CONSERVING/IMPROVING BIODIVERSITY IN RUBBER PLANTATIONS IN INDIA: A REVIEW OF POSSIBILITIES AND ECOLOGICAL IMPLICATIONS

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Traditional rubber growing regions in India were historically under homestead farming where multiple enterprises co-existed catering to the diverse needs of the farm family. Introduction of natural rubber (*Hevea brasiliensis* Muell. Arg.) to India by British planters transformed the land use pattern considerably during the last century; a major share of home gardens was converted to monoculture rubber plantations. The history of this transformation, various intercropping practices and research carried out at Rubber Research Institute of India to conserve/increase biodiversity in rubber plantations by developing suitable intercropping systems and permitting natural flora to co-exist with rubber and the impact of crop/species diversification on soil health and resilience are summarized in this review. Conservation of soil moisture by permitting other crops and weeds in rubber plantations and subsequent mitigation of the risks associated with climate uncertainties, revenue generation in the production system and future research priorities are also discussed. Rubber intercropping systems in other South and South East Asian countries are also discussed.

Key words: Biodiversity, *Hevea brasiliensis*, Intercrops, Natural flora, Natural rubber, Soil health

INTRODUCTION

Land use systems at local and regional landscapes are dynamic and they evolve gradually with the prevailing agro-climatic conditions. Socio-political and economic factors add to the momentum of these changes often with conflicting effects on the various components of the production systems. Past century witnessed a shift from the subsistence oriented to commercial farming in many parts of the tropics including parts of India in conjunction with the socio-economic development of the farmers.

Traditional home gardens in India are need-oriented, intensive and integrated farming systems with multiple enterprises around the farm houses (Kumar and Nair, 2004). The structural and functional diversity of these production systems helped farmers to meet the food, fuel, fodder, timber and other livelihood requirements to a large extent. The multi-layered canopy and root systems and synergistic interaction of the components in the home gardens ensured most efficient utilization of natural resources and resilience of the production system.

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Rubber (*Hevea brasiliensis* Muell. Arg), a forest tree indigenous to the Amazonian forests of South America is mainly cultivated in South East Asian countries. Introduction of natural rubber to India by British planters during late 18th century transformed the landuse pattern of India considerably, a large proportion of homegardens were converted to rubber plantations (Kumar and Nair, 2004). History of rubber cultivation in India forced rapid shift from the subsistence-oriented home gardens to commercial agriculture ushering intremendous socio-economic changes within a comparatively short time span. This was accelerated by the large community of small and marginal farmers who started rubber cultivation in the second half of the 20th century with the active support of Rubber Board.

Natural rubber cultivation expanded as a monoculture in India either displacing other crops or after felling forests. The shift in the cropping pattern due to various reasons has lot of consequences, important among them are the non-availability of land for cultivating other crops, increased dependence of the farm family on external market to meet their livelihood and vulnerability to the price fluctuations of agricultural commodities. Loss of traditional knowledge in farming is another important aspect which has not received adequate attention. Rubber cultivated areas fall under the Ecologically Sensitive Zones (ESZ) of Western Ghats (Thomas and Jacob, 2013) and there has been a serious debate over the erosion of biodiversity of Western Ghats due to the establishment of monoculture plantations such as rubber, tea and coffee in the region. Conserving the biodiversity in the plantations of Western Ghats has been recognized as very crucial for conserving the biodiversity of the region. In this context, the research activities carried out at Rubber Research Institute of India to increase biodiversity in rubber plantations and the impact of crop/species diversification on soil health and resilience are reviewed in this article.

