farmers' income. As a pioneering area for rubber cultivation in Sri Lanka, there is no plantations in production yet. Ampara climatic conditions are less suitable for rubber particularly due to episodes of intense drought and years of sugar cane production that have weakened the soil. The drought condition in Ampara is an important issue for the young rubber plant development. Indeed, rubber mortality can be really important (Figure 6: Rainfall pattern in Ampara).

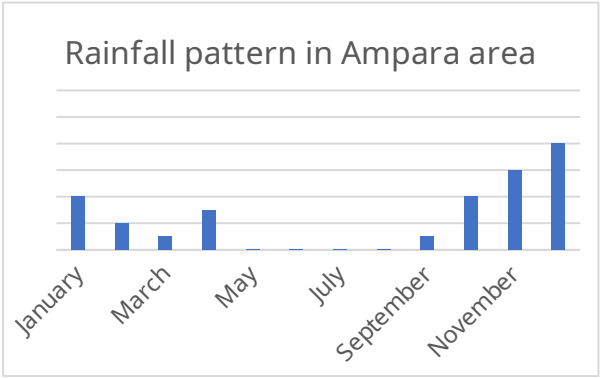


FIGURE 6- RAINFALL PATTERN IN AMPARA AREA

Through the “societies” (a type of cooperative), farmers had access to knowledge on rubber farming practices. They also received planting materials to involve their intercrop system from international development project as the STaRR Project. Farmers respect current spacing recommendations: 2.5x7 m. Due to the dry condition and elephant attacks, the plant growing development is very heterogenous (table 4).

The table 4 down below is summarizing the areas’ differences:

	Badalkumbura	Moneragala	Ampara
Former cultivations	Sugarcane and timber (teak)	Sugarcane and paddy on lowland	Sugarcane, paddy field and corn
Rainfall pattern (mm/y)	2000-2200	1500-2000	1000-1500
Defoliation pattern	6 months	1,5 - 2 months	--
Societies involvement	Low	Medium	High
Tapping rubber trainning	High	Medium	Low
Rubber spacing (m)	3,5x5	2,5x7	2,5x7
Plantation age (y)	20 to 30	10 to 15	< 5
Rubber fertilizers access	Low	Medium	High
Watter vailability	High	Medium	Low

TABLE 3 - SUMMARY OF THE HETEROGENITY OF STUDY AREAS

3.2 Rubber productivity

Rubber yields has been detailed in table 6. The average yield in Badalkulbura is a little bit higher than in Moneragala when the average gross product is higher in Moneragala. Farmers have two possibilities to sell rubber: liquid latex or RSS (Rubber Smoked Sheet). In Badalkumbura, farmers are selling liquid latex and cuplump (coagulated latex at 45 %) when in Moneragala, they sell mainly liquid latex.

Yield description in kg/ha/y		
	Badalkulbura	**Moneragala**
Min	700	405
Max	1 400	1 367
Median	1 120	1 125
Mean	**1 077**	**1 027**
Standard variation	187	315
Variation coefficient	0,17	0,31
Production gross product in LKR	809 526	1 071 132

Table 4 - Rubber yield description

3.3 Current existing intercrop systems description

3.3.1. Mature plantations

The rubber plantation is considered as mature when the rubber tree start to be tapped. At the mature stage, the canopy is very dense, and the shade range can be between 60 to 70%. This percentage of shadow is limiting the crop association possibilities. Four crops were observed to be used as intercrop with rubber on mature stage. All the characteristics has been resumed on the following table (Figure 5: Mature rubber intercrop systems description):

Mature rubber intercrop systems description			
Crops		**Badalkumbura**	**Moneragala**
Cocoa	plots number	10	11
	yield (kg/ha/y)	36	34
	average age	10-15 y	5-10 y
	unit price LKR/kg	360	
Pepper	plots number	5	1
	yield (kg/ha/y) fresh pepper	not producing anymore*	not producing anymore*
	average age	8 y	6 y
	unit price LKR/kg	800 – 1200	
Timber *Alstonia macrophylla*	plots number	4	0
	yield (kg/ha/y)	long term investment**	
	average age		
	unit price	Contractual	
Areca nut *Areca catechu L.*	plots number	4	2
	yield (nut/ha/y)	16250	Still not producing
	average age	10 y	2 y
	unit price LKR/nut	5	

TABLE 5 - MATURE RUBBER INTERCROP SYSTEMS DESCRIPTION

According to the farmers experience, the pepper variety established in Badalkumbura and Moneragala is no more adapted with the changing climate conditions and wetter conditions. The current pepper variety is more adapted for dried areas (for example Ampara).

Timber species are a long-term investment. For some timber species, farmers could havest it 10 to 15 years after planting. Because of the decreasing profitability of pepper and cocoa cultivation, timber (*Alstonia macrophylla)* is becoming an interesting opportunity in Badalkumbura however it has not been yet harvested.

Cocoa is not economically interesting however they are the most widely planted crops in Moneragala and Badalkumbura areas. Cocoa is not producing due to excess of shading. Others external factors are impacting the cocoa productivity: the wildlife attacks, the poor pruning and inter-row management and the variety. All these factors gathered don't all a satisfying income source for farmers. In Badalkumbura, the cocoa cultivation is gradually abandoned. Cocoa should be used only in double spacing systems with large spacing (between 18 and 25 m).

