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REVIEW ARTICLE

More than rubber: Exploring the benefits and practicalities of diverse intercropping systems in rubber plantations

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Abstract

Conventional monocrop rubber farming, while profitable, has led to significant environmental and socio-economic issues. These include deforestation, reduced soil fertility, loss of biodiversity, and increased carbon emissions. Economically, smallholder farmers face risks due to fluctuating rubber prices and income dependency on a single crop. This situation has resulted in low incomes, labour shortages and in some cases, abandonment of rubber plantations. Intercropping, or modern rubber agroforestry, offers a promising solution to these challenges. This approach involves planting other crops or trees alongside rubber, increasing revenue, enhancing soil properties, conserving moisture, reducing erosion and improving overall rubber crop yield. Various crops such as fruits (Salaca palm, gnetum, banana and lemon), vegetables (Cucumber, arrowroot, french bean, chilli, mung bean, broad leaf pumpkin, yam, cowpea and egusi melon), spices (Ginger, turmeric, coriander, fenugreek, black pepper, vanilla, cinnamon and nutmeg) and medicinal plants (Sarpagandha, kalmegh, lesser galangal, satavar and long pepper) can be successfully grown as intecrop under tappable rubber. However, implementing intercropping systems comes with challenges, including potential adverse effects on rubber growth and yield if not appropriately managed. Farmers must implement good agricultural practices and integrated farming strategies to achieve sustainable economic and ecological benefits from rubber-based intercropping. This includes careful selection of cultivars, optimal planting and spacing, regular maintenance and balanced fertilizer application. This review explored essential intercropping practices and highlighted successful case studies within rubber plantations. While more complex than traditional monocropping, a well-managed intercropping system can provide diverse income sources, improve agro-biodiversity and contribute to more sustainable rubber farming practices.

Keywords

rubber; agroforestry; crop diversification; intercrop; livelihood enhancement

Introduction

Para rubber (*Hevea brasiliensis* Muell. Arg.) belongs to the Euphorbiaceae family and is a perennial plant commercially cultivated to produce white exudates (latex), known as white gold. The major rubber-producing countries include Thailand (4573 MT), Indonesia (3135 MT), Vietnam (1292 MT), Ivory Coast (1286 MT), China (853 MT), India (843 MT) and Malaysia (377 MT). India ranks sixth among the major natural rubber (NR) producing countries and is also the second-largest consumer of natural rubber (Fig. 1), accounting for 9.3% of global consumption in 2022 (1). In India, Kerala ranks first (1534 kg/ha) in terms of production, followed by Tamil Nadu (1500 kg/ha), Tripura (1277 kg/ha), Karnataka (1275 kg/ha) and Assam (1153 kg/ha) (Fig. 2) (2). It is one of the most significant renewable resources and is regarded as a critical resource and a cornerstone of industrialization (3).

Conventionally, *Hevea brasiliensis* has been grown as a monocrop to produce large quantities of raw natural rubber. While intensive monocropping systems have generated substantial profits for smallholder rubber farmers and satisfied global demand, they have also significantly impacted agroecosystems. These detrimental effects include environmental disturbances such as deforestation, reduced soil fertility, erosion, climate change, loss of natural resources and decreased biodiversity. Additionally, these practices have contributed to higher carbon and greenhouse gas emissions. (4). Long-term monoculture rubber farming has led to socio-economic issues such as dependency and income source homogeneity. This makes it difficult for farmers to adapt to changes in market prices, putting their livelihoods at risk (5). As most smallholders depend only on rubber for their daily needs, the fluctuating prices (Fig. 3) have resulted in low income coupled with precarious employment and labour shortage. Additionally, farmers could not use appropriate farming techniques due to the rising production costs and lower farm gate prices. This has led to the abandonment of their rubber plantations in search of other sources of income, as they were unable to sustain due to the continuous decline in rubber prices (6). Planting different crops in vacant places of rubber plantations may be the best and most effective solution to handle such difficulties, especially since integrated rubber farming can lead to sustainable agriculture (7, 8). Intercropping in rubber not only increases the revenue but also enhances the physio-chemical properties of the soil (Fig. 4), conserves soil moisture, reduces soil erosion, assists in weed management (3) and increases the growth and yield of the rubber crop (9).

