



Rubber Management Systems: A Progression from Extractive to Regenerative Production

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Abstract: Introduction: Demand for natural rubber is driving an increase in acreage under production and tonnage of rubber produced. Conventionally managed rubber monocultures have presented multiple ecological, economic, and social risks, and alternative rubber management systems must be explored. The paper outlines a gradient of rubber management systems in the provinces of Phatthalung and Songkhla in Thailand. The field observations and exchanges considering the diversity of practices of various rubber farmers were conducted from October 2020-February 2022. Rubber management systems along a gradient ranging from degenerative to regenerative, suggesting each's key principles, characteristics, and benefits were synthesized to the results. Six rubber management systems were found: monocultural, organic, simple polyculture, complex polyculture, modern jungle, and traditional jungle. Outcomes of rubber production systems include ecological health, economic stability, social well-being, farmer knowledge, and increased relationship with nature based on the rubber regeneration production of conventional systems (monocultural) to complex agroforestry systems (Wanakaset). The continuum of regenerative practices with biological monoculture became a complex polyculture; there is a high level of natural regeneration.

Keywords: Rubber; agroforestry; wanakaset; jungle rubber; natural regeneration

1. Introduction

Demand for natural rubber is driving a continuous increase in acreage under production and tonnage of rubber produced [1]. Large-scale plantations and smallholder farmers (who account for 85% of the global output, ~90% in Thailand, Indonesia, and Malaysia) are forced to expand to keep up [2]. Demand mainly comes from the automotive industry for tires and non-tire applications [3], with footwear and industrial applications also driving demand [4]. Conventionally, rubber is managed as intensive monocultures, which presents many ecological, economic, and social risks [5]. Ecological degradation, biodiversity loss, global rubber price fluctuations, economic instability, clearing of natural forests, loss of natural capital, and erosion of farmer knowledge and relationship to the land are a few of many serious concerns that indicate an undeniable need to improve the way rubber production is managed [6, 7].



Rubber production systems have the potential to evolve from monocultures into regenerative and abundant complex agroforestry systems [8,9]. The shift aligns with broader sustainability goals to enhance environmental, social, and economic outcomes. This article provides an overview of management classes of rubber production on a continuum from degeneration to regeneration [10] based on lessons from working with rubber-producing farmers in southern Thailand. The progression of a rubber production system towards regeneration is not linear. Rather, each system evolves contextually, allowing farmers to design their system uniquely to suit their place [11]. The studies have reported agroforestry systems in Phatthalung, Songkhla, Satun, and Trang provinces, Thailand, with the kind of trees/shrubs and crops associated with rubber trees [12,13]. However, the study did not mention the regeneration of rubber production in complex agroforestry systems that influence ecological health, economic stability, social well-being, farmer knowledge, and relationship to the land. Songkhla and Phatthalung Provinces represent the study area in this issue. The paper describes systems observed in the field and communicated through the practice of various rubber farmers in Songkhla and Phatthalung and toward regeneration to complex agroforestry systems.

2. Methodology

Phatthalung and Songkhla provinces in southern Thailand were selected as the study sites. Rubber agroforestry has been studied extensively for its long history and is an area studied in many research reports. The population used snowball or chain-referral sampling, followed by rubber farmer purposive sampling, with those happy to share more in-depth information. The tool used in-depth interviews, group interviews, and farm survey tools. Sixty rubber farmers were involved in the sample size. First, we corresponded with knowledgeable key informants, such as the village leader and the staff of the Rubber Authority of Thailand (RAOT), about rubber agroforestry to advise key leaders and groups on this practice. They recommended rubber farmer agroforestry leaders in Rattaphum and Thepa districts, Songkhla province, Tamod and Srinakarin districts, and Phatthalung province, as all of these leaders had good successful models of practice and were either part of larger agroforestry rubber groups or recognized as places of learning for these systems. Second, visits were conducted with these local rubber agroforestry farmer leaders to interview them and visit their farms to learn about their systems, key intercrops, values, observed ecological regeneration, years of practices, and changes observed since shifting from monoculture. Then, they recommended other agroforestry farms from their groups/ networks for additional visits where we collected similar information. From this, a perspective was gained on different rubber agroforestry systems at various ages, their values, and their evolution. In subsequent interviews with key farmer leaders who had been involved in this movement for several years and had visited many other rubber agroforestry farms, supporting farmers to make this transition, they shared observations and learning as to the diversity of different rubber agroforestry systems, their evolution, benefits (and drawbacks if any). Third, we held joint discussion sessions in each community to share and exchange experiences involving several rubber farmers (10- 20) 60 different rubber farmers were involved in these sessions, including experienced rubber agroforestry farmers and about ten monoculture rubber farmers interested in learning about these methods (Figure 1). This whole process was conducted from project initiation in October 2020 through February 2022.

The data obtained were synthesized by identifying rubber production systems, sketching rubber production systems, summarizing conceptual characteristics of rubber production systems, evaluating from degenerative to regenerative rubber production systems, and focusing on the benefits of regenerative rubber production. This information was considered concerning academic papers related to this subject matter in public reference.



Figure 1. Visited rubber agroforestry farms, shared observations, and learning different rubber agroforestry systems

3. Results and Discussion

Six key classes of rubber production systems are identified in this report (Figure 2):

- . Monoculture
- . Organic monoculture
- . Simple polyculture
- . Complex polyculture
- . Modern jungle rubber
- . Traditional jungle rubber

The outlines several practices and options farmers have on their journey towards regeneration and associated outcomes. Traditional rubber systems, such as monoculture, have been reconstructed into biological and single polycultures. These early diversified rubber systems were developed and evolved into complex agroforestry systems.