Most of the areca nut intercropping systems are associated with another intercrop. Traditionally, farmers are growing areca nut trees as a fence around the rubber land or inside water stream. One of the farmers has tested an intercrop system with one row of areca nut trees under the rubber canopy. According to his experience, the tree is producing less nuts compare to under the sun but the high number of tree balance the efficiency loss. To resume, a system with areca nut crop can be interesting inside the plot or as a natural fence around the plot.

3.3.2. Immature plantations

Cropping systems diversity has been detailed for the first four year of rubber cultivation. The logic of the succession of the crops are presented for the three zones.

Moneragala. Most of the farmers are not in immature stage anymore. Half of the farmers intend to diversify their production to diversify their source of income. Because of the strong sugarcane implementation, farmers are familiar with this production and produce massively for a local private company. On the one hand, despite the financial constraints of the contract, farmers prefer to maintain their links with the company in particular for the agronomic services it offers: land preparation and fertilizers access. On another hand, because of the sugarcane company constraints, some farmers turn to banana cultivation or seasonal crops intercropping systems. The study shown that the farmers' preferences is limited by groundnut, corn and cowpea. The succession crops groups have been described in the following figure 7.

Succession crops groups	Plot distribution	Possible seasonal crops	1st year	2nd year	3rd year	4th year
Sugar cane SC	6					
Seasonal crops + banana SB	5	corn, groundnut, cowpea				
Seasonal crops S	2	corn or groundnut				

FIGURE 7 - CROPS SUCCESSION IN MONERAGALA

Ampara. In Ampara, the intercropping system strategies are completely different (Figure 8). Even if the market opportunities are rather limited, most farmers are doubling their efforts to improve their income. Traditionally, the corn cultivation is well implemented in Ampara and farmers usually use this crop as intercropping.

Succession crops groups	Plot distribution	1st year	2nd year	3rd year	4th year
Group A	6				
Group A2	4				
Group B	5				
Group C	2				
Group D	7				
Group E	6				
Group F	4				

Legend	
	Cycle of corn
	Banana cultivation
	Shorten crop cycle
	Semi perennial cultivations
	Sugar cane cultivation
	Purple gradient: succession of different shorten crops

FIGURE 8 : CROP SUCCESSION IN AMPARA

All farmers are cultivating seasonal crops in the interrow during the wet season (Yala season) between October and December. Sometimes, depending on the rainfall pattern, farmers are able to add a second cultivation cycle on the same plot (Group A2). After two years, rubber becomes higher and the canopy shade does not allow annual crops anymore. Under such constraints, some farmers try to be innovative with pineapple, cinnamon, passion fruit or pepper trials (Group B). Also, given the lack of water availability and the high number of young rubber plants mortality, farmers experience show that sugarcane cultivation could be a sustainable solution (despite potential water/resource competition in marginal area). Indeed, from farmer perspective, the shade produced by the sugarcane stems seem to be favorable for the rubber plant development (Group C). However, the sugarcane is not cultivated by the majority of the farmers in the region. Farmers prefer to stay auto entrepreneurs rather than

3.4. Economic performances

3.4.1. Descriptive analysis of economic performance diversity

To understand the economic performance of intercropping successions, we used the gross margin per hectare indicator. For each intercrop activities, a list of operational costs (inputs and labor costs) has been detailed, associated with the gross product. The gross margin per hectare (GM/ha) has then been calculated (GM/ha = value for the production (gross product) – operational costs). For Ampara and Moneragala, the gross margin has been calculated thanks to the median and quartiles. As a result, we can categorize each intercrop plot within a level of economic performance (Table 7).

	Low performance LP	**Low medium performance LMP**	**High medium performance HMP**	**High performance HP**
GM/ha in LKR	< 64 643	]64 643; 260 000]	] 260 000; 697 625]	> 697 625
Variation coefficient	2	0.37	0.3	0.43

Statistical description	
	GM/ha in LKR
Median	260 000
Average	403 524
Standard variation	534 059
Quartile 1	64 643
Quartile 3	697 625
Variation coefficient	1,32

TABLE 6 - GROSS MARGIN PER HECTARE STATISTICAL DESCRIPTION

Table 7 shows that the average GM is 403 500 LKR/ha. The variation coefficient (1.32) shows that it is existing a high economic performance variability.
This gross margin/ha is highly correlated with the return to labor of family labor. The family workforce can have a bigger impact than input application or labor employment.

3.4.2. External factors affecting the economic performance

In order to better explain the economic performance variability, a chi² test has been carried out to correlate the gross margin hectare with different external factors. The table below shows the chi² results:

P-value	Water availability	Wildlife attack	Land topography	Province	Surface	Distance
GM/ha	0,7325	0,4899	0,2848	0,6531	0,9398	0,8142

TABLE 7 - EXTERNAL FACTORS INFLUENCING THE ECONOMIC PERFORMANCE (CHI²)

None of the external factors are significantly influencing the gross margin per hectare.
Only the return to labor (for family workforce) could have an impact on economic efficiency of intercrop systems during immature period (except sugarcane).