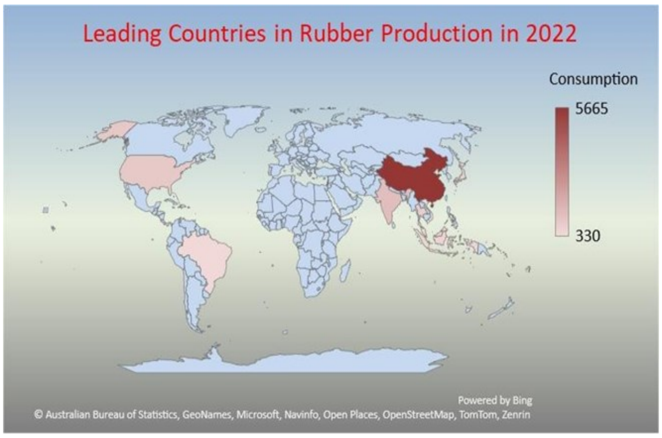

Fig 1. Major rubber producing countries in the world (29)

Hence, in this review, the history, evolution and types of intercropping suitable for rubber plantation and their success stories, challenges and constraints are identified to address their research gap.

Types of intercrops suitable for rubber plantation

Intercropping or modern rubber agroforestry involves planting or cultivating other trees or crops alongside rubber trees, typically using clonal rubber seedlings. These diverse intercropping systems can yield high-value cash crops, boosting farmers' income and alleviating poverty (10). Intercropping is generally practised in both pre-tappable and tappable stages of rubber plantation. Intercropping in rubber was classified into two types: permanent intercropping, which involves growing other crops or trees throughout the lifespan of rubber trees and initial intercropping, which consists of planting different crops alongside rubber during the initial establishment period. Intercropping in juvenile rubber trees differs significantly from intercropping with older rubber trees from biological and economic perspectives (3). The competition between the rubber and intercrop includes light availability to the canopy competition for water and nutrients. Such competition can be reduced by the appropriate selection and management of tree species (7). It is possible to produce various crops under rubber without negatively impacting the growth and productivity of rubber, such as vegetables, plantation crops, medicinal plants and spices. Fruits (Tab. 1) like banana and pineapple, tubers like cassava, elephant yam, giant yam and taro. Spices (Tab. 3) like turmeric and ginger, vegetables (Tab. 1) like bitter gourd, cucumber and chillies. Medicinal plants (Tab. 3) like kacholam were grown as intercrop in rubber smallholdings

Fig 2. Major rubber producing states in India (29)

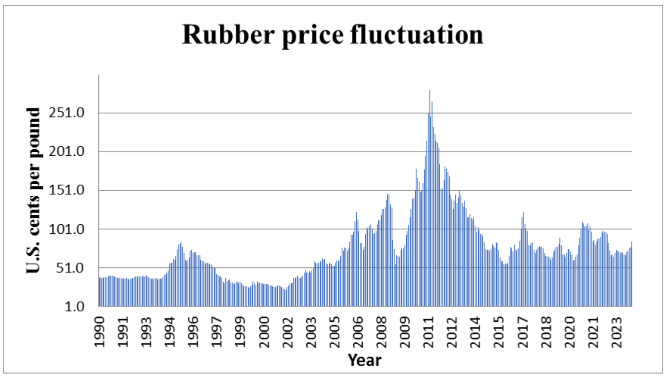

Fig 3. Rubber Price fluctuation from 1990-2023 (50)