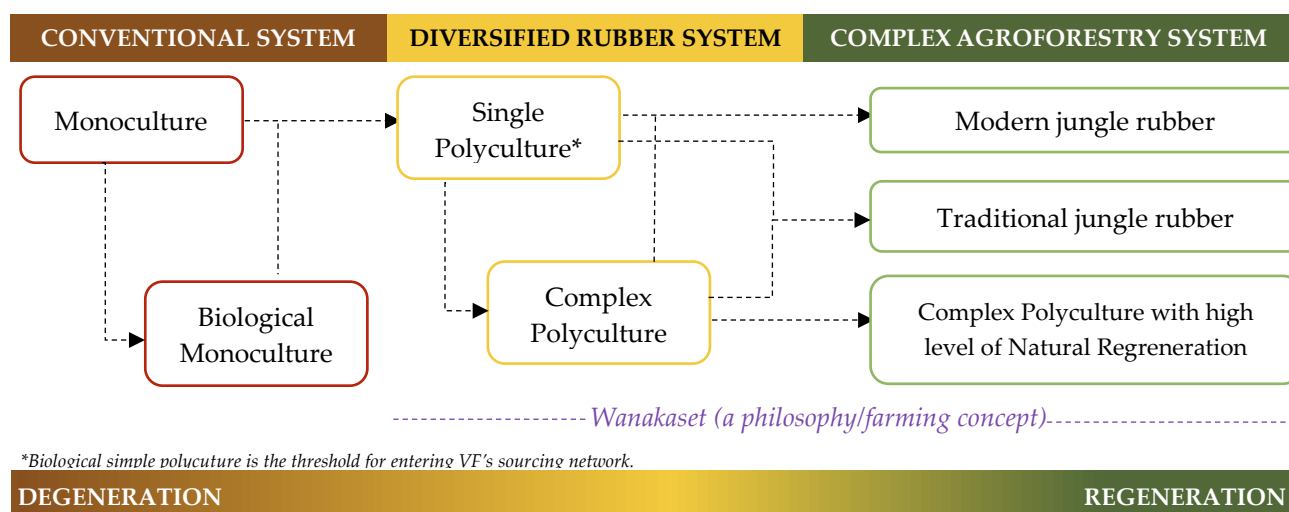


Figure 2. Evaluation from degenerative to regenerative rubber production systems

3.1 Characteristics of Rubber Production Systems

Below are brief descriptions of rubber management tiers ranging from monocultures

3.1.1 monoculture

Conventionally, rubber trees are managed as monocultures with high-yielding clonal rubber trees (Figure 3). This system requires intense management and uses synthetic inputs. Monocultures are present in

both small holdings and agro-industrial estates. Managing rubber conventionally is associated with significant ecological, economic, and social risks (Table 1).

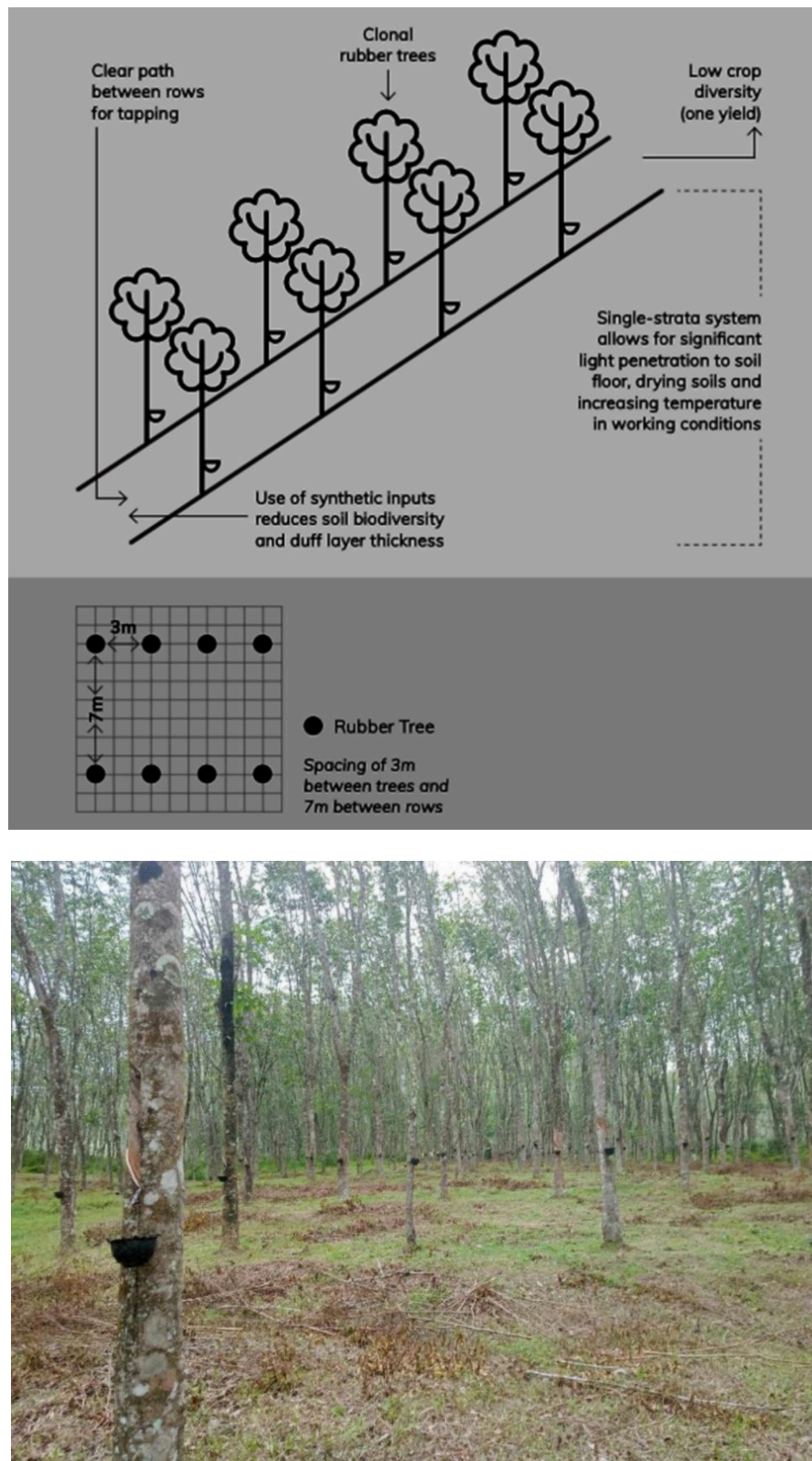


Figure 3. Monoculture rubber typology.

Table 1. Typical outcomes of monocultural rubber management systems.

Dimension	Typical outcomes
Ecological Health	. Deficient ecological health. Degraded ecosystem. . Very low biodiversity above and below ground. . There are no ground covers. No natural regrowth is allowed. . No wildlife or available habitat or fodder. . The rubber trees' low genetic diversity results in low disease resiliency.
Economic Stability	. Highly unstable. . Only one source of income is risky because global rubber prices fluctuate significantly. . Planting monocultures does not provide a yield/income for 7 years. . High input costs.
Social Well-being	. Farmers and communities are exposed to harmful chemicals - adverse health effects. . They lack a sense of culture and meaning: livelihood and economy solely for profit and export. . Farmers often feel forced into conventional production out of necessity and lack of alternatives. . Lack of agency.
Farmer Knowledge	. Farmer knowledge of land, plants, and ecosystems is mainly absent. . Lacking desire or opportunity to learn and develop knowledge.
Relationship with Nature	. Human control over the system is maximized. . Land only serves an economic purpose - farmers have no relationship to the land. . Farmers tending to monocultural, extractive plots that were only recently diversified systems, forests, or tended by a farmer's ancestors may feel emotional/psychological pain.

3.1.2 Organic Monoculture

Managing monocultures organically is an important first step away from degenerative rubber production management. In biological monocultures, synthetic inputs are reduced, phased out, and eliminated (Figure 4). Organic rubber production systems see improvements ecologically, economically, and socially (Table 2).