Evolution of monoculture rubber plantations in India

Commercial rubber cultivation was started in 1902 at Thattekkad in Travancore by the Periyar Syndicate (British partnership firm), and subsequently other plantations were also established, and by 1910, rubber was cultivated in a total area of 9652 acres spread over in all planting districts of Southern India (Anonymous, 1911). Later, several small plantations were started by individual Indian farmers and the share of small farmers in the rubber plantation industry steadily increased (Unny and Jacob, 1972). Extensive monoculture plantations of rubber were established during the colonial estate phase, but in all probability, rubber was introduced in the small holdings along with other standing trees/crops in new plantings in the beginning. The research team from Malaysia that visited India at the request of the Government of India to advise on immediate and long term means of improving the production of natural rubber in the country reported inter-planting of rubber with areca palms, coconut, cashew, banana, teak and pepper in various smallholdings (Newsam *et al.*, 1960). This practice continued and a survey showed that 88.6 per cent of the total area was inter-planted with other trees/crops. Farmers were reluctant to cut down other trees which existed in the plot before planting rubber as these tree crops were not perceived as affecting the growth of rubber considerably (Unny and Jacob, 1972).

The gradual shift from mixed planting to monoculture plantations in small holdings occurred when older plantations were replanted with high yielding clones during the second cycle. Apart from the Plantation Development Schemes of Rubber Board, which restricted the number of other trees in the plantation for financial support to a maximum of 20 other trees, 40 coconut and 80 arecanut palms in one hectare, comparatively higher and stable price of rubber and a change in perception of the farmers also might have caused this transformation. However, the growing evidence of the possibility of integrating diverse vegetation along with rubber without adverse impact on the performance of rubber, on the contrary with multiple ecological benefits and the vulnerability of monoculture plantations to price volatility has prompted intensive research in this area in the past few decades.

Research on improving biodiversity in rubber plantations

Intercropping in rubber plantations

Unlike in other rubber growing countries in South and South East Asia where research on various aspects of intercropping and advisories to farmers on intercropping were started very early (RRIC, 1941; Morales, 1949; Allen, 1955; Hunter and Camacho, 1961; Seotardi 1965; Blencowe, 1967; Pushparajah and Weng, 1969; FAO, 1975), intercropping did not receive adequate attention in the early years of rubber research in India. Documented experiments were started during late 1970s only. However, intercropping was a common practice in the small holdings, though in the estates, intercrops were not cultivated. Tapioca, banana, ginger, elephant foot yam, pineapple, pepper and coffee were grown as intercrops in small holdings mostly for own consumption and farmers were advised by Rubber Board to restrict intercropping to the first one or two years.The first documented study by Mathew *et al.* (1979) suggested further research to screen different crops, but such research was not immediately undertaken. Inventories of intercropping systems were later made by Srinivasan *et al.* (1987) and Rajasekharan (1989) and during this period, experiments on intercropping with perennial crops were also initiated by RRII. Intercropping coffee in mature rubber was started during 1987 (Rubber Board, 1991-92), followed by intensively studied cropping systems including various annual and perennial crops, case studies and surveys. Experiments with modified planting designs were also started in 1993 with an objective to extend the period of intercropping. Trials were also conducted in North East India during the past two decades to evolve suitable cropping systems for these regions with locally preferred crops.

While promoting mixed cropping systems, either the net return from the system giving equal importance to various component crops or additional return from subsidiary crops without affecting growth and yield of main crop is mainly considered. In India, the various intercropping systems adopted so far generates additional income from intercrops without adversely affecting the performance of rubber.