3.4.3. Intensification ratio

There are no criteria to identify which crop succession is the most suitable for farmers. The intensification ratio /IR is an economic indicator used to define the risk taken by farmers for one particular activity. IR is calculated by dividing the total input costs (except labor cost) with the value production of the crop activity. Generally, when IR is below 30 %: there is no risk for farmers, up to 50 %: it is a limited risk, above 50 %: it is risky. This indicator shows that if inputs prices do increase significantly, it will be a serious impact on GM. We grouped up the plot data according to their succession crop (Figure 7 & 8). After processing, we obtained the table below:

Succession crops group in Ampara	Intensification ratio	Gross margin per hectare
A	53%	573 682
A2	12%	807 409
B	19%	745 954
C	47%	455 818
D	17%	249 950
E	34%	228 573
F	24%	63 819

TABLE 8 - INTENSIFICATION RATIO DISTRIBUTION

Succession crops group in Moneragala	Intensification ratio	Gross margin per hectare
SB	14%	339 948
S	29%	292 288
SC	37%	362 958

Ampara. In Ampara area, it seems that the crop succession with banana in the third year (Group A) is the most risky compared to others. Indeed, A banana crop needs an investment period with no any income from this crop for minimum one year. Also, banana cultivation needs a high-level pesticides application.
The crop succession with double cycle (group A2) represents a high source of income and the smallest intensification ratio (low risk). On the same land, farmers are growing two different seasonal crops in distinctive year period. The first one is generally a corn crop during the wet season from October to December, the second one can be groundnut, cowpea or finger millet cultivation during “Maha season” (January to April). The sugarcane is not so risky but not profitable as well. In Ampara area, they concentrate their effort on corn cultivation and on self-consumption.
In Moneragala, the most economically efficient crop is the sugarcane cultivation (Group SC). However, this crop represents a higher risk for farmers compared to the succession crop group with banana (SB).

4. Identify typologies to adapt recommendations to farmers’ types

4.1 Structural typology

We propose a structural farm typology based on the type of rubber agroforestry patterns in order to create farmers' profile with the same economic structure and similar production systems. The structural typology is based on two discrimination factors: i) the part of the rubber gross margin on total farm income and ii) the area as the 3 zones have significantly different soil/climate conditions (Figure 13) For the first discriminating criterion, the rubber crop is considered as main farm activity (Type1) when the part of the rubber gross margin is superior to 50%. When the farmer has only one farm activity (the rubber) but still not in production (source of income only from intercrops), is counted as a type 2 farm system. Finally, for farmers who are doing several other farm activities as paddy, pepper, timber and are more important than rubber, they are considered as a type 3 (off-farm activities are not taken into account at that level). For the second discriminating criterion, the three study zones were taken into account. Indeed, for each of the types, differentiation by zone homogeneously discriminates between farmers' farming systems. For type 2 (The rubber is the main farm activity but still in immature stage), only the Moneragala and Ampara zones are represented because there are no immature systems in Badalkumbura.

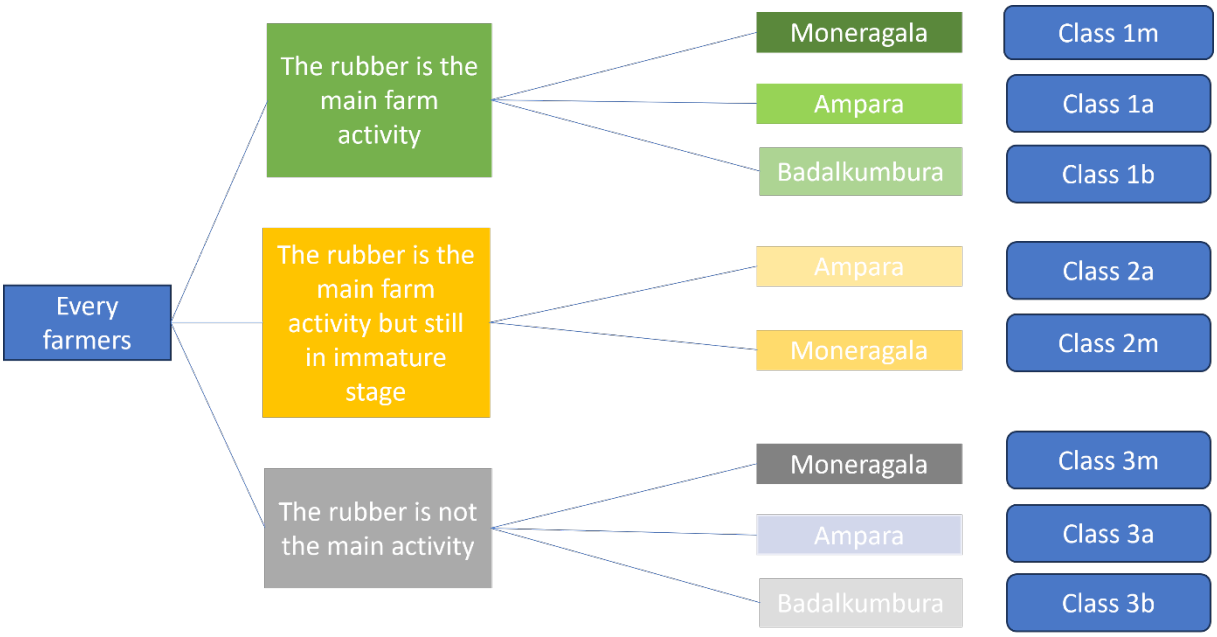


FIGURE 1 - THE STRUCTURAL TYPOLOGY

4.2 Behavioural typology

A second type of typology has been developed to characterize the behavior of farmers from each type according to their own strategy. This typology is called a behavioral typology. LOAM, the GNO implementing training in the project area need to categorize each type of farmers facilitate adapted trainings. Three different farmers' behaviors have been identified according to reliable classical typology:

A) Innovative farmers. Innovative farmers are the group of farmers who has a high interest in diversifying activities. Most of the time, they already put in place some trials and they don't really take in account the RRISL recommendations. Also, they are at the origin of farmers initiatives like societies or collecting shops. Most of them have a second main crop or activity. For example, in Ampara, farmers are mainly counting on paddy field cultivation as a first income source (Structural typology - Type 3).