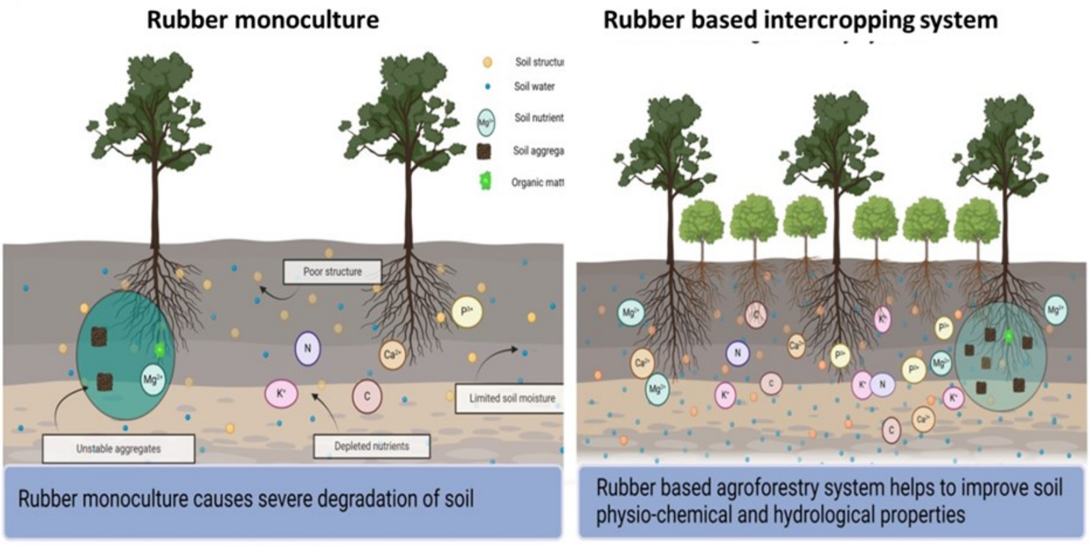

Fig 4. Effect of monocropping and rubber-based intercropping on the properties of the soil

Table 1. Fruits, vegetables and plantation crops based intercropping system in rubber

Category	Name of the crop	Reference
Fruits	Salaca Palms (*Salacca zalacca*)	(27)
	Banana (*Musa sp.*)	(16)
	Gnetums /Melinjo (*Gnetum macrostachyum*)	(19)
	Lemon (*Citrus lemon*)	(25)
Vegetables	Cucumber *(Cucumus sativus)*	(28)
	Arrowroot (*Maranta arundinacea*)	(20)
	French bean *(Phaseolus vulgaris*)	(20)
	Chilli (*Capsicum annuum*)	(29)
	Melon (*Cucumis melo)*	(18,20)
	Mungbean (*Vigna radiata)*	(30)
	Egusi melon (*Cucumeropsis manni*)	
	Broadleaf pumpkin (*Cucurbita pepo*)	(31)
	French bean *(Phaseolus vulgaris*)	(20)
	Yam (*Dioscorea sp.)*	(20)
	Cowpea (*Vigna unguiculata)*	(29)
Plantation crops	Cocoa *(Theobroma cacao)*	(25,33)
	Coffee (*Coffea arabica)*	(25,20,28,34))
	Cola nut tree (*Cola nitida)*	(25)
	Tea *(Camellia sinensis* var. *assamica*)	(11, 13)

Table 3. Medicinal and aromatic plant based intercropping system in rubber

Category	Name of the crop	Reference
Medicinal and Aromatic plants	Indian sarsaparilla (*Hemidesmus indicus*)	(39, 40)
	Kali Musli (*Curculigo orchioides*)	
	Prickly chaff flower *(Achyranthes aspera*)	(40)
	Crown Flower (*Calotropis gigantea*)	
	Hill glory bower (*Clerodendron infortunatum*)	
	Indian moon-seed (*Cyclea peltata*)	
	Black creeper (*Ichnocarpus frutescens*)	
	Licorice weed (*Scoparia dulcis*)	
	Little Ironweed (*Vernonia cinerea*)	
	Malabar nut (*Adathoda beddomei*)	(28)
	Lesser galangal (*Alpinia calcarata*)	
	Kalmegh (*Andrographis paniculata*)	
	Satawar (*Asparagus racemosus*)	
	Beggars lice (*Desmodium gangeticum*)	
	Long Pepper (*Piper longum*)	
	Sticky Desmodium (*Pseudarthea viscida*)	
	Sarpagandha (*Rauvolfia serpentina*)	
	Strobilanthes cuspida	
	Clerodendranthus spicatus	(34)

(11). It is possible to cultivate rubber trees along with native flora, other fruit trees, food crops and other species. In addition to early rubber harvesting, this pattern helps farmers gather food crops, herbs, fuel wood and wood for buildings. It also improves soil fertility and agro-biodiversity and lowers soil erosion (7).