Natural flora in rubber plantations

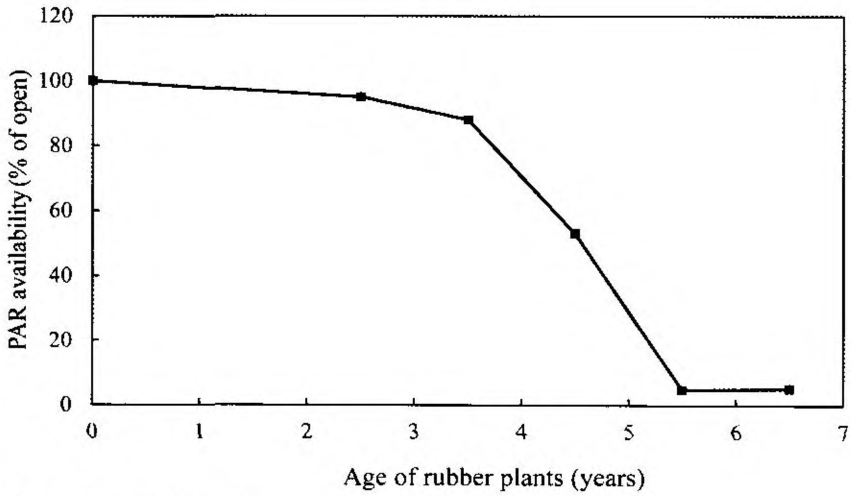
Natural flora or weeds were generally not permitted in rubber plantations either due to the perception that weeds compete with rubber for natural resources or for aesthetic purpose. The practice of cultivating leguminous cover crops or intercrops during early years of plantation cycle and cattle grazing during later years also restricted growth of natural vegetation. A weed free platform was also necessary to facilitate latex harvesting. The large scale mechanization which reduced the cost of weed control considerably also lead to clean weeded rubber plantations. With the growing awareness about the ecological significance of natural flora, various aspects of retaining natural flora in rubber plantations were studied in detail.

Experiments and case studies

As the rubber canopy develops, radiation availability within the plantation gradually decreases. Light availability was 97, 76 and 43 per cent of the open during the first, second and third year, respectively and it decreased to less than 10 per cent by the seventh year in North Central Kerala (Joseph, 1999; Jessy *et al.*, 2017) (Fig.1).

Rubber is a deciduous species and a short period without shade is available within the mature plantation during the annual leaf shedding period. In India, this period is generally December-January, though minor variations are observed depending on the clone, location and the rainfall pattern.

Under the popular planting systems in India, light is limiting for cultivation of most crops in mature rubber plantations. Hence attempts were made to develop modified cropping systems to extend the period of intercropping and to include more crops in the cropping system (Jessy *et al.*, 1998, 2005, 2013; Roy *et al.*, 2001; Datta *et al.*, 2011). Similar attempts were made in other rubber growing countries like Sri Lanka also (Rodrigo *et al.*, 2004; Pathiratna and Perera, 2006; Wibawa *et al.*, 2006; Xianhai *et al.*, 2012). However, unlike in some other countries where rubber was planted as shade trees for other crops (Townsend 1964; Partelli *et al.*, 2014), in India, priority was given to include other crops in the existing system with rubber continuing as the main crop.



Source: Jessy *et al.* (2017)

Fig. 1. Age of rubber plants and availability of photosynthetically active radiation inside the plantation

Jessy *et al.* (2005) and Datta *et al.* (2011) could extend the period of intercropping to throughout the gestation period under paired row system of planting in South as well as North East India. Sequential intercropping with food crops was adopted selecting the intercrops judiciously based on their shade tolerance. In another experiment, un-shaded area for intercropping was available up to 11 years when the distance between the paired rows was increased to 12m. In North East India also, modified planting systems were evaluated to extend the period of intercropping (Roy *et al.*, 2001; Dey *et al.*, 2007; Gohain *et al.*, 2002). But in these experiments, the period of intercropping could not be extended beyond a certain period since the inter-row area was not wide enough to avoid shading by rubber trees. Evaluation of other planting designs *viz.* twin system, triangular system and four cluster system of planting also showed superiority of twin and triangular systems over control in terms of growth of rubber plants during early years (Rubber Board, 2012). These planting systems also released more land and light for intercropping.

