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Is rubber plantation threat in Tripura? A review on consideration of eco-environmental and socio-economic impact

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Abstract
Initially, the *Havea brasiliensis* was introduced in Tripura, a Northeastern state of India for ecological benefit, primarily for restoration of soil erosion in denuded forests. Subsequently, such plantation was linked to resettlement of tribal Jhumias (Shifting cultivators), which also revolutionized the socio-economic conditions of the concerned populace as it has been found as a lucrative alternative to shifting cultivation among the tribal population of the state. Subsequently, it has also been taken up by other sections of the populace too.
But, globally, as well as in Tripura there are now voices that, expansion of rubber plantation has negative consequences on local climate resulting decrease and change in local rainfall, negative impact on local thermal climate, depletion of sub-surface water, reduction of flow of stream resulting drier catchment, deterioration of soil quality and loss of biodiversity. Even there are voices that it has negative impact on certain sections of the concerned populace in socio-economic aspects too.
In the present paper, it has been tried to review all these aspects based on available literature on the studies carried out in different places in the globe including in Tripura and on that basis, it be asserted that, in Tripura situation, it has not made impact on changes on microclimate (rainfall, thermal climate, ground water and flow if streams). Played positive role in enriching soil fertility, preventing soil erosion and even in increasing both above and below ground biodiversity.
However, precautionary emphasis should be on addition of other plants/intercropping instead of single-species both in existing and future plantations. Expansion be restricted to suitable area classified on the basis of landscape ecological analysis. For further expansion, if any and for long term planning for plantations including rubber, another landscape ecological analysis be undertaken on the basis of up-to date status.

Keywords: *Havea brasiliensis*, monoculture, biodiversity, micro-climate, Socio-economic impact

Introduction
Civilization as we know today cannot be thought of in absence of 'rubber'. The 'rubber' refers to a group of materials which are highly elastic, hydrocarbon polymer; may be synthetic as byproduct of petroleum industry, or natural, a byproduct of certain plant cell metabolism.
In plants, it occurs as milky, colloidal suspension, known as 'latex', in the sap of certain varieties. Though, no fewer than 8 botanical families, 300 genera and 2500 species have been found to produce natural rubber in their latex, the *Hevea brasiliensis*, which is also called 'para rubber tree', a member of spurge family Euphorbiaceae occupies an important position (Venkatachalam *et al.*, 2013) [99]. It is the source of virtually all the world's commercial natural rubber production. It is a native tree species of Amazon basin. It has been successfully introduced as a cash crop in many developing countries, especially in Southeast Asia to produce natural rubber (Thomas and Panikkar, 2000; Nath *et al.*, 2010) [95, 72].
In India, the hinterland of southwest coastal region comprising of the state of Kerala and adjoining Kanyakumari District of Tamil Nadu is recognized as 'traditional rubber belt'. That area reached to a saturation level in area coverage. Therefore, the non-traditional areas are now in focus. In non-traditional areas, the Northeastern region is emerging as one of the most important rubber growing zones (Sinha, 2007) [89]. Among Northeastern states, the state of Tripura ($23^0 50'$-$24^0 32'$N, $91^0 10'$-$92^0 21''$S) is fore runner (Roy, 2014) [80].

Entry and take-off in Tripura: An Overview

Far ahead of recent political and economic reforms which facilitated shift in agriculture away from shifting cultivation and towards a diverse array of cash crops, among which rubber being one of the foremost (Ziegler *et al.*, 2009) [103], in Tripura, the *Havea brasiliensis* was introduced in early fifties of the last century in Tripura for ecological benefit, mostly in barren field or in denuded forests or on the lands effected by continuous shifting cultivation for restoration of soil erosion (Bahuguna, 2006; Sinha, 2007) [14, 89], as it was valued for its capacity for giving soil cover in soil conservation afforestation program (Bahuguna, 2006) [14].

Thereafter, effort was made to link it with the resettlement scheme of tribal jhumias (Shifting cultivators) in 1976, which in fact later on revolutionized the socio-economic condition of the concerned beneficiaries.

In 1976 with the establishment of Tripura Forest Development and Plantation Corporation Limited (TFDPC Ltd.), the Government of Tripura took up the issue for improvement of degraded forestlands as a principal strategy and simultaneously to wean away a cluster of tribal families of Warangbari from shifting cultivation by providing wage employment through rubber plantation (Sinha, 2012) [90]. Sinha (2012) [90] also mentioned that, in a queer coincidence, soon thereafter, the Soil Conservation Department of undivided Assam had also raised rubber plantations, and according to Bhattacharya (1992) [15], TFDPC Ltd like public sector organization also came up in Assam, Meghalaya, Mizoram, Nagaland and Arunachal Pradesh of Northeastern states, but it was in Tripura only the enormous potential was promptly realized and pursued (Sinha, 2012) [90].