B) Followers' farmers. This farmers' profile does not have the same financial flexibility than farmers from innovative group. Indeed, farmers are doing intercropping because they financially need it. They don't have any extra income and they are expecting a lot from rubber cultivation (Structural typology – type 2). Most of the time, they don't like to take risks, they turn to classical intercropping systems with banana or annual crops.

C) Risk-free farmers. This category of farmer doesn't have any crops in association with rubber and remain prudent waiting for more people to develop a robust and largely recognized intercropping system.

Farmers' groups selection for trainings

It is clearly not possible to train farmers at the same scale on the same agroforestry patterns because of climatic, economic and social differences. Through the behavioral typology, we observed that farmers clearly don't have the same motivation to innovate. The idea is to use the structural and behavioral typology to identify the best bet cropping patterns according to farmer's profile.

The study reveals some behavioral generalities:

1 Farmers from **Type 1/rubber is the main activity**: the most sustainable strategy is to convince him to develop other associated crop to ensure various source of incomes to overcome rubber price volatility at the condition the crop is effectively producing. The counter example is cocoa, provided freely by the government but with a production close to zero due to excess of shadow. The result is that most farmers abandoned cocoa. They have not the curiosity to switch on a new intercrop plantation because the income from rubber seems sufficient. They would be interested in shorten cycle extensive crops with no risk.

2 Farmers from **Type 2/rubber is the main activity but still in immature stage**: farmers don't feel confident to invest in another crop except rubber as there are already in debt for the rubber plot. Nevertheless, the debt is largely covered by the farmer's off-farm activities. This extra remaining income cover family expenses, as well as various farming activities, off-farm activities as well as for improving livelihood. If the off-farm income source is largely sufficient, farmers might spend money on bigger crops investment.

3 Farmers from **Type 3/rubber is not the main activity:** These farmers are the perfect match for innovative cropping models. They generally have a capital

from a previous agricultural investment (timber for instance). These farmers have sufficient funds to take risks and try innovative systems.

The RIVER project could pay attention to mix farmers from innovative group with other to stimulate the improvement land and practices desire and trigger a cascade reaction. At the beginning, it advised to mix farmers from innovative group and followers to create a knowledge sharing environment.

5 Technical recommendations

5.1 Agronomic models in single spacing

Three models are presented corresponding to the climate constraints for each area. These models are innovative and have already been tried out by a minority of farmers in Sri Lanka. In the field, these trials have shown that the models can be economically efficient, as long as they are well managed and a varietal selection adapted to the climatic constraints. the models are made up of flexible examples depending on the weather and market opportunities. The idea is to develop the logic of model's construction. Models have to be adapted in function of the water availability and ecological constraints **to avoid the "one size fits all" model**. Also, all the models are designed according to the existing and RRISL's recommendations (except RAS patterns with timber), so they can be largely spread.

5.2 Agronomic model in Badalkumbura area

The Badalkumbura models' proposal is presented on the figure down below:

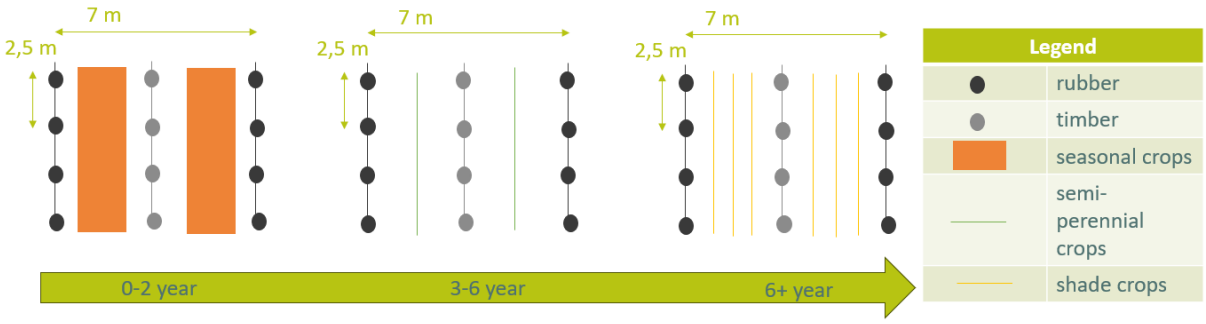


FIGURE 2 - INTERCROP MODEL IN BADALKUMBURA

Immature period. The farmers proposal during the immature period is to involve firstly 2 years of seasonal crops between rubber rows. Indeed, in Badalkumbura area, farmers are not interested in crops for self-consumption. The idea is to give farmers the opportunity to develop high-value annual crops over one or two cycles during this period. According to the focus group discussion, it seems that the cowpea or sesame have a high market value and several collecting shops for selling.