Food crops as intercrops

Intercropping with food crops was a common practice from the early years of rubber cultivation in India (Rubber Board, 1963). This trend continued over years as indicated in subsequent surveys also (Srinivasan *et al.*, 1987; Rajasekharan, 1989; Anilkumar *et al.*, 2006; Siju *et al.*, 2013). Banana, pineapple, various vegetables, tapioca, tuber crops, ginger and turmeric were commonly cultivated as intercrops in young rubber plantations. In other rubber growing countries, a variety of other crops were also cultivated as intercrops *viz.* upland rice, corn, groundnut, mung bean, black gram, sorghum, cow pea, ground nut, soybean *etc.* (Garot, 1958, Arope, 1974; Narong and Soonthorn, 1976; Nguema *et al.*, 1998). In Orissa, Brahman *et al.* (1997) reported that pigeon pea can be cultivated profitably in the inter-row spaces of rubber in the first three years. Nendran banana continued to be the most preferred intercrop in the traditional belt. However, shifts in regional preferences were observed over time andpineapple emerged as the choicest crop in Central Kerala, with majority of pineapple cultivation on lease basis (Siju *et al.*, 2013).

The comparatively stable and high price of rubber in the past hasled to planting of rubber even in very small farm units. In many such farm units, the entire farm area is planted with rubber and the dwelling is also within the plantation. By utilizing the sunlight available within the plantation during the leaf shedding period effectively, short duration vegetables could be cultivated to meet a part of the household requirement (Jessy *et al.*, 2017).

Root activity and root level competition for resources studied by tracer technique in a rubber-banana (var. Poovan) intercropping system showed that up to three years, substantial area was available for cultivating other crops without appreciable root competition (Joseph, 1999). More than 90 per cent of root activity one-year-old rubber was confined to a lateral distance of 50 cm and a depth of 25 cm. During second year, about 80 per cent activity was confined to a zone of 100 cm lateral distance and 50 cm depth and during 3rd year, maximum recovery of soil applied ^{32}P was from a lateral distance of 50 cm followed by 100 and then by 150 cm.

Spices and plantation crops as intercrops

Though a variety of shade tolerant perennial crops like coffee, cocoa, *Garcinia,* nutmeg, cinnamon, clove *etc.* are cultivated in mixed stands with comparatively tall crops like coconut, arecanut *etc.* or as under storey crops in homesteads such crops are seldom consciously cultivated and integrated with rubber. Apart from the limited light availability, concern of negative effect of other perennial crops on the growth and yield of rubber is also a deterrent for integrating these crops with rubber.

As early as in 1955, coffee and cocoa were suggested as suitable intercrops for rubber in Malaysia (Allen, 1955; Holdridge, 1957). Hunter and Camacho (1961) reported that net returns from a mixed planting of rubber and cocoa were 35 per cent higher than that from a rubber plantation of equal area. Almost during the same period, farmers in India were also advised to grow cocoa as an intercrop with rubber where abnormal leaf fall is not prevalent (Rubber Board, 1963). However, systematic studies were not immediately under taken to study the various aspects of intercropping long duration crops with rubber. There were restrictions on cultivating other crops with rubber in development schemes also and the cultivation of cocoa or other perennial crops along with rubber continued to be absent or minimum, restricted to certain localities, like black pepper in high elevation tract of Idukki district (Joseph *et al.*, 1988). Several shade tolerant spices and plantation crops were evaluated in rubber plantations during the past two decades. These crops were planted at different growth phases of rubber, at planting (Jessy *et al.*, 2017), after removal of food crops, (Jessy *et al.*, 2015) and during mature phase (George *et al.*, 2012) and the performance was best when intercrops were planted along with rubber.

Medicinal plants as intercrops

Many medicinal plants are shade tolerant/loving and their natural habitat is the ever green forests in the rubber growing regions adjacent to the Western Ghats. Several medicinal plants established and grew well in mature rubber plantations. Among them, karimkurinji, (*Strobilanthes* sp.) chuvannakoduveli (*Plumbago* sp.) and aratha (*Alpinia* sp.) were identified as suitable intercrops in mature rubber plantations (Sathik *et al.*,1995, Neerakkal *et al.*, 2005; Jessy *et al.*, 2017). However, marketability should be ensured before venturing in to large scale cultivation of medicinal plants and co-ordinated efforts by all concerned Departments/Agencies are needed for this purpose.