It is also fact that, though later on it has been experienced that through rubber plantations, the shifting cultivators of the state could improve their socio-economic conditions, initially the beneficiaries have not took it spontaneously, rather they reacted against the endeavor (Bhattacharya, 1992) [15]. In Warangbari, soon after the site clearance had began, concerned community got wary of permanent loss of land for shifting cultivation and an array of other livelihood necessities that the land delivered, which resulted protest *en masse* (Sinha, 2012) [90]. On the face of that determined protest, the government had to accept their unusual demand for commitment to allot the planted land to them on maturity. The families thus worked on daily wages under the corporation for establishment of rubber plantations in government land, which were allotted to them subsequently on maturity. It was amazing that, protest of the beneficiaries gave birth of a system design of rehabilitation of shifting cultivators in Tripura where wage labourers of the plantations acquired the status of owner of the plantations having steady income. In fact in Warangbari and subsequent endeavor in other places of the state this has played vital role in making rehabilitation of shifting cultivators' success (Sinha, 2007; Roy *et al.*, 2015) [89, 82]. Hence, the said scheme better be designated as peoples initiative.

Initially, the Rubber Board of India too did not show interest towards expansion of rubber in Tripura, rather argued negatively on the ground of harsh winter and protracted dry season of the state (Sinha, 2012) [90]. But, when the 'traditional rubber belt' of the country reached to saturation and demand of natural rubber increased, the situation compelled them to search for non-traditional areas. Side by side from trials in mid 1970s in Tripura by the Forest Department, they came to realize that, as *Hevea brasiliensis* is fairly adaptable to some deviations from the ideal climatic requirements and as adverse impacts to an extend can be moderated through management, it will have prospects in Tripura (Sinha, 2012) [90]. Therefore, they took interest and set up initially one man office in 1967 and upgraded it to a regional office in 1979 at Agartala for undertaking development and extension activities (Paribalam, 2006) [75]. In the same year, a Regional Research Station too was established for undertaking location specific research. On the other hand, the Warangbari experience induced the state government too to establish a separate agency named Tripura Rehabilitation Plantation Corporation Limited (TRPC Ltd.) in 1983, solely for rehabilitation of marginal tribal families on rubber plantations. These events, no doubt acted as impetus in rehabilitation scheme of shifting cultivators through rubber plantations in Tripura.

The endeavor again got new dimension on introduction of World Bank aided Block Plantation scheme in 1992-93 (Bhowmik, 2007) [17], coinciding with initiation of global economic reforms (Roy *et al.*, 2015) [82]. Scheme was designed on the basis of earlier experiences. Important key features were: minimum 50 hectors contiguous land, each beneficiaries had to have clear land title, beneficiaries had to hand over the land to Rubber Board for a period of 7 years, they were expected to work as labour and also engage other family members in the plantation, the beneficiaries had to agree to form a Rubber Production Society (RPS) after the period of maturity of the plantation, further plantation had to be given for 2 more years to the Rubber Board for stabilizing harvesting, processing and linking up for marketing before finally and fully handing over the plot back to beneficiaries with mature plantations (Matouleibi, 2012) [66].

In Tripura, as the beneficiaries at least at initial stage mostly were poor tribal, it can also be designated as 'Rubber for the Poor' project. In human development report of the state published in 2007, it has been mentioned that, the Tripura experiment was modeled on the experiment of the Kerala rubber economy, where the 'Rubber for the Poor' project attempted to provide tribal and other marginal farmers with a steady income (Anonymous, 2007) [7]. This also has been supported by Sinha (2012) [90], as he mentioned that, desire of replication of Kerala success of commercial rubber plantation in Tripura have played role.

In overall, from Government of Tripura, the Forest Department, two agencies, *viz*., TFDPC and TRPC, the Department of Tribal Welfare, the Department of Rural Development, Sub-Divisional Administration, the Tripura Tribal Areas Autonomous District Council (TTADC), from government of India, the Rubber Board and the World Bank made contribution to make rehabilitation of shifting cultivators a success.

Finally, taking into consideration of agro-climatic suitability, established evidences of excellent venture for settling tribal jhumias (shifting cultivators) permanently and positive role in improvement of soil health, as per recommendation of National Bureau of Soil Survey and Land Use Planning (NBSSLUP) on the basis of bio-geographic analysis the Government fixed target to cover 1,00,000 hecters land out of total 1.05 hecters land in the state, which is only less than 10 per cent of the total geographical area of the state. Against the said target, till 2014-15 area covered by rubber plantation is 70,295 hecters

(Chakraborty, 2018) [22], which is only 6.69 per cent of the total geographical area and 70.29 per cent of the target and hence, there is scope to expand in further area of 29,705 hecters.