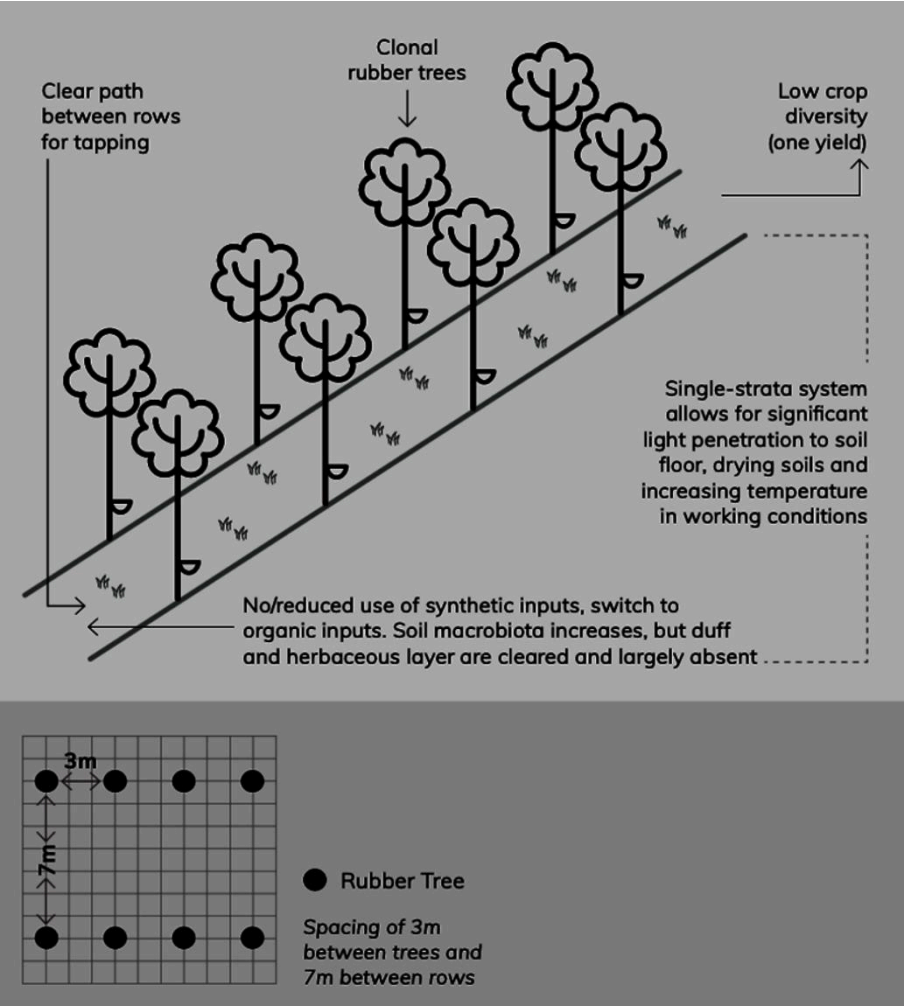


Figure 4. Organic rubber typology.

Table 2. Typical outcomes of organic rubber management systems.

Dimension	Typical outcomes
Ecological Health	. Poor ecological health. . Low but increasing biodiversity above and below ground. . Some natural regrowth may be allowed. . Minimal wildlife habitat or fodder. . The rubber trees' low genetic diversity results in low disease resiliency.
Economic Stability	. Unstable. . Only one source of income is risky because global rubber prices fluctuate significantly. . Planting monocultures does not provide a yield/income for 7 years. . Input costs can still be high.
Social Well-being	. Farmer and community exposure to chemicals decreases. . Lack of sense of culture and meaning: livelihood and economy solely for profit and export. . Lack of access to other nutritious foods. Income constraints purchase of diverse foods.
Farmer Knowledge	. Interest in doing less harm grows, but farmers likely still feel locked into conventional production. . Farmers begin to see ways in which they can work with nature.
Relationship with Nature	. High human control over the system. . Farming biologically can be the start of a deeper relationship with the land.

3.1.3 Simple Polyculture

Simple polycultures are systems that practice intercropping alongside rubber trees (Figure 5). Farmers can temporarily grow an intercrop (such as pineapple) during rubber replanting for a few years until the rubber trees mature. After this, the system is reverted to a monoculture. Alternatively, farmers can choose to intercrop permanently throughout the plantation cycle. This decision marks the starting point for evolving rubber systems towards regeneration. A farmer yields two or more food or non-food products for simple polycultures, and most natural regrowth is removed to maintain order. Ecological, economic, and social outcomes begin to see important improvements (Table 3).

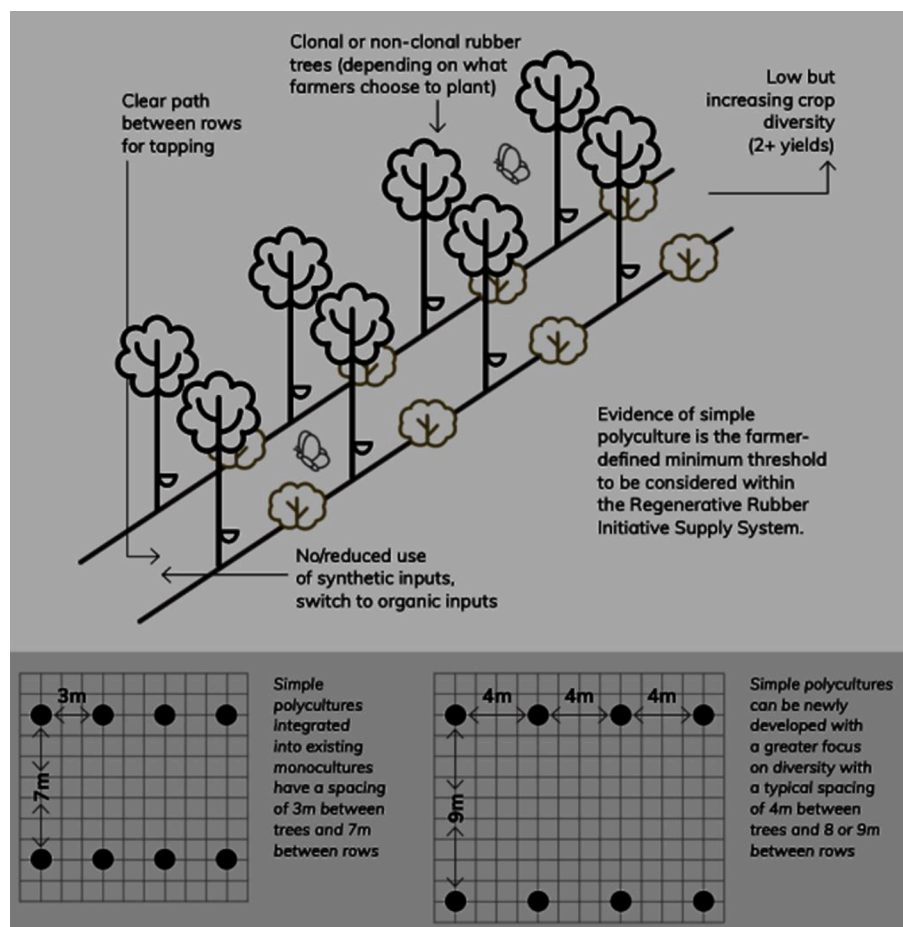


Figure 5. Simple polyculture rubber typology.