Economic analysis of rubber-based intercropping system

Intercropping under rubber is a valuable tactic to eliminate a few significant problems the growers face, including unstable prices for raw rubber, high cost of cultivation, unproductive immature periods and loss of tappable days due to heavy rainfall. Adopting intercropping in rubber trees results in 18-32% additional total farm income (12). Rubber-tea intercropping was more profitable compared to monocropping. Rubber-tea intercropping can produce more LER (Land Equivalent Ratio) than rubber and tea monocultures in current socio-economic conditions (13). However, rubber and plantain intercropping systems with different treatments, including one (PR), Two (PPR) and Three rows (PPPR) in Ghana and the results indicated that though all the treatments were profitable, the PPPR yielded the fetched the highest income (USD 6624.42/ha and BCR of 3.95) making it the most profitable (13). From 2010 to 2014, the Rubber Research Institute of Nigeria (RRIN) conducted a study to evaluate the economic viability of rubber intercropping. Intercrops such as plantain, cassava, cherry, and avocado were planted between the rows of rubber trees. The study resulted in a gross margin of 1465.02 USD and a net farm income of 1464 USD, demonstrating high economic viability. In another study comparing monoculture rubber systems with three rubber agroforestry systems *viz*., ironwood + eaglewood, ironwood + champak, and bamboo, it was found that rubber in agroforestry systems began tapping earlier (6.6 years) than in monoculture systems (7.2 years). Among these, the rubber-bamboo system proved to be the most profitable, followed by ironwood + eaglewood and ironwood + champak, showing increases in Net Present Value (NPV) of 71.5, 70.4 and 46.3%, respectively, compared to monoculture rubber (Fig. 5).

The economic performance of rubber-based farming systems was studied by (14), including fruit trees such as durian, rambutan, longkong and champada, rubber + livestock and integration of other two species was compared to monoculture rubber systems. The results indicated that all three diversified systems were more profitable than the monoculture rubber system, with the rubber-fruit tree combination yielding the highest net farm income at 1451% higher, followed by the rubber-integrated system at 770% higher and the rubber-livestock system at 413% higher.

Case studies and Success stories of intercropping in a rubber plantation

Rubber intercropping with fruits:

In high-yielding agro forests, integrating fruit trees and other plant species helps improve crop diversity, benefiting species richness without sacrificing yields-the impact of intercropping on the yield and properties of latex in rubber (15). The study focused on three intercropping systems: rubber with bamboo (RB), rubber with melinjo (RM) and rubber with coffee (RC). The results showed that latex yield in the RB and RM systems was 40% higher than in monoculture rubber. Additionally, the latex from the RB and RM contains the highest amount of phosphorous and reduced thiols with reduced sucrose content, representing the better physiological status of the tree with effective utilization of sucrose for latex production.

The performance of bananas under rubber plantation was examined by (14). The results revealed that rubber + banana-based intercropping recorded better results with a higher yield of 1,838 kg per year, possibly due to better microclimate around the rubber plantation. Also, gnetums (*Gnetum macrostachyum)* thrived well under the shades of rubber trees, producing good-quality leaves (16).

Rubber intercropping with vegetable crops

As an intercrop, legumes can be grown in available interspaces or alternate interrows (11)**.** Rubber trees can benefit from intercropping legume plants because it increases their nitrogen supply and improves their water-use efficiency (17). Cassava intercropped in rubber interrows can successfully suppress weeds as much as *Pueraria phaseoloides* in rubber interrows (18) and management expenses are reduced by 60% in both