Natural rubber Vs. Synthetic rubber: Environmental Advantage

Natural rubber is an unusual industrial material, not only of natural origin, but also renewable in nature (Jones, 1997) [47]. It also takes less energy (Rahman, 1994) [78]. While to produce 1 ton of synthetic rubber (finite product) energy requirement is between 108 and 174 GJ, the same amount of natural rubber only takes 13 GJ (IRRDB,1998). Therefore it is postulated that, natural rubber is inherently environment-friendly (Jones, 1994; Wan and Jones, 1996) [46, 100].

Moreover, in contrast to synthetic rubber, which consumes energy and produce CO_2 to convert pure energy (crude oil) into elastomers, the natural rubber plant absorb CO_2 to meet the need to produce latex inside the tree (Jones, 1997) [47], thereby plays role in minimizing global warm.

Further, in recent times, on development of protocols for processing rubber wood, apart from 'latex', when the productive period is over, the tree is being used as 'timber'. In early nineties of last century, the International Trade Centre estimated that, globally 0.6 million hecters of tropical rain forest can be conserved with the utilization of economically available rubber wood, which indirectly can play role in conserving biodiversity. The estimates further showed that, if all the available physical potential of rubber wood are in use, an additional 0.3 million hecters of tropical rain forests can be saved. Even India can be able to save 20,000 hecters rain forest on an annual basis (Dhamodaran, 2008) [33].

Synthetic rubber too has got advantages over natural rubber in certain aspects, one of which is related to biodiversity. It does not cause loss of biodiversity, whereas rubber plantation when takes place on commercial scale replacing natural vegetation, destructs biodiversity. Perhaps, this is the largest drawback of the rubber plantations from the eco-environmental point of view (Bhowmik, 2006) [17].

Hence, expect its negative impact on biodiversity (that to when planted on replacement of mixed/natural vegetation and its monoculture), considering its natural origin and renewable nature, capability of playing role in minimizing global warming, requirement of less energy and potentiality to save huge area of rain forest, it can be concluded that, natural rubber is environment-friendly in comparison to synthetic rubber.

Advantage of '*Hevea*' as a species as/over other trees

Hevea brasiliensis is deciduous and indigenous to the tropical rain forests of Amazon basin (Thomas and Panikkar, 2000) [95]. Due to its robust nature and economic importance, its cultivation has since extended away from the equator to latitudes as far as 29^0 N in India and China, down to 23° S in Sao Paulo state, Brazil (Rahman, 1994) [78]. As deciduous, wintering causes decrease in photosynthesis (falling nearly to zero because of annual leaf exchange) for short spell of time, say for little more than one month (Moreira *et al.*, 2009) [69]. But, due to its heavy canopy owing to large leaf area index (LAI), often 6 or more, particularly beyond a certain age of growth (Devakumar *et al.*, 1998) [32] shows better photosynthesis in overall. According to Rahman (1994) [78], beyond a certain age of growth, rate of photosynthesis is even comparable to that of forest ecosystems. According to Jones (1997) [47], it is probably at least equal to that of virgin forest and may even exceed it. The photosynthesis rate of a mature rubber leaf is 10 to 15 *u*mol CO_2 per m^2 per second as compared to 5 to 13 *u*mol CO_2 per m^2 per second in many other trees (Sethuraj and Jacob, 1997; Nataraj and Jacob, 1999) [88, 71].

Thus, due to large LAI, high rate of photosynthesis, it is reported to be relatively efficient converter of solar energy into dry matter production, even comparable with virgin jungle, especially once the tree reaches maturity (Rahman, 1994) [78] and in that way plays role as carbon sink in assimilating carbon from atmosphere. Physiological studies have shown that *Hevea* is more effective than teak in taking up CO_2 (Sethuraj and Jacob, 1997) [88].

Hence, it can be inferred that, the *Hevea brasiliensis* occupy advantageous place as that of forest species or even better in purifying atmosphere by assimilation of CO_2 in photosynthesis and releasing O_2 as byproduct of photosynthesis.

Role in Carbon sequestration

With the recognition of increasing green house gases (GSHs) in atmosphere due to human intervention, resulting in global warming, attention has been drawn in attempting minimizing carbon from the atmosphere by adopting appropriate actions. The plants can play role in this respect. However, there is an argument that, the old-growth forests store carbon for centuries, whereas plantations and young forests are actually net emitters of carbon due to disturbance of the soil and the degradation of the previous ecosystem. But, when there is question of choices among plantations both for economic and environmental causes, as in Tripura, where even forests too consist of mainly of plantations, the rubber plantations have glittering opportunities (Roy *et al.*, 2014) [80].