Table 3. Typical outcomes of simple polyculture rubber management systems.

Dimension	Typical outcomes
Ecological Health	. Ecological health begins to improve. . Biodiversity increases and more wildlife are attracted. . Some ground cover helps improve soil health. . Natural regrowth is limited. . Synthetic chemicals are eliminated from the system or comply with organic standards.
Economic Stability	. Stability improvements. . Additional yields may be initially used for household consumption/use but can turn into a second income. . Reduced dependence on rubber during periods of low prices. . Constraints on land and labor availability can affect profitability.
Social Well-being	. Human health improves as chemical inputs are used less and less. . Health may also improve as the diversity of local fruits, vegetables, and herbs become part of a regular diet. . It can require intensive labor.
Farmer Knowledge	. Appreciation of other life in the garden grows, but knowledge and understanding are limited.
Relationship with Nature	. Human control over the system is still high. . Farmers often desire an ordered, organized system. . Relationship to the land remains largely economic.

3.1.4 Complex Polyculture

Complex polycultures are systems with several yielding species and crops introduced intentionally or by allowing natural regrowth (Figure 6). Farmers may remove some less desirable species to leave more room and light for more desirable species; however, synthetic inputs are limited. Complex polycultures are much more diversified production systems that produce significant ecological, economic, and social benefits (Table 4).

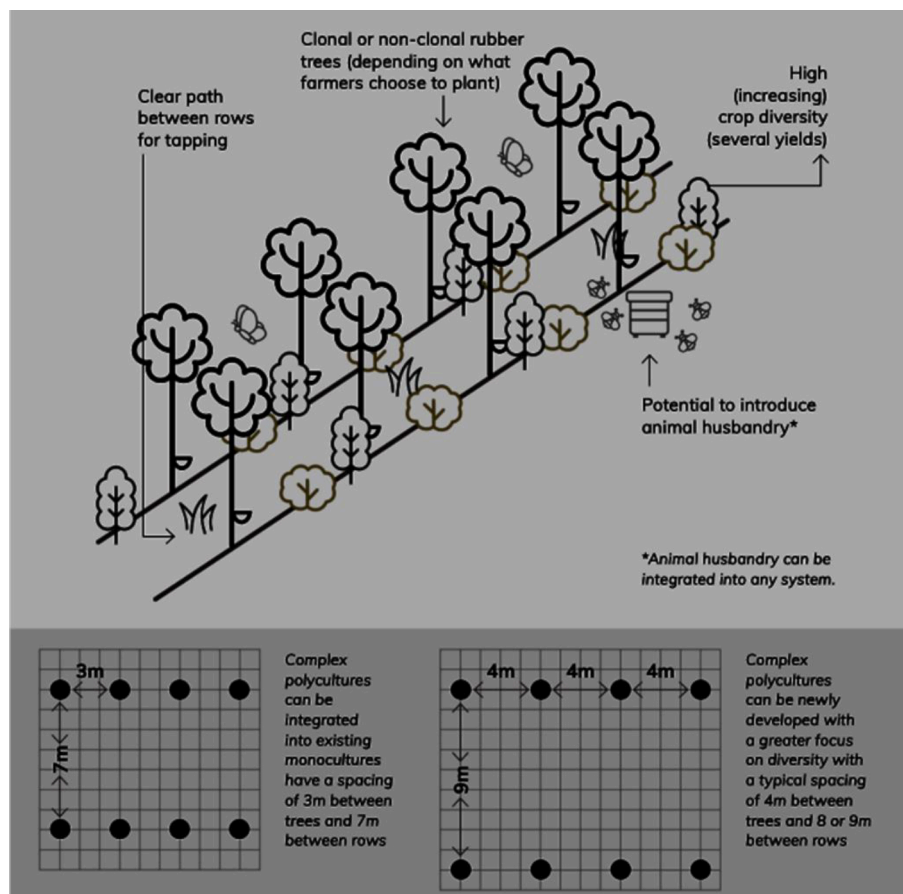


Figure 6. Complex polyculture rubber typology.

Table 4. Typical outcomes of complex polyculture rubber management systems.

Dimension	Typical outcomes
Ecological Health	. Ecological health continues to see improvements. . Biodiversity increases, more wildlife is attracted, and more habitat and fodder are available. . Natural regrowth is allowed, but farmers favor desirable species and weed less desirable species.
Economic Stability	. Increased stability due to several yields that provide for needs and offer alternative incomes. . Not only reliant on rubber.
Social Well-being	. Very limited/ eliminated use of chemical inputs - significant health risks are reduced. . Farmers and communities experience continued health benefits from the additional, nutritious yields their systems provide. . Increasing sense of culture and meaning. . Some labor requirements may be reduced (e.g., the intensity of weed removal may be reduced).
Farmer Knowledge	. Knowledge and understanding continue to increase as farmers learn more. . Beginning to learn the values of more species. . Farmers may not understand the value of certain plants in their system yet.
Relationship with Nature	. Farmers recall a more balanced relationship with nature and are more courageous and open to try something new. . Values and relationships with other plants and animals begin to be explored. . Farmers begin to feel good about their role in helping and working with nature. . Attachment to former ideals of order and organization may remain.

3.1.5 Modern Jungle Rubber

Modern jungle rubber production systems result from leaving a monoculture unmanaged or an intentional decision by farmers. This system consists of clonal rubber trees and naturally regenerating species. While evolution is primarily driven by nature, farmers often select certain species to protect or remove and choose to plant or spread specific species (Figure 7). Modern jungle rubber systems' ecological, economic, and social state are high (Table 5).