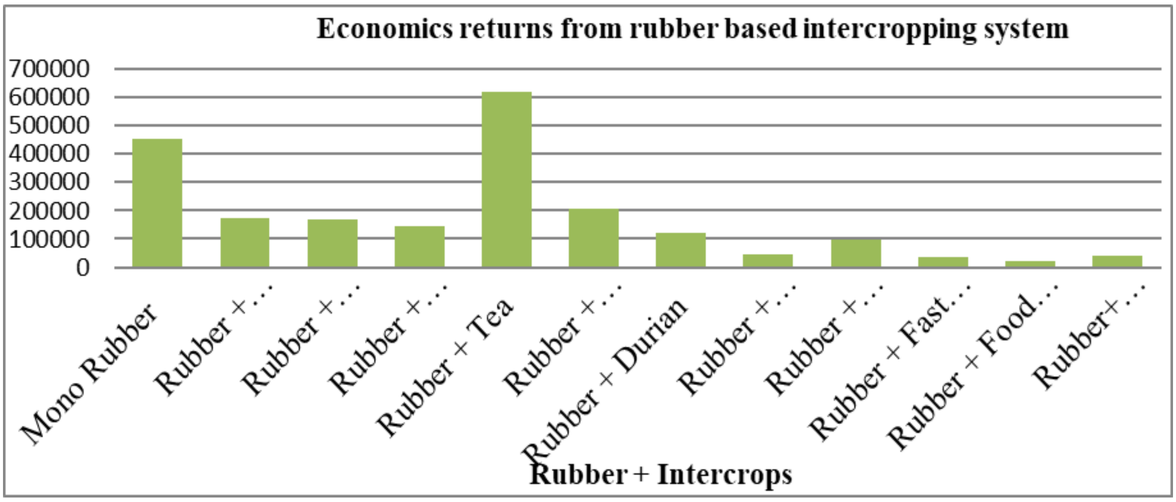

Fig 5. Net farm income from rubber based intercropping system (25)

tappable and pre-tappable phases (19). Similarly, cowpea intercropping in rubber reduces weed density and biomass throughout the growth cycle (17).

Cucumber, cowpea, amaranthus, salad cucumber and ash gourd were grown in the available interrow space of 20-year-old rubber trees (clone RRII 105) in India. The results also revealed that amaranthus 3.50 kgm^{-2} and salad cucumber 670 g $plant^{-1}$ got a good yield compared to other intercrops due to the availability of light conditions. The light intensity was 63% during planting and decreased to 22% during the plant's vegetative stage, which tends to improve the yield of the vegetables (20).

However, mung bean, corn, cowpeas, yam, bean, peanut, maize, soyabean, elephant grass and ginger were planted in the interrow of the tappable rubber plantation in China and rubber + yam bean (13.1 t ha^{-1}) are the promising intercropping system (17). Consequently, the maximum yield of okra 5133 (kg ha^{-1}) was obtained from strip relay intercropping. In contrast, strip intercropping gave the highest yield of sweet corn (8001 kg ha^{-1}) and concluded that sweet corn and okra intercropping did not affect the growth of young rubber plantations (18).

Rubber intercropping with plantation crops

Plantation crops such as coffee and cocoa (Fig. 6) are recommended for tappable rubber plantations. In India, intercropping tea with rubber has generated interest in different nations (21). In China, various combinations have been tested in rubber plantations, and it has been reported that rubber + tea has gained the most attention and remains the ideal combination. In contrast to rubber monoculture, the root system of rubber thrives well in rubber and tea intercropping plantations. It helps to improve the water use efficiency of rubber (22).

Comparing typical rubber monocultures with rubber intercropped with coffee, cocoa and lemon or cola nut tree, individual rubber tree productivity was unaffected by intercropping and rubber + coffee and rubber + cocoa were the most profitable than other intercrops (23). Similarly, when growing coffee as an intercrop under rubber plantations, the yield of coffee was lower than that of pure stands, and the growth and yield of rubber were unaffected by coffee due to the continuous limited availability of light intensity as a canopy developed (24).

Rubber intercropping with spices

Cinnamon, a valuable crop often produced as a sole crop, is appropriate for cultivating as an intercrop under rubber cultivation. Based on various experimental results, it is possible to maintain high bark yields from cinnamon while reducing competition from rubber by modifying inter-row spacing and adhering to proper cultural practices. Intercropping rubber with cinnamon is only viable when the rubber rows are farther apart. Most compelling are paired row systems with broader inter-rows of 14.4 m, 15.6 m and 16.8 m with 10, 11 and 12 cinnamon rows in the interrow. High densities of cinnamon bushes and rubber trees can be accommodated in these systems without significantly impacting the productivity and growth of either crop (25).