Review of several studies indicates that, natural rubber plants are good sink for atmospheric CO_2 (Brahma *et al.*, 2016; Jacob, 2003) [20, 43]. Amount of carbon fixed in the rubber tree has been assessed in different genotypes and geographic locations (Sivakumaran *et al.*, 2000; Wauters *et al.*, 2008; Annamalainathan *et al.*, 2010) [93, 101, 5]. On an average a rubber tree is capable of fixing approximately one MT of CO_2 during its 30-year economic life cycle and therefore, within a hecter of rubber having over 300 trees, a minimum of 300 MT of CO_2 is fixed.

Cheng *et al.* (2007) [23] also compared the carbon sequestration of *Hevea brasiliensis* with rain forest and secondary rain forest in Hainan Island of China and estimated that, the carbon sequestration of rubber trees per hecter accounted for 272.08 tons within 30-year life period (57.91 per cent was fixed in litters), whereas in case of rain forest and in secondary rain forest those were 234.305 tons and 150.203 tons respectively.

Study conducted in Barak Valley, part of North East India revealed that, in rubber plantations with density of 688-784 trees per hecter, above and below ground biomass increase is 41 Kg (under 5-10 years age group of plants) to 307 Kg (under 30-40 years age group of plants) per tree (Brahma *et al.*, 2016) [20]. Total vegetation carbon stock (Mg h^{-1}; above and below grounds) ranged from 16.00 (under 5-10 years age group of plants) to 105.73 (under 30-40 years age group of plants), which is more than many tropical forestry and agro-forestry systems across the world. From the said study,

the vegetation carbon sequestration rate revealed that, *Hevea brasiliensis* accumulate 2.56 Mg organic carbon per hecter per year.

Impact on rainfall

Certain studies in Kerala indicate that, significant decrease of rainfall has taken place (Meher-Homiji, 1980; Soman *et al.*, 1988) [67, 92], and there is a tendency to blame expansion of rubber platations for that. Similarly, in Tripura too, not only among lay people, even in certain literature though not supported by valid scientific data concern has been raised of rainfall deficit due to rubber plantation (Majumder *et al.*, 2014) [63]. But, the fact remains that, though the rubber plantation is artificial vegetation, group of scientists are of the view that, they exhibit similar hydrology to rain forests (Jiang and Wang, 2003; Tang *et al.*, 2011) [45, 94].

The Amazon River, the basin of which is the homeland of the *Hevea brasiliensis*, carries the most amount of water of all the rivers in the world and hence, even if there is any decrease in rainfall in Kerala or in Tripura at all, than too, it will be ironical to blame rubber plantations *'per se'* for that decrease. Decreasing trend reported from Kerala or from other places might be due to deforestation resulted due to replacement of natural vegetation by rubber plantations, unlike in Tripura. In Tripura, in over all green cover has increased due to rubber plantations (Nath *et al.*, 2010) [72],

In Tripura, though changes of seasonal distribution of rainfall in the state are being experienced, the trend analysis of 20th century does not indicate any significant decrease in annual rainfall (Bhattacharjee, 2002) [16]. Analysis of the database corresponding the period 1984-2008 of Agartala too indicates no decrease in annual rainfall, though changes of distribution pattern has been observed (Sailajadevi, 2010) [86].

In Hainan Island of China, massive changes of land use and land cover have occurred due to replacement of forests (11.6% rubber plantations in total forest coverage), farmland and traditionally managed fallow land. Based on 40 years (1951-1990) climatic data of that Island comprising of 19 counties, analyzing the hydrological dynamic characteristics of rubber plantations and estimation of the water balance in the rubber plantations, the researchers came to conclusion that, there is no impact on local rainfall (Jiang and Wang, 2003) [45].

Based on the above and analyzing the Tripura situation it can be concluded that in no way rubber plantations of Tripura caused local rainfall deficit or its change in pattern. Rather, as it has increased total green cover (Nath *et al.*, 2010) [72], if any impact, it be increase in rainfall, but, as the data do not support tha, it be assumed that, such increase have no significant impact. The real fact is that, most of the rainfall in Tripura is brought by the climatic condition of the Bay of Bengal and wider geographical areas beyond the boundary of the state (Bhattacharjee, 2002; Roy, 2014) [16, 81].

Effect on thermal climate

From the analysis of the database corresponding 1984-2008 of Agartala (Sailajadevi, 2010) [86], it appears that, there is increase in minimum temperature at a rate of 0.05^0C per year, and increase of minimum temperature in all seasons, though no change in mean annual maximum temperature. Further, increase of maximum temperature at a rate of 0.04^0 C, while non increase of hot days during summer, increase of hot days at the rate of 0.9 days per year and decrease of cold night at a faster rate at the rate of (-) 1.7 days per year. But, as mostly the rubber plantations in Tripura are in barren field or in denuded forests (that too mostly plantations) or on the lands effected by shifting cultivation, rubber plantations cannot be made responsible.