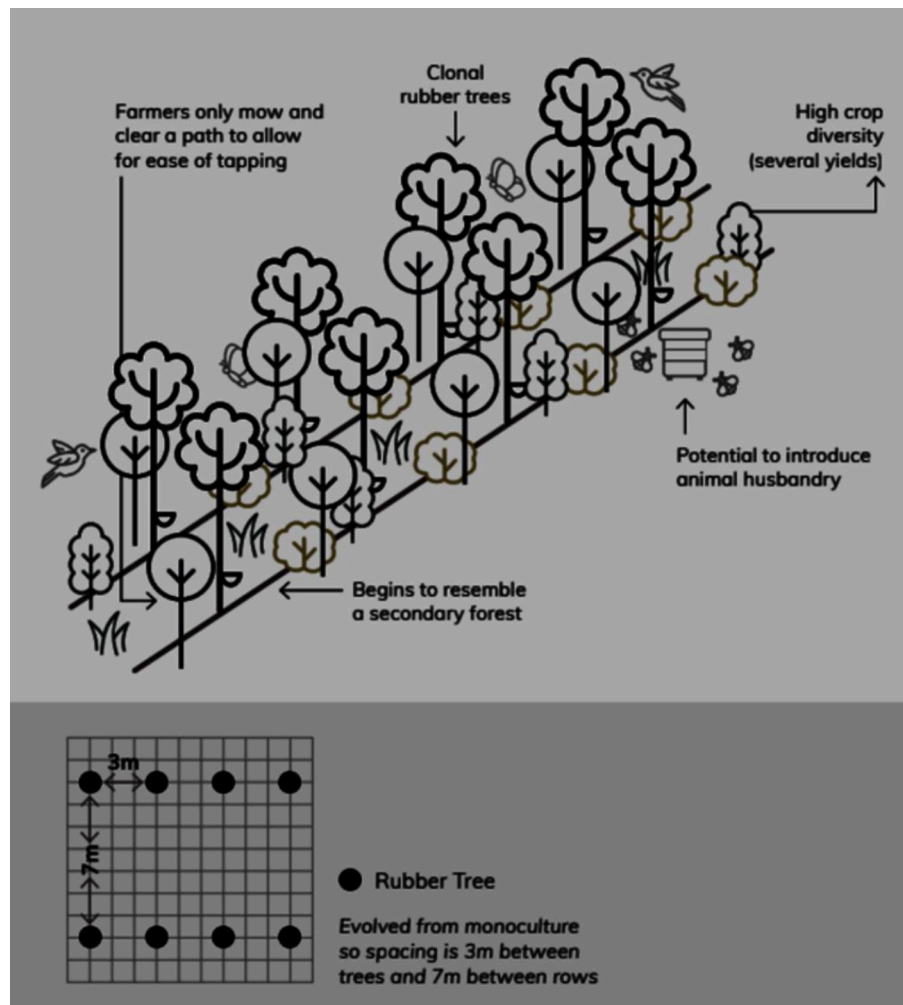


Figure 7. Modern jungle rubber typology.

Table 5. Typical outcomes of modern jungle rubber management systems.

Dimension	Typical outcomes
Ecological Health	. High ecological health. . High biodiversity, high number of wildlife are attracted, abundant habitat and fodder available. . Wildlife brings seeds from surrounding forest areas. . Ground cover and several layers of natural growth. More desirable species are supported. . Many native species are established.
Economic Stability	. Several yields mean more economically stable. . Aside from rubber, there may not be larger regular yields but rather a greater diversity of smaller yields with potential yields developing.
Social Well-being	. Years without the use of synthetic inputs result in greater overall health. . Higher sense of culture and meaning. . Health improves with the availability of medicines and nutritious foods.
Farmer Knowledge	. When part of larger Wanakaset networks that hold and develop knowledge on plant uses for food, medicine, cosmetics, natural dyes, essential oils, biopesticides, and much more, farmers build their knowledge and thus learn the value(s) of many of these species over time. . Many farmers who choose such management are happy to explore their forest gardens as vast libraries of knowledge to discover, to which new titles are always arriving.
Relationship with Nature	. Evolution is primarily driven by nature. . Increased trust and deeper relationship with the land and nature.

3.1.6 Traditional Jungle Rubber

Traditional jungle rubber describes systems using unselected, non-clonal rubber trees introduced into thinned forests or as part of swidden agriculture. These systems are extensive and resemble secondary forests (Figure 8). Management and synthetic inputs for traditional jungle rubber are very limited. Traditional jungle rubber systems operate in a more stable ecological, economic, and social state (Table 6). These systems are an inspiration for designing new regenerative rubber systems.

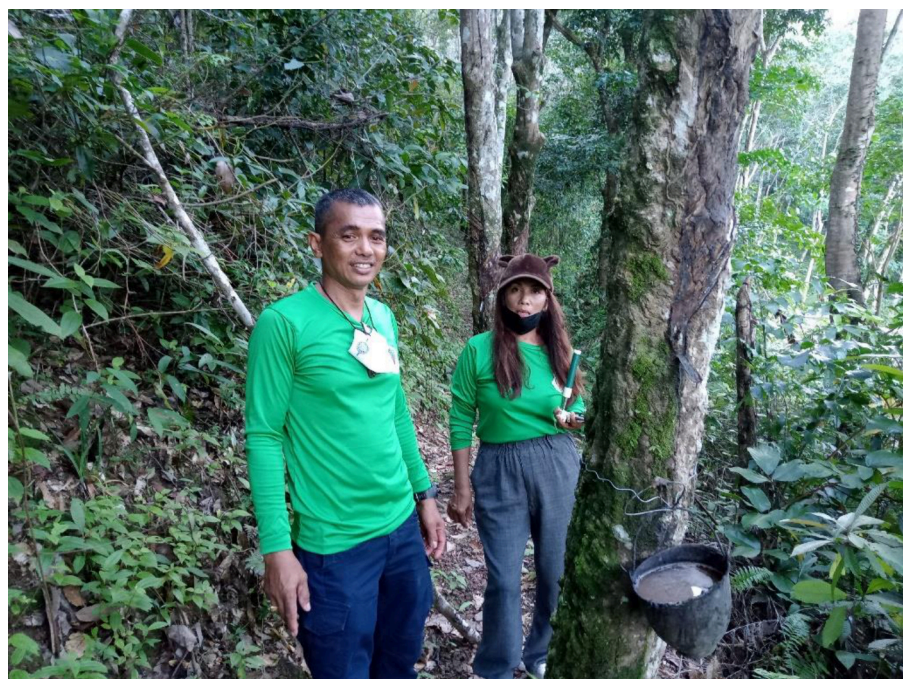
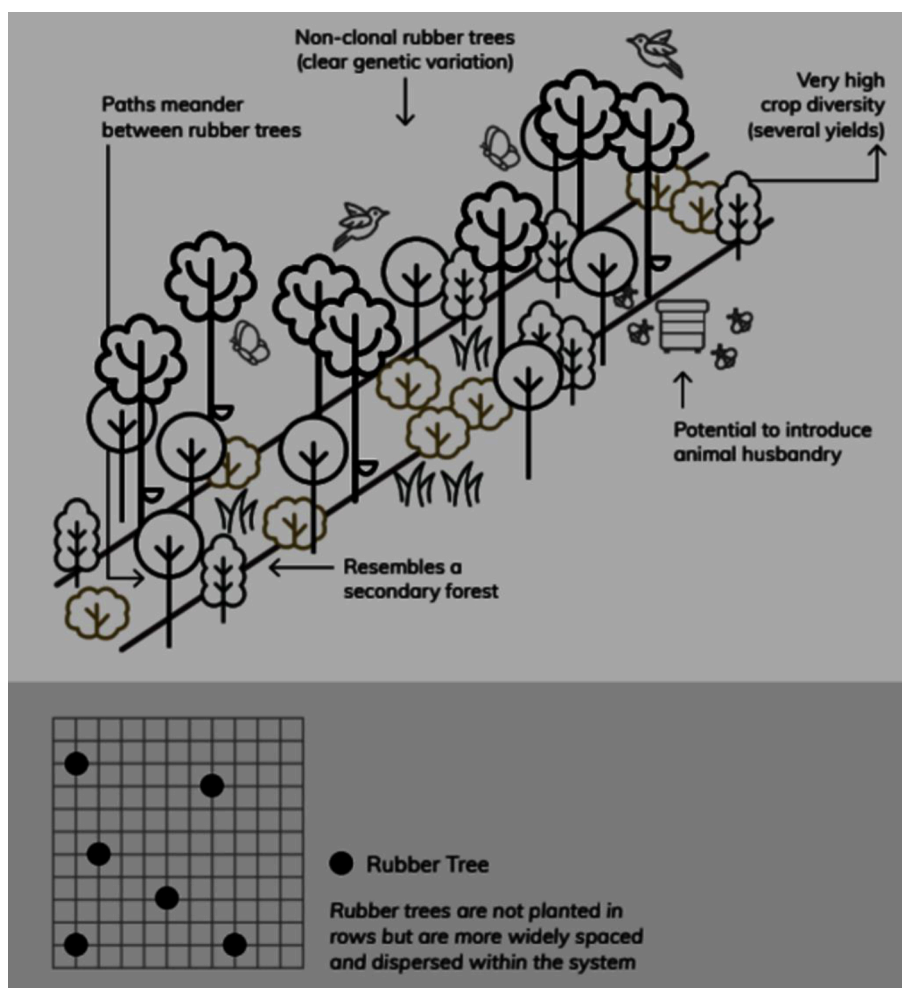