Further, vanilla on glyricidia standards, garcinia and nutmeg were grown along with rubber trees without changing the planting design or density. Rubber growth was substantially higher under mixed planting without affecting yield. All the intercrops had good yields in the first several years. Due to high shade, the development of the garcinia was affected, but the vanilla plants continued to produce well since these crops did not have any effect on the rubber yield of rubber plantations (20).

Rubber intercropping with medicinal and aromatic plants

Many weeds with medicinal potential grow under the shade of rubber plantations, suggesting that these plants can be grown as intercrops. *Hemidesmus indicus* and *Curculigo orchioides* thrive well under dense rubber canopies (26).

The Total biomass production of medicinal plants under rubber plantation. For example, plants such as *Achyranthes aspera, Calotropis gigantea, Clerodendron infortunatum, Cyclea peltata, Hemidesmus indicus, Ichnocarpus frutescens, Scoparia dulcis* and *Vernonia cinerea* were observed and quantified by (27). Due to their ability to withstand drought, these species thrive well during arid months. The study also showed that these medicinal plants can be grown as intercrop in rubber plantations and might effectively yield a significant amount of crude pharmaceuticals for use in manufacturing medicines.

Consequently, nine shade-tolerant medicinal plants (*Adathoda beddomei, Alpinia calcarata, Andrographis paniculata, Asparagus racemosus, Desmodium gangeticum, Piper longum, Pseudarthea viscida, Rauvolfia serpentina* and *Strobilanthes cuspida* were grown in an established rubber plantation. All these medicinal plants grew well and produced adequate biomass. However, *Strobilanthes cuspida* (390 kg ha^{-1}- dry weight) and *Alpinia calcarata* (1276.79 kg ha^{-1} - DW) performed significantly better without affecting the yield of rubber (20).

Intercropping sharp-leaf galangal (Fig. 7) with rubber could improve the sustainability of the rubber planting industry. In this agroforestry system, competition for water was minimal and did not negatively impact the rubber trees' water-use efficiency. Additionally, the negative Phosphate (P) concentration relationship between rubber trees and sharp-leaf galangal indicated their competition for soil P resources. However, such competition did not affect the nutritional status of the rubber tree leaves (28).

The performance of ginger *(Zingiber officinale* L.), turmeric (*Curcuma longa* L.) and lesser galangal (*Kaempferia galanga* L) under cashew (*Anacardium occidentale* L.) and rubber (*Hevea brasiliensis* Muell. Arg.) plantation was examined by (29). During the growing period, there were notable differences in rhizome production among the different land use systems. The highest rhizome yields (3.46 and 3.06 t ha^{-1}) for ginger and galangal were found in treeless open areas, but the highest yields (7.63 t ha^{-1}) for turmeric were found in cashew plots. Photosynthetic active radiation plays the most critical impact on understorey productivity. The biomass production potential is determined by available light; specifically, the efficiency with which intercepted light is turned into biomass. Furthermore, belowground root

Fig 6. Cocoa as an intercrop under rubber plantation

Fig 7. Greater galangal as an intercrop under rubber plantation

competition for water and minerals may contribute to the variation in productivity.

Rubber intercropping with flower crops

The impact of intercropping of calla lilies (*Alocasia macrorhizos* L.) on the growth, development and uptake of nutrients under rubber (*Hevea brasiliensis* Müell. Arg.) plantation was studied by (30). In the rubber + calla lily intercropping system, the amount of nutrients nitrogen (N) and potassium (K) absorbed by calla lilies and soil urease activity in the rhizosphere and non-rhizosphere soil decreases, thereby affecting the growth and biomass. Intercropping considerably increased the abundance of microorganisms in non-rhizosphere soil while dramatically reducing the abundance of bacteria, actinomycetes and total microbial abundance in rhizosphere soil. Similarly, tropical red anthurium and gauthamala types were grown in three different shade levels *viz*., 60 - 75%, 80 - 85% and 90 - 95% were used. The results revealed that tropical red successfully produced blooms under three shade levels, whereas the gauthamala variety showed poor flowering performance. There was no change in floral quality among the three shadow levels (straight petioles, asymmetric and overlapping percentage flowers and flower size) compared to those of the tropical red variety (31).