Rather, as rubber plantation has increased the overall green cover, it might have played role in minimizing temperature. Overall changes in thermal climate resulting in slightly warmer weather may be due to the other factors mostly related to global warming.

Impact on flow of stream and Ground water

Number of researchers has reported that, the introduction of rubber plantation can reduce the flow of streams, and lead to drier conditions throughout the catchment area (Guardiola-Claramonte *et al.*, 2008; Anonymous, 2015) [36, 10]. But, analysis of the same studies reveals that, it is not for rubber plantations '*per se'*, for concerned land use change, which affected the stream flow and water use pattern, which is different that of Tripura situation.

In studies, conducted on river flow in several river systems in Tripura, including in Haora, Gumti and Muhuri (Bera and Namasudra, 2016; Debnath *et al.*, 2015; Dey, 2014) [13, 27, 28], though reduction in flow in streams and siltation in river beds has been reported, for such effect they made responsible to several anthropogenic activities including vegetation loss in upper catchment, but, not to rubber plantation.

High water uses by rubber plantations and water depletion in basins where they are grown have also been reported (Guardiola-Clamonte *et al.*, 2008, 2010; Qui, 2009; Tang *et al.*, 2011) [36, 37, 77, 94]. Significant deep root water uptake during leave flushing coinciding with the driest and hottest period and greater annual catchment water loss through ET (Evapo-transportation) compared to traditional vegetation cover has also been predicted (Guardiola-Clarmonte *et al.*, 2008) [36] and even rubber has been referred as 'water pump'(Qui, 2009) [77]. But, in several studies it has been disputed that the high rate evapo-transpiration could deplete ground water tables and reduces soil moisture, as the data are too sparse to quantify the extent of the impacts (Ziegler *et al.*, 2009) [103], which indicates that, such prediction is not based on sufficient research on the evaluation of the extent of hydrological threat and hence, Dr. A. D. Ziegler of National University of Singapore is of the opinion that we should be cautious in using the term 'water pump' (Anonymous, 2012) [9].

Rather, according to TICA, 2010 in investigation conducted at the instant of the Government of Thailand, no conclusive evidence has been found of any drop in the groundwater table or reduction of soil moisture under a rubber plantation (Raj and Roy, 2012). On the other hand, there are evidences that the rubber trees utilize much less water than many forest species for a comparable biomass production (Krishnakumar and Meenamattor, 2003) [57].

From Tripura too, there is report that, the levels of ground water remained the same even after introduction of rubber plantation (Bhowmik, 2006) [17]. In contradiction, Sinha (2012) [90] reported that, drying of hill streams and the village wells are being noticed now and for that reason the concerned villagers and civil society are blaming the large scale substitution of indigenous vegetation by rubber plantation. But, these reports/observations are also lack of scientifically reliable data.

On the other hand, data in State Environment Report – 2002 of Tripura reveals that, there is not all decline in ground water level in the state for 0 to > 4 m, rise in the ground water level at 0-2m level has been noted in 42.11 per cent, at 2-4m level the figure is 57.89 per cent and above 4m level no rise (Anonymous, 2002) [6].

Moreover, as the rubber plantations in Tripura mostly are on bare land or in denuded forests (that too mostly plantations) or on the lands effected by shifting cultivation and hence substitution of natural vegetation is negligible, and as in overall, for that, as green cover increased, have no adverse impact on ground water.

However, for scientifically valid conclusion, comparison of catchment water loss through evapo-transpiration (ET) from rubber dominating landscapes and general vegetation cover similar to original displaced vegetation in Tripura situation is needed.

Impact on soil health

Number of researchers has reported positive impact of rubber plantations on soil health including in Tripura (Aweto, A.O., 1987; Cheng *et al.*, 2007; Jacob *et al.*, 2000; Joshep, 1991; Krishnakumar and Potty, 1992; Mandal and Pal, 2010; Rahaman, 1994; Eappen *et al.*, 2005) [11, 23, 42, 48, 54, 10, 78, 34] and even reported that rubber plantation is comparable to forest tree species in terms of its impact in soil on texture, bulk density, moisture and can be grouped with sal in the same cluster (Thomas *et al.*, 2000) [95]. Negative impact on soil health also has been reported by number of researchers (Anonymous, 2015; Balagopalan, 1995; Guillaume *et al.*, 2015; Karthikakutty Amma *et al.*, 1996) [10, 12, 52].

Restoring soil erosion: We know that nutrients are naturally available in top soil and the soil erosion decreases the nutrient of soil, it is a problem. But, from analysis of different observations (Philip *et al.*, 1996; Sethuraj, 1996; Jacob, 2000) [76, 86, 42], it appears that, 'as plant', the rubber can play role in restoring soil erosion.