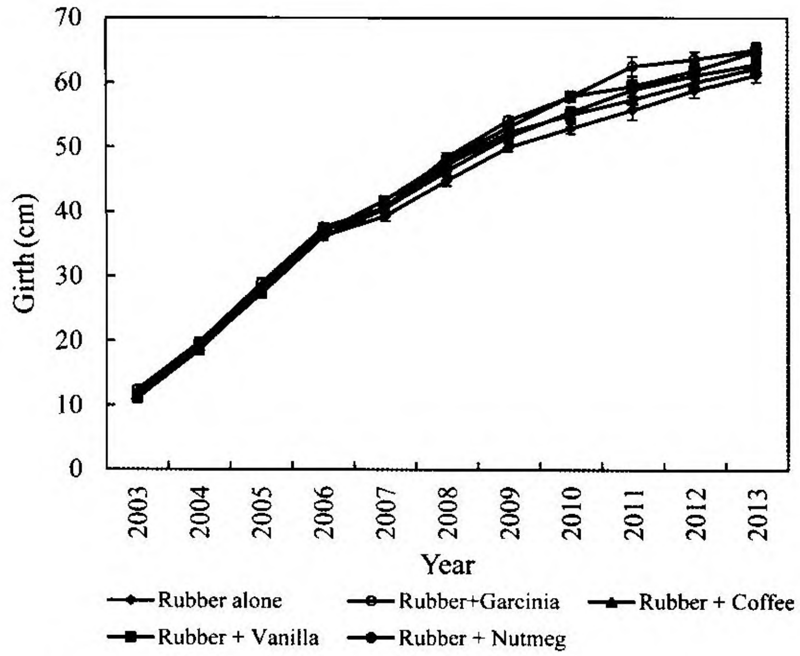
Timber yielding trees

Several timber species like wild jack, teak, mahogany *etc.* sprout naturally and grow in rubber plantations and many farmers retain them as a long term investment even at the expense of a few rubber trees. Unlike crops with canopy underneath rubber, interaction between rubber and timber trees are more complex. Performance of wild jack was better and when planted with rubber; both grew simultaneously without any adverse effect on growth of rubber trees during early years (Rubber Board, 2012). However, the impact of anjili (*Artocarpus hirsutus*) trees on rubber depend on the number of anjili trees, their canopy coverage and competition for light between rubber and anjili trees. In case studies, girth of rubber was significantly affected when wild jack density increased beyond 20 per cent (Meti *et al.*, 2007).

Effect of intercropping on growth and yield of rubber

In almost all reports from different rubber growing countries, (Morales *et al.*, 1949; Garot, 1958., Buranatham *et al.*, 1980; Chandrashekara, 1984; Junaidi and Arifin, 1989; Yousof *et al.*, 1989; Rodrigo *et al.*, 1997) including India (Mathew *et al.*, 1979; Jessy *et al.*, 1998, 2005; Anilkumar *et al.*, 2006; Rubber Board, 2009; Dutta, 2011; Chaudhury and Jessy, 2013), intercropping increased growth of young rubber plants. Modified planting designs and extended intercropping either improved growth (Jessy *et al.*, 1998, 2005, 2013; Gohain *et al.*, 2002), or did not influence growth of rubber (Dey *et al.*, 2007; Datta *et al.*, 2011; Rubber Board, 2012). The beneficial effect of intercropping on growth during young phase was continued to the mature phase also (Anilkumar *et al.*, 2006; Rubber Board, 2009). However, the effect of intercrops on growth of rubber will depend on the cultivation practices. In some case studies, intercropping decreased growth of rubber (Sutrisno and Sastrosoedarjo, 1976; George *et al.*, 2012). Intercrops planted close to the rubber plants may compete with rubber for nutrients and water and may adversely affect performance of rubber.

Intercropping with perennial crops also either had a positive effect or no effect on growth of rubber. When planted along with rubber, there was a positive effect on growth of rubber (Fig. 2) but this effect was not substantial (Jessy *et al.*, 2017). When planted after removal of pineapple or during mature phase, there was no effect on growth of rubber (Jessy *et al.*, 2015; George *et al.*, 2012; George and Meti, 2018). In case studies, intercropping rubber with cardamom in



Source: Jessy *et al.*(2017)

Fig. 2. Influence of intercropping perennial crops on growth of rubber

comparatively higher elevations enhanced growth of rubber by 22 per cent (Thomas and Kuruvilla, 2005).