Rubber intercropping with cut Foliage

Shade is necessary to cultivate filler crops (Tab. 2), typically cultivated under artificial shade nets. Instead of artificially creating shade conditions, natural shade, such as growing under plantation crops such as rubber, provides a twofold benefit to both rubber and filler crops (Fig. 8). The performance of various cut foliages under ten-year-old rubber plantations was studied by (32) (Fig.8). Among the cut foliages, *Dypsis lutesence* had recorded the greatest plant height (65.3 cm), highest dry matter content (104.1 g/plant) and most extended petiole length (34.5 cm), whereas *Dracaena fragrans cv. Massangeana* flowered early (10.23 days) with the highest leaf yield (29.7 Nos) and shelf life (32.06 days) under rubber plantations. A similar trend was observed by (33). Yield is a complex concept that depends on both internal and external factors. The uptake of nutrients and water from the soil and the incidence of light has a significant role in leaf

Table 2. Spices, flowers and cut foliage-intercropping system in rubber

Category	Name of the crop	Reference
Spices	Ginger (*Zingiber officinale)*	(20,35)
	Malabar cardamom *(Amomum villosum)*	(34)
	Turmeric (*Curcuma longa)*	(35)
	Coriander (*Coriandrum sativum*)	(29)
	Fenugreek *(Trigonella foenum-graecum)*	
	Black pepper (*Piper nigrum* L. cv. Bragandina)	(32)
	Vanilla (*Vanilla planifolia)*	
	Garcinia (*Garcinia gummigutta*)	(28)
	Nutmeg (*Myristica fragrans)*	
	Cinnamon (*Cinnamomum verum*)	(26)
Flowers and cut foliages	Calla lilies (*Alocasia macrorhizos* L.)	(36)
	Anthurium (*Anthurium andraeanum)*	(37)
	Asparagas	
	Dracena mahathma	
	Dracaena fragrans cv. *Massangeana*,	
	Schefflera variegated	
	Dypsis lutescens,	(38)
	Philodendron xanadu	
	Spathiphylum	
	Syngonium	
	Calopagonium	

Fig 8. Cut foliage as an intercrop under rubber plantation

production.

Factors affecting the success of the intercropping in rubber plantations:

The introduction of new plants into rubber plantations faces several biophysical difficulties related to light availability and competition for water and nutrients (Fig. 8). Agroforestry systems are viable, only when both their tree and intercrop components are complementary with one other (34).

Abiotic factors

Light availability

In rubber plantations, the amount of radiation penetrating the rubber canopy determines the success of intercropping. Due to the dense rubber canopy, only a little light intensity (851.57 to 977.60 lux) may reach the understory (34). Rubber has low light transmission rates (44.1%) throughout its production cycle. In standard single-row spacing of approximately 7 (5-10) m and a height of 2.3 (2-3.5) m, the canopy typically closes after 5-7 years. In 8-year-old plantations, light transmission rates (e.g. photosynthetic active radiation - PAR) decreased to 2%. Low light intensity affects the yield of intercrops. Except for lettuce, peanuts, sweet potatoes, soybeans and eggplant, yield declines are seen with increasing shade. When considering intercropping possibilities, it is essential to note that although the yield of shade-tolerant crops may decrease depending on the level of shade, it's crucial to discuss shade tolerance from an ecological and production standpoint (23).

Competition from invading roots:

For long-term farm revenues, most farmers began intercropping on their rubber farms once the rubber trees reached a tappable stage. They choose perennial shade-tolerant crops, including coffee, tea, cocoa, ginger, salacca and bamboo (32). Rubber is surface feeder that creates a dense root mat in the top 30 cm of the soil, although it has an impressive taproot (36). The canopy can lead to intense competition in above and belowground interactions if the intercrops are planted in a high-density or dense rubber tree. Competition between rubber and intercrops can be minimized through proper resource allocation by considering their distinct characteristics, such as root systems, shade tolerance, vegetative growth and harvested portions of the crops. Therefore, choosing intercrops with a different root strategy will prevent competition between rubber trees and intercrops. To minimize the competition effect, intercropping in young rubber with root crops such as sweet potato, and tapioca should be planted two metres apart from the rubber plants (19). For permanent intercropping, rubber planting densities are typically minimized (400 trees ha^{-1}) than conventional densities (500 trees ha^{-1}), especially for perennial timber and fruit crops.