Figure 8. Traditional jungle rubber typology.

Table 6. Typical outcomes of traditional jungle rubber management systems.

Dimension	Typical outcomes
Ecological Health	- High ecological health. - Seed-grown, non-clonal rubber trees are stronger and can survive and produce for decades. - Very high biodiversity. Abundance of wildlife, habitat, and fodder.
Economic Stability	- Economically, farmers have a high level of self-reliance with many yields used for the household. However, when these production systems are found in more remote jungle regions, they will likely experience higher logistic costs. - Farmers describe that when these systems were common, they had minimal dependency on money.
Social Well-being	- Almost all of their needs are met with resources they can harvest and use. - Tapping larger trees with a higher volume of rubber requires less labor. - High level of self-reliance. - Communities, relationships, and local culture are stronger. - In remote areas, there may be fewer public services or market access. There is no electricity or cellular access in very remote areas, and transport is difficult.
Farmer Knowledge	Farmers describe - and some still remember from previous times - a great deal of knowledge about how to use biodiversity and its products to meet their needs.
Relationship with Nature	- There is a great deal of connection with the ecology, which provides food, materials, medicine, fuel, and much more. - This sort of relationship and knowledge is what many leaders of the Wanakaset rubber movement seek to revitalize and return to their lands and communities.

The findings in this study revealed that rubber farmers have various systems for growing rubber. They are starting to adjust to increasing rubber in a more integrated way. That aligns with the government policy of changing single-crop rubber cultivation to mixed cultivation. The RAOT has promoted the creation of mixed rubber plantations by planting rubber together with other plants, namely creating rubber plantations with 1) rubber as the main crop and 2) perennial trees and trees with economic value as wood for use or 3) fruit trees, vegetables and medicinal plants for consumption or household income generation. Plants in rubber plantations are other plants that can coexist with rubber and be planted together with rubber. They are ground cover crops, rubber intercrops, rubber companion plants, and forests in rubber plantations without negative impact on rubber. The goal of creating integrated rubber plantations is to reduce costs and increase farmers' income for stability, prosperity, and sustainability while improving environmental health. RAOT has principles for selecting plant types and income-supplementing activities in rubber plantations—guidelines for planting plants to suit the rubber planting distance of 7x3 meters with recommendations for planting distance, number of plants, height, exposure to light, canopy layer, and income-generating crop. They present seven rubber systems: System 1: rubber + perennial and economically valuable trees + fruit trees + vegetables and herbs; System 2: rubber + perennial crops and economic trees + fruit trees; System 3: rubber + perennial crops and economic trees + vegetables and herbs; System 4: rubber + perennial crops and economic trees; System 5: rubber + fruit trees + vegetables and herbs; System 6: rubber + fruit trees; and System 7: rubber + vegetables and herbs. [14].

3.2 A Regenerative Approach to Rubber Production

3.2.1 Wanakaset

Rubber system: simple polyculture, complex polyculture, modern jungle rubber, and traditional jungle rubber; they are called 'Wanakaset.'

Wanakaset is a philosophy and values-driven approach to farming that can be incorporated into rubber plantations. The word "Wanakaset" directly translates to "forest agriculture" and refers to a farming

concept developed by Pooyai Viboon in Chachoengsao, Thailand [15]. Building upon traditional knowledge, Wanakaset looks at self-sufficiency and the relationship between humans and the natural environment. This philosophy focuses on developing land to provide resources for basic needs while also growing knowledge and understanding about using these resources efficiently. The greatest loss from clearing natural forests for conventional production has been farmers' and communities' knowledge and relationship with the land and its biodiversity. Without knowledge, experience, relationships, and stories, communities don't know what plants can be eaten, used as medicine, processed into suitable fibers and natural dyes, or many other uses. Leading farmers participating in the Wanakaset process are evolving their rubber gardens into more diverse and integrated systems while developing their knowledge and relationship with the land. This induces a virtuous cycle towards ecological regeneration and increasing diversity of yields and values.

In the case of rubber production in Wabajaset, the characteristics of rubber production systems are on a continuum from degenerative as a rubber monoculture to regenerative as traditional and modern jungle rubber; ecological health, economic stability, social well-being, farmer knowledge, and relationship to the land/system were increased. While clear production classes can be identified, evolving production systems to become regenerative is a highly complex process (Table 7).