Studies on the effect of intercropping during young phase on latex yield of rubber are limited. Kouadio *et al.* (1997) and Rodrigo *et al.* (2000) reported higher yield of rubber when intercrops were cultivated during immature phase. Jessy *et al.* (2013), also observed higher latex yield when intensive intercropping was practiced during immature phase. Intercropping with perennial crops did not affect the yield of rubber in several experiments (Jessy *et al.*, 2015, 2017; George and Meti, 2018).

Competition for nutrients under intercropping

Significantly lower leaf nitrogen status of rubber during the active growth period of banana and a lower leaf potassium status during the active growth period of tuber crops indicated the possibility of competition for these nutrients at certain growth stages. However, this competition was not reflected on growth of rubber, suggesting that this was only transient. During the later period, leaf phosphorus (P) status was significantly higher in the presence of intercrops (Jessy *et al.*, 2005). In all other experiments, intercropping did not affect the leaf nutrient status of rubber (George *et al.*, 2012; Chaudhury and Jessy, 2013; Jessy *et al.*, 2013: Jessy *et al.*, 2015; 2017).

Revenue from intercropping

Revenue from intercropping is highly variable depending on the price fluctuations, prevailing labour wages and cost of inputs. During the initial years, light is not limiting for intercrops and the income from intercrops was comparable with that of monoculture (Jessy *et al.*, 2017). When perennial intercrops are cultivated, the revenue depend on the shade tolerance of the crops also. Yield of coffee ranged from 30 to 100 per cent of that of monoculture depending on the growth phase of rubber (George *et al.*, 2018; Jessy *et al.*, 2017), whereas that of cocoa ranged from 25 to 60 per cent (George *et al.*, 2018; Jessy *et al.*, 2015). Coffee yield was poor when planted in a three year old plantation. Some other shade tolerant crops like vanilla and medicinal plants yielded well within rubber plantations, but their market price is highly variable.

Permitting more biodiversity through crops and natural flora: Impact on soil health

Intercropping sustained soil fertility status and resulted in a build-up of soil available phosphorus in almost all the studies (Jessy *et al.*, 1998; Rubber Board, 2009; George *et al.*, 2012, George and Meti, 2018). A temporal effect of banana intercropping on available K status was observed in some studies, with a decrease near banana during its active growth period (Jessy *et al.*, 2005). A decline in soil pH was observed immediately after the removal

Table 1. **Change in soil pH under various ground covers**

Type of ground cover	Soil pH at the time of planting	Soil pH after 4 years	Statistical significance
Pueraria phaseoloides	4.88	4.88	NS
Mucuna bracteata	5.02	4.16	**
Natural flora	4.88	5.16	**

** Significant at (P=0.05) *Source: Jessy et al. (2013)*

Table 2. **Soil nutrient status in clean-weeded and no-weeded rubber fields at 0-15 cm soil depth**