Comparison of soil texture of soil under 10 – 15 years old rubber plantation with adjacent fallow / Jhum land in Tripura revealed that, by adopting proper agro-management practices, rubber plantation helped in the enrichment of soil organic matter which in turn improved soil-nutrient storing capacity, soil porosity, moisture retention and infiltration rate of rain water (Krishnakumar *et al.*, 1990) [54]. Moisture retained at field capacity was 5.4 per cent higher under rubber soil. The increase in soil moisture under rubber plantation is attributed to higher organic matter which has an aggregating properties. It has also been seen that, about 90 per cent of available moisture was desorbed from surface layer in rubber plantation at tension of 0.5 Mpa. The corresponding values of Jhum land were 67 per cent only. The above tension limit has been reported to be of permanent importance for moisture availability vis-à-vis nutrient uptake by the rubber plant. The initial rate of infiltration under rubber plantation was 67.5 per cent higher than that of fallow land and after attaining steady state, these values were further increased up to 125-138 per cent. This has a practical significance, as high rate of infiltration reduces surface run-off and soil erosion (Krishnakumar *et al.*, 1990; Mandal and Pal, 2010) [54, 10].

The root concentration in rubber plantations occurs in the top 18 cm of the soil and horizontally they spread up to 2 meters from the plant base (Philip *et al.*, 1996) [76]. Being a surface feeder, rubber tree affords good soil binding and reduced erodibility of soil considerably (Sethuraj, 1996) [87]. The thick canopy helps to cut down direct radiation and intercepts rain. According to Rahman (1994) [78], once the trees have established a complete canopy, the rate of run-off generally differs little from that for similar areas with natural forest. Thus, soil moisture status is improved and soil erosion is prevented. The reduced soil temperature leads to reduced oxidation of soil organic matter and favour its built up (Jacob, 2000) [42].

The negative impact on soil erosion due to rubber plantations (Anonymous, 2015) [10], is due to replacement of natural vegetation associated with erodibility risk of that particular soil on which rubber plantations has been raised and on the techniques adopted for that particular plantations, not for rubber '*per se*'. Observations in Tripura are contrast, where it has prevented soil erosion in state specific situation, where improvement of the bare soil, soil of denuded forests as well as areas subjected to continuous shifting cultivation is a challenging task as exposure of the bare soil to the sun and the impact of rainfall lead to accelerated decomposition of the organic matter, leaching of nutrients, breakdown of the aggregate structure of the surface soil, diminish infiltration and increase run-off and erosion of soil (Rahaman, 1994) [78].

Physical and nutrients status: Krishnakumar *et al.* (1991a) [59] examined soil properties, nutritional enrichment, under storey vegetation and biomass recycling under rubber and natural forest. Based on the study, they opined that, rubber plantations present almost a closed ecosystem, in a near steady state during their life span.

In Tripura, it has been found that, its plantations enrich organic matter which consequently improves physical properties such as bulk density, soil porosity, moisture retention and infiltration (Krishnakumar *et al.*, 1990) [54]. Joshep (1991) [48] also reported that, the nutrient recycling through litter decomposition is very rich; as a result significant accumulation of organic matter to the soil takes place, which helps to improve soil organic matter and water content. Eappen *et al.* (2005) [34] also conducted a comparative study on the influence of different forest species, *viz.*, Sal (*Shorea robusta*), Acacia (*Acacia auriculiformis*), Cashew (*Anacardium occidentale*), Teak (*Tectona grandis*) with rubber (*Hevea brasilensis*) in Tripura and found that, the influence of the rubber plantations on soil properties are comparable to other tree plantations particularly Sal and Teak. Raj and Roy (2012) has estimated that because of deciduous nature of rubber tree, 1 hectare of matured rubber plantation can add 7 to 8 tons of dry leaf annually, enriching the soil environment. According to them, studies in Tripura found that decomposition of these litter added 94 to 130 Kg Nitrogen, 5 to 6 Kg Phosphorous and 22 to 25 Kg Potassium per hectare enriching the soil fertility every year. Organic matter content of soils under rubber has also been found be on increasing.

However, there are also reports that, organic carbon and nitrogen reduces in the soil under rubber plantation (Anonymous, 2015; Balagopalan, 1995; Guillaume *et al.*, 2015; Karthikakutty Amma *et al.*, 1996) [10, 12, 52], but, analysis reveals that, that is also not for rubber '*per se*', but for loss of top soil due to soil erosion, resultant of loss of

green cover due to replacement of natural vegetation. Moreover, in comparison of degraded forest and the land under different plantations, it has been observed that, rubber plantations show higher value of organic carbon and nitrogen (Anonymous, 2015; Karthikakutty Amma *et al.*, 1996) [10, 52].