Table 7. Characteristics of rubber production systems

Characteristics	Continuum			
	Degeneration			Regeneration
	Rubber monoculture		→	Traditional/Modern jungle rubber
Ecological Health	Low-degrades ecosystem	Increases	→	High-enhances ecosystems
Economic Stability	Low-reliance on single income	Increases	→	High reliance on multiple incomes
Social Well-being	Low-experience poor well-being	Increases	→	High-experience high well-being
Farmer Knowledge	Low-little knowledge of ecology beyond rubber trees	Increases	→	High-deep understanding of land and system
Relationship with Nature	Low-relationship is only economic	Increases	→	High-deep relationship and connection

3.2.2 Continuum of Practices

Embarking on a journey towards regenerative rubber production presents farmers with many choices. Rather than following a linear path, systems progress and evolve in a way unique to the place and to each farmer's practices. The complexity of this progression is illustrated in the continuum below (Table 8). Rubber monoculture uses very high synthetic inputs such as fertilizers and herbicides. Intentionally (re) plant-integrated rubber helps reduce the use of synthetic inputs. Then, clonal varieties and non-clonal seeds were used for genetic variations. Mature forests produce seedlings that can yield valuable yield and help others make the transition. Intentional intercropping, introducing 1-3 additional crops (simple polyculture) or introducing several (3+) different crops (more complex polyculture) increases the use of organic inputs, and synthetic inputs gradually phased out; there is a reduced need for any fertilizer application as the soil improves and more sources of organic matter, and attention to protecting key natural areas around the garden, such as riparian buffers. Allowing natural regrowth was generating natural regrowth that limited maintaining order. It favors desirable species that attract wildlife and remove other less desirable species. Intentionally fruits continue attracting wildlife; secondary unintentional yields are present in bees, wild trees, wild fruit, and herbs. Moreover, farmers can collect valuable profits from several intentionally planted crops, and natural regrowth, wildlife, and seeds are protected in the garden but also spread into the surrounding areas. The mature trees can be harvested, providing space and light for other species.

Table 8. Continuum of rubber management practices.

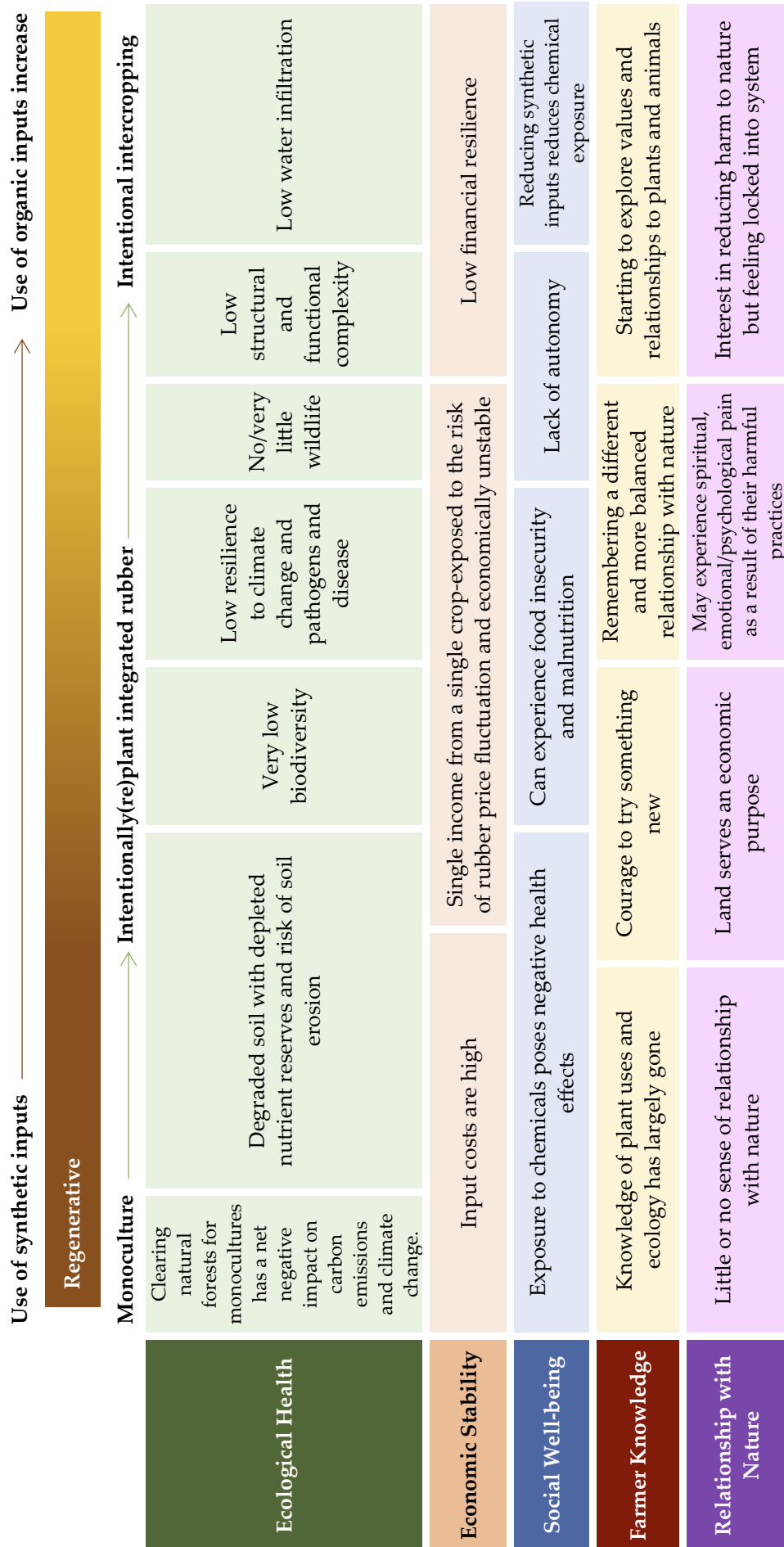


Table 8. Continuum of rubber management practices.