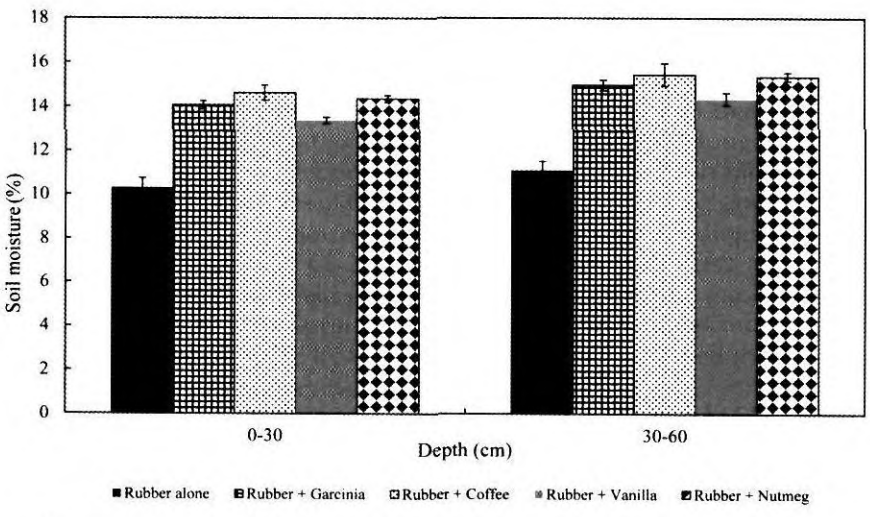
Rubber fields	OC (%)	Total N (%)	Available nutrients (mg kg^{-1})			
			P	K	Ca	Mg
Weeds controlled	2.52	0.21	0.45	7.9	91.2	26.0
Weeds retained	2.98	0.27	0.13	10.3	204.3	62.8
Significance	*	*	**	**	**	**

Source: Abraham and Joseph (2015)

of pineapple (Rubber Board, 2009) strongly suggesting the need for soil test based fertilizer application after the intercropping period to avoid over or imbalanced manuring. Intercropping with perennial crops also improved major and micronutrient status of the soil (Jessy *et al.*, 2017), which might be due to addition of farm yard manure to intercrops. Intercropping improved soil microbial population also in various experiments (Vimalakumari *et al.*, 2001; Jessy *et al.*, 2017). Presence of diverse crops harboured more earth worms as indicated by higher number of earth worm casts (Jessy *et al.*, 2015).

When perennial intercrops are cultivated, the fertilizer dose to intercrops can be reduced to half after canopy closure, since the yield of these crops will be lower than that of monoculture when grown in rubber plantations (George *et al.*, 2012; Jessy *et al.*, 2015).

Retaining natural flora/weeds in rubber plantations increased soil pH, which was apparently due to the high cation content in the litter (Jessy *et al.*, 2013) (Table1). Soil organic carbon status, calcium and potassium contents also significantly improved when natural flora was retained (Abraham and Joseph, 2015) (Table 2).



Source: Jessy *et al.* (2017)

Fig. 3. Influence of intercropping with rubber on soil moisture status (%)

Soil acidity and low content of cations are major constraints for rubber cultivation in India and liming has been recommended for ameliorating acidity and supplementing calcium. Liming is a costly practice and immediate economic gain through liming may not compensate for the cost of liming, which is a constraint for large scale adoption of liming by rubber growers. Retaining natural flora is an alternative low cost strategy for reducing soil acidity and increasing cation contents in soil.

Mitigation of drought by improving biodiversity

Judicious crop mixing improved soil moisture status during summer (Jessy *et al.*, 2015; Jessy *et al.*, 2017; George and Meti, 2018) apparently by preventing sunlight falling directly on the soil during the wintering period of rubber (Fig. 3). Retaining an undergrowth of weeds also improved soil moisture status during summer season (Abraham and Joseph, 2015) (Table 3).

Improving biodiversity through intercrops and weeds -concerns

Though intercropping has several benefits, its success depend on choice of intercrop, the age of the rubber plantation when the crops are introduced and the market price. There is also a growing concern about some of the intercropping practices followed. Pineapple cultivation is generally on lease basis and excess application of fertilizers for pineapple was observed in several case studies and surveys (Rubber Board, 2009; Siju *et al.*, 2013), which is not advisable. In an extensive study on pineapple intercropping, growth of rubber was improved when there was adequate distance between rubber and pineapple, but pineapple very close to the rubber plants reduced growth (Rubber Board, 2009). Indiscriminate tilling of the land for cultivating intercrops by earth movers resulted in high rates of soil erosion from the field (Joseph and Jessy, 2012). Intercrops should be selected judiciously considering the terrain and cultivation of soil disturbing crops should be restricted to level lands and gentle slopes, to reduce soil erosion. All good cultivation practices should be followed judiciously and marketability of the product should be assured before cultivating the intercrops on a large scale.