After 2 years, the canopy shadow is too dark for annual crops. We proposed to implement a semi perennial crop in double row between timber and rubber rows for 2 or 3 years maximum, knowing the fact that production in year 4 and 5 would be very low due to rubber canopy closure. Crops such as bananas and pineapples are already widely cultivated in Badalkumbura. Some farmers keep banana plants until

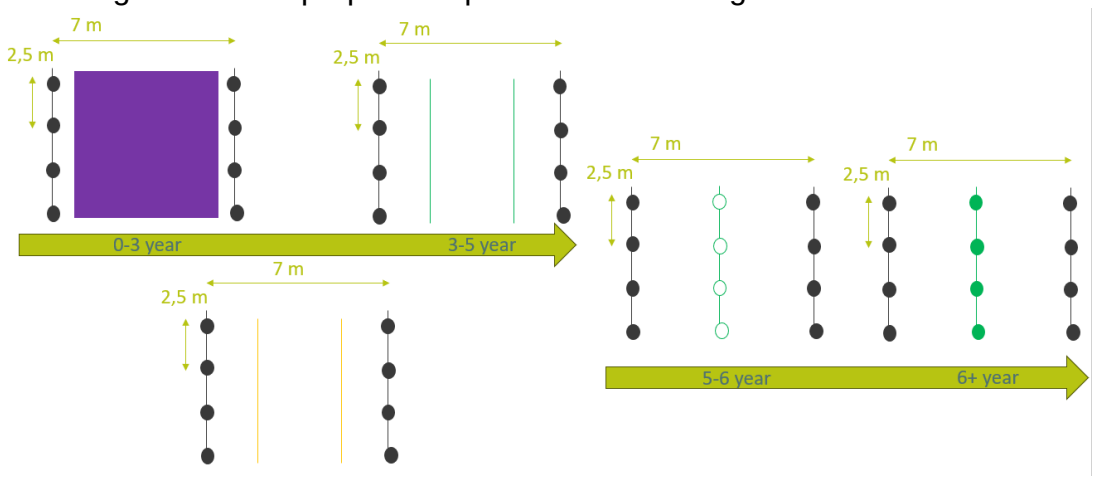
the 6th year, while others manage to keep pineapple plants until the rubber production period. The banana as pineapple cultivations is easy to maintain and some high value varieties can be simply sold in Badalkumbura.
After 6 years, according to the farmer's desire, it is possible to plant *Cendrella asiatica* or cardamom (3 rows maximum) between timber and rubber rows. They are shade-lovely plants very adapted to the shadow conditions under timber and rubber trees.

Mature period. According to the farmers' experience, *Alstonia machaphylla* could be a suitable crop with good opportunities market however we didn't have a look to the timber value chain and the price system (information based on key informants talks). The planting material nurseries can be developed thanks to the seedling technic at low cost. However, the land preparation (digging hole, plant trees, watering) remains high; Timber species are easy to maintain and can provide high income after 15 to 20 years of production. Research plots with timber are not very common at the RRISL, although there are a few recommendations. The fear is that the timber canopy will compete with the growth of the rubber tree during their growth.

Focus on areca nut trees. Areca nut trees are well established in particular in Badalkumbura and Moneragala area. In addition to a small investment cost, areca nut is providing an extra high source of income for farmers. Traditionally, areca nut trees are planted around the rubber plot as a fence but also on water stream. For every model's proposal, it advises to diversify farmers systems with areca nut plantation according to farmers' willingness.

5.3 Agronomic models in Moneragala area

The Moneragala models' proposal is presented on the figure down below:



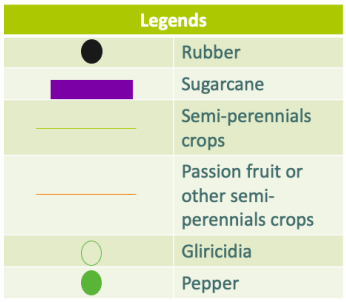


FIGURE 3 - INTERCROPPING MODELS IN MONERAGALA

Immature period. At the immature stage, we can propose two potentials models. As we saw, farmers from Moneragala have an attract for cash crop plantations. Also, the majority of farmers have sugarcane as intercrop in their rubber plantation. So, the first immature models' proposal takes in account farmers' agricultural practices in keeping the sugarcane within the first three years. Indeed, even if sugarcane has a great power protection for young rubber plant in dried period, the sugarcane cultivation pump too much nutrient from the soil and reduce the land fertility within the years. Furthermore, sugarcane compagnies are taking lot of benefits from farmers' yield, in long term, maintain sugarcane will not being a profitable crop selection.
The second choice is the most innovative model. Indeed, some farmers are doing some trials with passion fruit crop during the immature period with rubber. Despite the few collecting center in the city, it is existing a better place to sell passion fruit production in Bathula area in 20 km far from Moneragala. The passion fruit plant is producing only for 4 years. After that point, is better to directly switch on gliricidia and pepper cultivation. Nevertheless, passion fruit can be replaced by or any pluri-annual similar crops such as banana or pineapple.
Mature period. In mature period, the existing intercropping system with cocoa are not performant. Some systems with pepper are already existing but the variety is not anymore adapted. Indeed, the variety currently recommended in Badalkumbura and Moneragala is a variety specific for dry area. However, the global warming is increasing the rain and wet period in these areas. Pepper cultivation remains recommended but with an adapted variety (confirmed by Sri Lankan researchers during the RRISL's restitution).