Biotic factors

Incidence of diseases

Intercrops such as sweet potato or cassava (residues during cassava harvesting) might lead to considerable soil disturbance and cause damage to the root system of rubber, causing white root rot (*Lignoporus lignosus*). However, the disease spreads to other intercrops, including tea, coffee and cocoa (37).

The deciduous nature of the rubber

Rubber trees are deciduous trees that experience defoliation (leaf fall) for three to four months during the dry season (November to February) due to severe water shortages. Rubber farms could not provide canopy shade for the understory ecosystem during that period. The light's intensity affects water availability, crop growth and yields of the intercrops (38).

Future directions for research and implementation

Advancing rubber-based intercropping systems requires focused research in critical areas. Researchers should explore the compatibility of various intercrop combinations, focusing on plants with complementary structures and resource needs. This could lead to more efficient use of available resources and improved overall productivity. Additionally, breeding programs aimed at developing regional crop varieties with complementary genetic traits could enhance the performance of intercropping systems across different environments. Another crucial area of study is the impact of intercropping on soil nutrients and water availability, particularly in rubber agroforestry systems. This research could help identify the most suitable intercrop species for sustainable growth, ensuring the long-term viability of these systems. Investigating methods to boost natural pest control in intercropping systems is vital. This research could reduce reliance on chemical pesticides and promote more ecological farming practices. However, studying potential drawbacks, such as increased pest reservoirs, is also essential. Researchers should work on strategies to minimize any adverse effects of intercropping on pest migration to cash crops. Comprehensive economic analyses comparing rubber agroforestry with monoculture rubber plantations are needed. These studies should account for the total value of secondary products to accurately assess the financial benefits of intercropping.

Additionally, research into the environmental impact of intercropping is crucial, focusing on reducing carbon footprints, improving resource use efficiency and evaluating overall ecological benefits. Crop selection and management research could significantly improve farm productivity and profitability. This research could enhance resource efficiency and climate resilience by identifying optimal intercrop combinations and regional varieties. Studies on pest and disease control in intercropping systems could lead to more sustainable pest management practices. This would reduce reliance on chemical inputs and promote ecological intensification in farming. Research into the economic viability and environmental impacts of intercropping can provide valuable insights into rubber-based systems overall sustainability. This information could guide farmers and policymakers in making informed decisions about agricultural practices.

Conclusion

The economic outcomes of rubber-based intercropping systems are the subject of extensive research and have yielded valuable insights. Intercropping rubber with various species, such as fruits, vegetables, spices, and medicinal and aromatic plants, is more profitable than monoculture rubber production in many cases. However, the profitability is closely related to factors such as the biophysical interactions between rubber and secondary crops and the lifespan of the secondary species. While the variability of results and the limited number of studies are acknowledged as limitations, the potential benefits of rubber agroforestry systems for people, the environment and wildlife are evident. These systems can provide multiple benefits, including increased water infiltration, reduced soil erosion, and enhanced biodiversity. The evidence suggests that rubber agroforestry systems hold promise for sustainable rubber production without compromising yields and can contribute to the resilience of smallholder farmers in the face of price volatility and market risks. Researchers must focus on deciphering and managing the intricate interplay between intercrops, rubber trees and soil nutrients. This understanding should account for site-specific conditions and local climate variability, enabling more effective system design and management. Overcoming obstacles related to policy support, financial incentives and farmer adoption is essential. Addressing these challenges will pave the way for widespread implementation of rubber-based intercropping systems, potentially transforming agricultural practices in rubber-growing regions.

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Authors' contributions

M collected data from literature, G, A, D, T, K.R, K, B and JD provided valuable guidance, corrected the manuscript, and M drafted the entire manuscript.

Compliance with ethical standards

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None

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Not applicable

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