In Tripura, impact on physical and nutrient status needed to be assessed on the basis of ground situation. A team of ICAR Research Complex for NE Region, Tripura reported that, shifting cultivation decline in soil pH, organic carbon, available nitrogen, available phosphorus, available potassium (Datta *et al.*, 2001) [26]. Mandal and Pal (2010) [64] also observed that the shifting cultivation usually proceed by clearing of vegetation and burning the organic debris, which lead to destruction of organic matter, soil structure, thereby decreas the soil fertility and soil microbial population as well as reduce water intake capacity of soil due to deposition of hydrophobic aliphatic hydrocarbons. In such a situation, in Tripura, the rubber plantation has shown credibility to improve the physical (bulk density, porosity), chemical (nutrient availability), and biological (soil microbe) properties of the soil (Krishnakumar *et al.*, 1991a; Krishnakumar and Potty, 1992) [59, 56].

Issues on biodiversity

Environmental consequences of rubber plantation replacing natural vegetation and also traditional land use practices have been a matter of serious concern among the natural rubber producing countries across the world (Fox, 2014) [35]. Significant loss of both above ground and belowground biodiversity has been reported by number of researchers due to land-cover transitions to rubber monoculture (Li *et al.*, 2007, 2008; Nath *et al.*, 2010; Ziegler *et al.*, 2009, 2009a) [61, 62, 72, 103, 104]. Ziegler *et al.* (2009) [103] reported the case of conversion of natural forests into rubber plantation and associated environmental issues in the mainland South East Asia, where rubber plantation coverage was five lakh hectares in 2001and by 2050 it may be tripled.

But the question arises; weather the species '*per se*' is responsible? Whether as Species the *Havea brasiliensis*, have any extra-ordinary antagonistic properties towards other form of life in ecosystem? Rather Jacob *et al.* (2002) [44] reported high population of fungus, bacteria and actenomycetes in the soil of unmanaged rubber plantation compared to teak or jarul plantation. Pal and Dey reported natural vegetation like ferns, grasses, herbs and shrubs in soil surface of the rubber plantation. Abraham and Abraham (2000) [1] reported 88 species of weeds in rubber plantation in Kerala. Pal *et al.* (2006) [74] observed presence of herbal medicine too. According to Kox (1990) [53], the leaf coverage and the root system of rubber trees regulate the microclimate allowing a range of secondary plants to flourish and the trees also offer habitat for a great variety of fauna.

In a comparative study of the plantations of *Hevea brasiliensis*, *Tictona grandis* and natural forest in north Bengal in India, where for considerable years there were no anthropogenic interferences/disturbances, it was found that in terms of total number as well as in terms of diversity of living organisms, the rubber plantation is rich and almost nearer to natural forest (Krishnakumar *et al.*, 1991) [58]. Number of plants, herbs and shrubs were more in rubber plantation in comparison to *Tictona grandis*. In natural forest, monocot plants were recorded 20,000 numbers per hectares and diocot plants 60,000 numbers per hectares, whereas in rubber plantation these were recorded 18,000 and 80,000 numbers respectively.

In Tripura, from rubber plantations, Krishnakumar *et al.* (1991) [58] recorded 50 species of plants. A comparative Study of the flora under different plantations in Tripura was also carried out by Chakraborty *et al.* (2002) [21], and recorded highest number of species (40) in rubber plantations followed by Sal (34), Cashew (33), Acacia (28) and Teak (17). Majority of the species in rubber plantations were abundant or frequent with 9 species of rare occurrence. Distribution pattern of the weed species in land under other agricultural crops in the locality also tally with the said observation in rubber plantation. Ratio of the monocots to dicotos in rubber plantations in Tripura also has been reported by Deb (1981), which is at par with the monocots to dicots ratio of flora of the state. Mukherjee *et al.* (2000) [70] reported Nematode association in rubber plantation in Tripura and Karmakar *et al.* (2001) [55] reported acromycoflora association. Mandal *et al.* (2001) also reported higher population of fungus, bacteria and actenomycetes in the soil of rubber plantation in Tripura. Some orchids and lichens has also have been noticed to be growing in the mature rubber plants in Tripura (Dey, 2004; Mandal and Pal, 2011) [65]. Survey conducted by Choudhury *et al.* (2008) on earthworm species in rubber plantations of Tripura with reference to their diversity, biomass, density, frequency and distribution revealed the presence of at least 20 species of earth worms belonging to 10 genera and 5 families. The presence of earth worms in rubber soil indicates that the soil health is hospitable to micro flora (Dey, 2011) [29].

According to Kox (2000) [53], the leaf coverage and the root system of rubber trees regulate the microclimate allowing a range of secondary plants to flourish, while the soil is protected against dehydration and the erosive influence of rain. Kox (2000) [53] also mentioned that, the trees also offer a habitat for a great variety of fauna. Jones (1997) [47] also reported that, biodiversity remains remarkably high in rubber plantation in marked contrast to most other forms of monoculture.