5.4 Agronomic model in Ampara

Farmers organizations in Ampara are doing their best to profit from some market opportunities, thanks to the StarR project's planting materials supply.

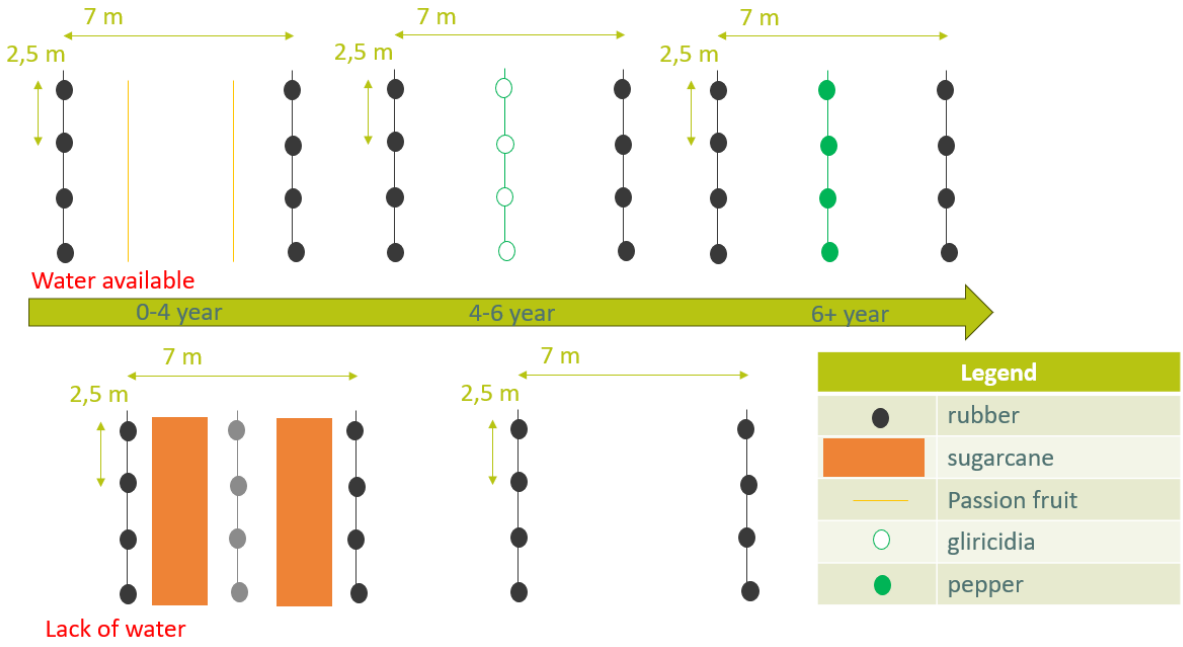


FIGURE 4 - INTERCROPPING MODELS IN AMPARA

Immature period. For the immature period, passion fruit seems to be a good associated crop.

However, the biggest constraint in Ampara is the water availability on rubber plot. Indeed, the first two years in Ampara would be are very critical as we observe already that the majority of young rubber plant are dying for that period due to drought and possible competition with intercropping. According to the climate pattern, the water availability for irrigation and local market opportunities, it seems more comfortable and less risky for farmers grow only one annual crop cycle during the wet season. However, in Ampara, the most economically efficient system is a double cycle of annual crops within one year with the second crop adapted to drought (short cycle). Farmers are perfectly capable of adapting and making the best choices for their farms. The shorter the crop cycle of the intercropping plant, the more flexible the farmer can be with regard to rainfall.
Some field observations have also shown that sugar cane can have a beneficial effect on young rubber seedlings. This is why it could be interesting to study and monitor rubber cultivation models in association with sugarcane. After 3 years of sugar cane, it would be ideal to leave the land to rest in order to limit any competition for resources.

Mature period. RAS are based on pepper with Gliricidia and cinnamon with large double-spacing systems. In Cambodia, after a GPSNR session on agroforestry in September 2022, the group of researchers and farmers introduce the rule of optimize planting density between rubber and associated trees with a limitation to 550 trees/ha. In that case, only double-spacing patterns with large inter-rows are possible and better adapted to water competition.
Demo-plots with various systems chosen by farmers in a participatory process would be very effective. The objective is to reduce risk and increase the domain of recommendations, in particular to suggest potential alternative to sugar cane with fruit trees, cinnamon, pepper, and other crops depending on markets. Sugar cane

currently being developed on contractual agriculture, most farmers do prefer to maintain full control on their cropping systems.

Conclusion

The survey implemented in 2023 displays a real interest from local farmers for rubber agroforestry patterns adapted to local climatic conditions, supported by local or export markets. The objective is to provide an agricultural income during immature rubber period and diversify income during mature period depending on farmers types. Two typologies have been identified: a structural typology and a behavioral typology (based on behavior regarding innovation process) that could be used by the RIVER project to identify the right agroforestry pattern for the right farmer at the right place. The objective is to provide more operational and adapted agroforestry patterns to local farmers.

Current intercropping practices with banana, chili, maize, cowpea and sugarcane seems to be adapted. We observed a real climatic difference between the 3 areas with gradient of longer dry season from West to East. Agroforestry patterns need to take into account that serious climatic constraint that probably will getting worse in the next 20 years.