Retaining undergrowth of weeds also require judicious management. In young rubber plantations, weeds compete with rubber for resources if permitted to grow in the root zone area, which will adversely affect growth of rubber. In mature rubber plantations, weeds growing on the platforms should be managed carefully to facilitate harvesting operations. The possibility of rubber plantations becoming habitats of small wild animals is also a concern to be addressed. This is particularly problematic in regions close to forests where man-wild animal conflicts are on the rise.

CONCLUSION

Improving biodiversity in rubber plantations through judicious crop mixes and retaining undergrowth has multiple benefits like diversification of income sources, conservation of soil and water and mitigation of the risks associated with climate and price uncertainties, which are gaining more relevance in the current scenario.

There are lot of possibilities during initial years for intercropping a variety of crops, two tier or three tier systems harvesting sunlight at different strata and sequential intercropping considering the light requirement of crops will maximize returns. Intercropping improved growth of rubber and sustained soil health. In addition to the tangible benefits there are other advantages like food production, employment generation and cost saving.

Low light availability within the plantation during the mature phase limits the choice of crops after canopy closure. Several shade tolerant crops are suitable for intercropping in mature rubber plantations. Intercropping with long duration crops in rubber plantations either improved or did not influence growth of rubber, reduced weed growth, conserved soil moisture and sustained or improved soil fertility status. Yield of rubber was also not affected by intercropping. There is also the possibility of getting higher yield from long duration intercrops during next replanting cycle particularly during the initial years.

Evaluation of more crops and timber trees with multiple utility in rubber plantations is to be continued for better revenue and ecosystem level services. Modified planting systems release more land and light for intercropping, and such planting designs should be developed for large scale adoption by small holders. Canopy growth of high yielding clones should be monitored, since clones which manifest symmetrical canopy growth pattern under paired row systems of planting and with less canopy density will be more suitable for rubber agroforestry systems. The better exploitation of periodicity in sunlight availability within the plantation and exploiting photoperiodicity of short term crops to maximise income will diversify the cropping systems further. Considering the well documented advantages of integrated nutrient management, farm level generation of organic manure by integrating livestock in the system should be given adequate importance. A homestead approach with diverse components including crops with multi-utility and livestock to meet the various requirements of the farm family will reduce the market dependence of the growers and better empower them to face the challenges. In the cropping systems adopted in India so far, intercrops generated additional income without compromising growth and yield of rubber, but the alternate concept of maximising income from unit area considering the production from all components also can be taken forward for better livelihood security of rubber growers.

Developing agro-climatically suitable and socially acceptable rubber based cropping systems for North East India is also a priority area of research. Employment generation through crop diversification has added relevance in these regions for the social and economic up-liftment of the rural marginalised population. In areas where rubber cultivation is under expansion, consciously designed, productive, stable and resilient permaculture systems integrating agroforestry, farm water management and soil building measures might be more socially and environmentally acceptable and studies along this line are to be taken forward.

Scarcity of labourers and changing grower profile are increasing cultivation of intercrops on lease basis. Indiscriminate mechanization for land preparation for intercrops, over-manuring, unscientific cultivation practices *etc.* affect soil sustainability and awareness needs to be generated among growers for regulating such undesirable practices. Since rubber plantation sector is dominated by small and marginal farmers, strengthening community capacity for marketing and value addition of farm produce is also crucial for ensuring better revenue and increased adoption of various cropping systems.

Retaining weeds or natural flora without affecting growth of rubber and harvesting operations improves soil health and reduces cost of weed control apart from mitigating drought. It is also a viable low cost strategy to reduce soil acidity and increase content of cations which are the major fertility constraints in rubber growing areas. Nutrient dynamics also varies with the type of weeds and needs further study to exploit these natural strategies for improving soil health. A rubber ecosystem with diverse vegetation-crops and weeds judiciously managed will be ecologically and economically more sustainable and may need careful social engineering to trigger the shift in this direction.

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