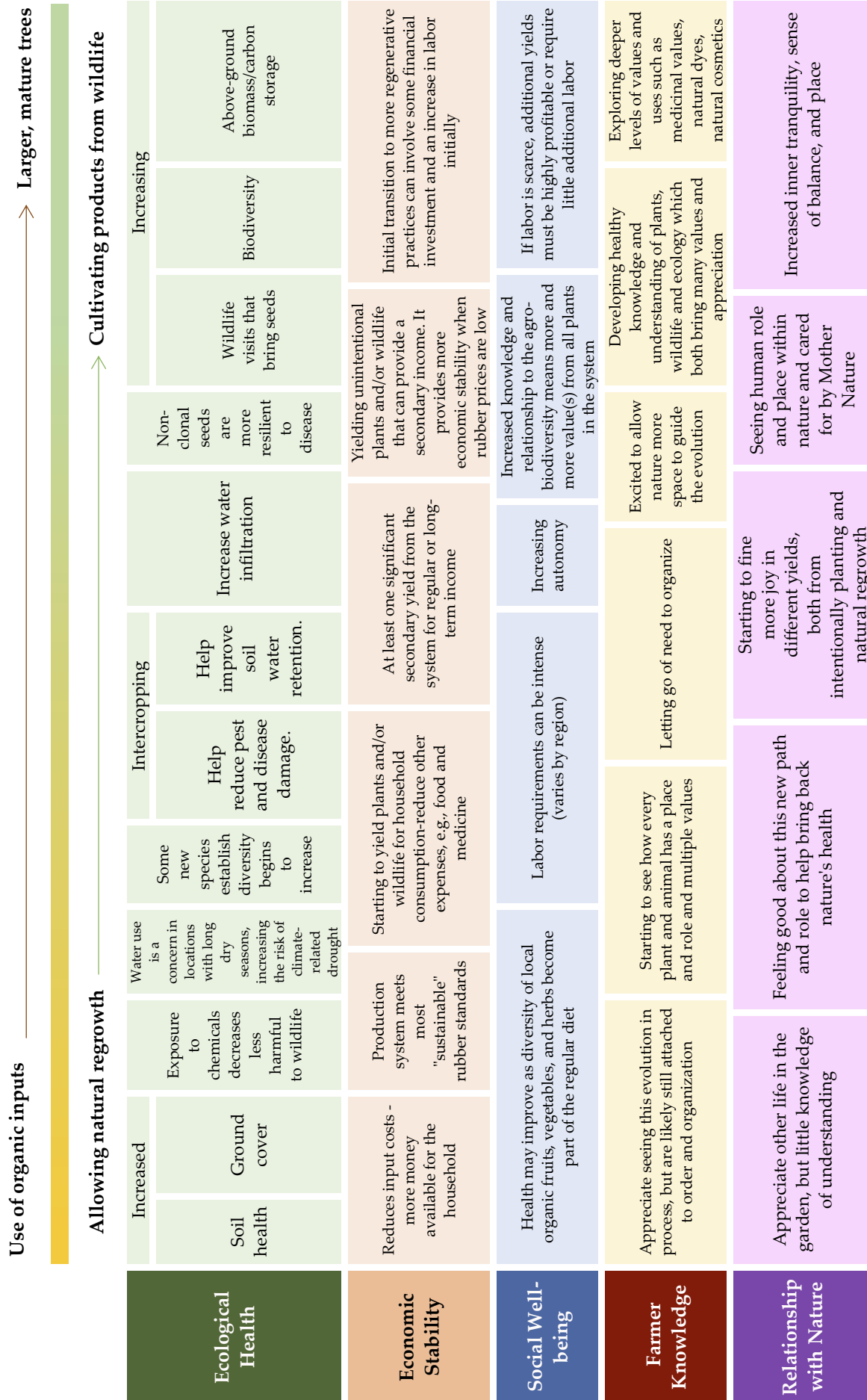
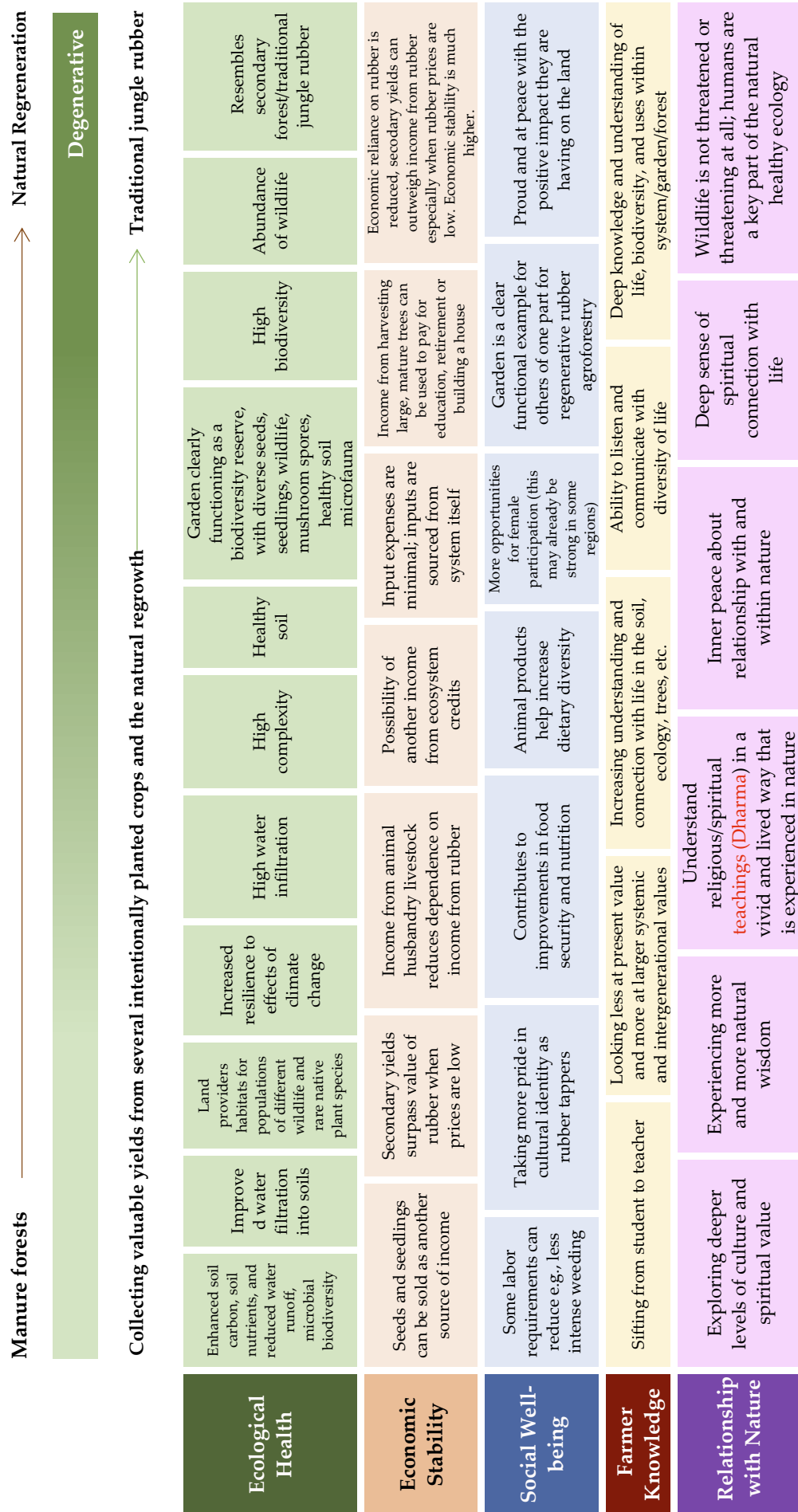


Table 8. Continuum of rubber management practices.



4. Conclusions

The continuum presents many practices that farmers can adopt to suit their land best. Some practices have been identified as progression barriers because they inhibit or limit the ability of the system to continue progressing toward regenerative outcomes. Along the progression from degeneration towards regeneration, the continuum identifies key ecological, economic, and social characteristics and important knowledge and relationship shifts that occur along the journey.

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