Concerning associated crops during mature period, coca was originally promoted with normal planting density. This is a complete failure as cocoa do not produce with 70/80 % of shadow in such situation. The main question is to suggest to farmers new crops, more adapted to shadow with normal planting density (timber for instance, pepper…) or using a double-spacing system with large inter-rows, for cocoa, cinnamon, timber or even annual crops such as maize. These double-spacing systems are quite new for local farmers and have never been promoted by local research or development institutions, however RRISL made in the past some interesting small-scale trials.

There is a real challenge for the RIVER project, in collaboration with RDD and RRISL and local private actors to release technical recommendations adapted to climatic and specific market conditions in order to propose best-bet and reliable alternatives to farmers.

Bibliography

Chandrasiri, R.S.S., Gunarathna, N.P. a. S., 2022. Socio-economic Context of Rubber Growing in Non-traditional Rubber Cultivating Areas. Sri Lankan Journal of Agriculture and Ecosystems 4, 96–111. https://doi.org/10.4038/sljae.v4i1.50

Douangsavanh L, Thammavong B, Noble A .2008. Meeting regional and global demands for rubber: a key to poverty alleviation in Lao PDR? The Sustainable Mekong Research Network (Sumernet). Pathumwan, Bangkok 10330, Thailand. https://lad.nafri.org.la/fulltext/2023-0. pdf.

Gunnarathne P. K. K. S.. TMSPK Tennakoon Jagath. C. Edirisinghe. KGJP Mahindapala. 2020. The present status and role of the Thurusaviya Rubber Societies in the smallholder rubber sector in Moneragala District: Extension Officers' perception. Journal of the Rubber Research Institute of Sri Lanka, vol. 100, no 0: p. 55. Consulting [2022/06/29]. URL : https://doi.org/10.4038/jrrisl.v100i0.1899

Imbulana, K.A.U.S., N.T.S. Wijesekara., B.R. Neupane .2006. Sri Lanka Water Development Report 2010. UNESCO and Ministry of Irrigation and Water Resources Mangement, Colombo, Sri Lanka

I. Y. Huang. K. James. N. Thamthanakoon P. Pinitjitsamut N. Rattanamanee. M. Pinitjitsamut. S. Yamklin. J. Lowenberg-Deboer. 2022. Economic outcomes of rubber-based agroforestry systems: a systematic review and narrative synthesis. Consulting [2022/06/29].

Jessy MD, Joseph P, George S .2017. Possibilities of diverse rubber-based agroforestry systems for smallholdings in India. Agrofor Syst 91:515. https://doi.org/10.1007/ s10457-016-9953-8

J. K. S. Sankalpa. Wasana Wijesuriya. P. G. N. Ishani. 2020. Do rubber-based agroforestry practices build resilience upon poverty incidence? A case study from Moneragala district in Sri Lanka. Consulting [2022/06/25].

Karunaratne, S., Gunathilake, J., Wijesuriya, W., Herath, K., Samarappuli, L., 2011. Land suitability model for rubber in Moneragala district: first approximation using GIS. Journal of the Rubber Research Institute of Sri Lanka 91, 49–60. https://doi.org/10.4038/jrrisl.v91i0.1852

Ministry of Mahaweli Development and Environment. 2016. National Adaptation Plan for the climate change in Sri Lanka. Consulting [2022/04/20]. URL : https://www4.unfccc.int/sites/NAPC/Documents%20NAP/National%20Reports/National%20Adaptation%20Plan%20of%20Sri%20Lanka.pdf

Munasinghe ES, Rodrigo VHL, Gunawardena U .2014. Modus operandi in assessing biomass and carbon in rubber plantations under varying climatic conditions. Exp J Agric 50(1):40–58. https://doi.org/10.1017/S0014479713000410

Penot E., 2010. Basic economic calculations. Annex 2. Cirad, GSDM, 28 p

Premalal, K.H.M.S. 2009. Weather and climate trends, climate controls and risks in Sri Lanka. Presentation made at the Sri Lanka Monsoon Forum, April 2009. Department of Meteorology, Sri Lanka.

Punyawardena, B.V.R., S. Mehmood, A.K., Hettiarachchi, M, Iqbal, S.H.S.A Silva, and A. Goheer. 2013. Future Climate of Sri Lanka: An approach through dynamic downscaling of ECHAM4 General Circulation Model (GCM). Tropical Agriculturist 161: 35-50

Ratnayake, U. and Herath, G. 2005. Changes in Water Cycle: Effect on Natural Disasters and Ecosystems. In S. Wijesekara, K.A.U.S. Imbulana, B. Neupane (eds.), Proceedings of the Preparatory Workshop on Sri Lanka National Water Development Report, World Water Assessment Programme, Paris, France: 192-205.

Rodrigo, V.H.L., Stirling, C.M., Naranpanawa, R.M.A.K.B., Herath, P.H.M.U., 2001. Intercropping of immature rubber in Sri Lanka: present status and financial analysis of intercrops planted at three densities of banana. Agroforestry Systems 51, 35–48. https://doi.org/10.1023/A:1006449230436

Rodrigo, V.H.L., Iqbal, S.M.M., Dharmakeerthi, R.S., 2011. Potential for rubber (Hevea brasiliensis Muell. Arg.) cultivation in the Eastern Province of Sri Lanka. Journal of the National Science Foundation of Sri Lanka 39, 403–411. https://doi.org/10.4038/jnsfsr.v39i4.3888

RRISL. 2020. Annual Report. Consulting [2022/04/20]. URL : http://www.rrisl.gov.lk/content/files/annualReports/Annual%20Report%202020%20- %20English.pdf

RRISL. 2018. Annual Report. Consulting [2022/04/20]. URL : http://www.rrisl.gov.lk/content/files/annualReports/Annual%20Report%202018%20English_%20Final.pdf

RRISL. 2021. Hand book Volume 1 Agronomy. Consulting [2023/03/02]. URL : https://drive.google.com/file/d/1MCSfZmuKPmAKSTkqzCNCqbhajUrXSV2T/view?usp=sharing

RRISL. 2021. Handbook Volume 2 Processing Technology. Consulting [2023/03/02]. URL :http://www.rrisl.gov.lk/content/files/downDoc/Hand%20Book-Volume%202-Technology.pdf

Samarappuli, L., Wijesuriya, W., Dissanayake, D., Karunaratne, S., Herath, H., 2014. Land suitability for sustainable rubber cultivation in Moneragala district. Journal of Environmental Professionals Sri Lanka 3, 48–61. https://doi.org/10.4038/jepsl.v3i1.7313

T. Jansz, K. Li, J. Belgrave, I. Urkina. 2022. The food crisis in Sri Lanka is likely to worsen due to low agricultural production, soaring prices and the current economic crisis, warn the FAO and WFP. Consulting [2023/03/02]. URL: https://www.wfp.org/news/food-crisis-sri-lanka-likely-worsen-amid-poor-agricultural-production-price-spikes-and-ongoing

Viswanathan PK, Shivakoti GP .2008. Adoption of rubber-integrated farm-livelihood systems: contrasting empirical evidence from the Indian context. J For Res 13:1–14

Workman D. 2022. Sri Lanka's Top 10 Exports. World's Top Exports. Consulting [2022/06/01]. URL : https://www.worldstopexports.com/sri-lankas-top-10-exports/

WorldAtlas. 2017. The World's Main Natural Rubber Producing Countries. . Consulting [2023/03/13] URL: https://www.worldatlas.com/articles/the-leading-natural-rubber-producing-countries-in-the-world.html

YAPI Expertise. 2022. Study on intercropping in rubber cultivation in the Moneragala and Ampara regions of Sri Lanka.p31. Consulting [2023/03/13]

Yasarathna S.E., Jayatilake A., Senevirathne C. 1993. An environmental profile of the Moneragala District. Central environmental authority. Consulting [2022/04/20]. URL : https://core.ac.uk/download/pdf/52178704.pdf

Annex 1: Table 9 - RRISL's intercrops recommendations

Crop suitable for different growth stages of rubber			
Crop type	Variety	Caracteristics	Spacing
Only during the immature phase of rubber			
Banana *Musa x paradisiaca L.*	Embul	commonly variety but low local price market	two or three rows between rubber
	Kolikuttu	dried climate and quality superior	
	Anamalu/Ambum	wetter areas	
	Alukehel	dried climate	
Pineapple *Ananas comosus (L.)*	Maurities	very popular in local market	Two paired rows between rubber
	Kew	used specially for canning	
Passion fruit *Passiflora edulis Silms*	Traditionnal yellow	for wet and dry area	one or two rows between rubber
	Mani	Wetter areas	
Sugar cane *Saccharum officinarum L.*		dried areas and Moneragala	four to five rows between rubber
Seasonal crops			
Plants	Propagation		Shade requierement
Aerva lanata (Polpala)	by seeds (soaking seeds overnight in water)		Full sunlight
Solanum virginianum (Katuwelbatu)	by seeds (soaking seeds overnight in water)		Full sunlight
Piper longum (Thippili)	By stem cuttings		Medium shade
Indigofera tinctoria (Nilavariya)	by seeds (soaking seeds overnight in water)		Low shade
Plumbago indica (Ratnitul)	By stem cuttings		Low shade
Only during the mature phase of rubber			
Crop type	**Variety**	**Caracteristics**	**Spacing**
Cardamom *Elettaria cardamomum (L.)*	EC1/100	low altitude and wetter areas	two to three rows between rubber
	EC1/101		
	EC1/102		
	EC2/400MT		
Vanilla *Vanilla planifolia*		soil well drained and rich in organic matter	
Rattan	Maweval	rubber canopy suitable with	Single row between

Calamus deerratus		rattan	rubber
Throughout the life cycle of rubber			
Coffee	*Coffea arabica*	high altitude and cooler climate	Single row between rubber
	Coffea canephora	low altitude, warm and humid conditions	
	Coffea liberica	warm and wet conditions and soil types of tolerance	
Cocoa *Theobroma cacao L.*	Criollo	good quality but low êst resistance	Single row between rubber
	Forastero	Productive and resistant	
	Trinitario	Intermediate characteristic	
Anthurium *Anthurium andreanum*	Tropical red	Performance under rubber	Eight rows between rubber
Tea *Camellia sinensis*		Wetter areas	7 rows between rubber in double spacing (12 m)
Cinnamon *Cinamomum verum*		stable market, skilled labour needed	7 rows between rubber in double spacing (12 m)
Pepper *Piper nigrum L.*			3 to 5 rows between rubber