Therefore, in the case of Tripura, it has also to be taken into consideration that, unlike in other places, in Tripura, as mostly the rubber plantations are on bare soil, on soil of denuded forests as well on areas of subjected to continuous shifting cultivation, it has resulted both in increase in above ground and below ground biodiversity.

It should also to be taken into consideration that, as species, by inherent nature, it does not possess the characteristics which result in almost clear ground devoid of flora and fauna, rather co-existence of different forms of life in natural vegetation of rubber in Amazon basis prove opposite. Where such plantations are due to replacement of natural vegetation, causes loss of biodiversity, and in fact globally it is happening and in fact in spite of the presence of different forms of life in rubber plantations as mentioned above, globally destruction of biodiversity is being taken place for promotion of monoculture of rubber to meet the industrial need and as a result loss of biodiversity. Therefore, recently this phenomenon is being termed as 'green desert' by the environmental activists. (Roy *et al.*, 2014) [81].

Monoculture vs. Inter-cropping

The single-species plantations are thought to offer less favorable habitat than natural forests (Hartley, 2002; Hunter, 1990) [39, 41] and have a reputation of being 'biological deserts' (Allen *et al.*, 1995) [3].

Available research findings on recent expansion of rubber plantation reveals that, the loss of biodiversity, in fact, is due to replacement of natural vegetation, and that replacement by monoculture, not due to rubber as species '*per se'*. If, there is large scale monoculture, and if it in replacing natural mixed vegetation, it possesses threat in ecology in terms of loss of biodiversity.

Again, apart from that, other threats are that, the monocrop draws on same nutrients with uniform rooting system resulting imbalances in soil nutrient stock and the susceptibility to disease.

Thomas *et al.* (2015) [96] brought out the concentration of rubber plantation areas of Southeast Asian countries in comparison to worldwide extent, which reveals that, the monoculture of rubber are expanding in Southweast China, Laos, Combodia, Mynamar, northwest of Vietnam replacing natural vegetation, leading to large scale decrease in the region's forest cover. The Kerala experience from India also reveals that, in the said state, rubber plantations are mostly in replacement of natural vegetation and replacement of small holding crops such as tapioca, cashew, coconut etc. (Anonymous, 2015) [10].

In Tripura, though mostly in earlier effort, rubber plantations were on barren field or on denuded forests (that too mostly plantations) or on the lands effected by prolonged and continuous shifting cultivation, recently being expanded in substitution of indigenous vegetation (Sinha, 2012; Roy *et al.*, 2014: Roy *et al.*, 2015) [90, 81, 82]. Mapping of the rubber plantation areas in Barak basin of the North Eastern India in selected sub-watersheds in parts of North Tripura, Mizoram and major portion of Karimganj district of Assam using temporal satellite data of IRS LISS III of 23.5 m resolution revealed that, the plantations took place even in dense forests, open forests apart from in degraded forest areas (Chakraborty *et al.*, 2018) [22]. Nath *et al.* (2010) [73] raised concern that, though in Tripura, the rubber plantations have increased green cover, in most of such plantations, there are only standing trees and clear ground with dry leaves, which does not sense true forest.

There are also concerns that, there are attempts even for rubber monoculture in forest lands (both planted and natural) illegally, on the lands distributed by the Government under Scheduled Tribes and other Traditional Dwellers (Recognition of Forest Rights) Act., 2006 and on the privately owned agro-forestry (occupied by horticultural crops) lands. Owners of some privately owned tea garden are also attempting to replace tea plantations with rubber monoculture.

However, Dey (2011) [29] and Dey *et al.* (2014) [30] cited number of successful examples of intercropping with rubber in different places including from Tripura. Rubber plantations usually take about 7-8 years to begin production. The canopy usually closes at the end of the 5th year. Up to 5th year inter rows can be effectively used for growing intercrops. A variety of intercrops has been cultivated during initial years of a plantation. Intercropping of banana and pineapple during the initial years in the immature stage is very popular in different states. Similarly, the crops like ginger, turmeric, pigeon pea, sesame, groundnut, chilli and vegetables like ladies finger, cowpea, amaranthus and cucumber has also been cultivated in different situations in the initial years. Tuber crops like Amorphophallus, diocorea, colocasia and arrowroot also cultivated. Other crops including upland rice, mungbean, soyabean, corn, cassava, castor bean, jute etc. were cultivated in rubber plantations in Thailand. In China, many forms of mixed farming have been practiced in rubber plantations. Perennial crops like Cocoa and Coffee can be grown as intercrop in mature plantations. The growers in China, Sri Lanka and some parts of India have been growing tea in rubber. Rubber trees have been intercropped with tea bushes, sugarcane, pineapple, pepper, cinnamon apart from various cover crops like *Calopogonium mucunoides*, *Centrosema pubescens* and *Pueraria phaseoloides.* The shade loving plants such as orchids, vanilla and some species of medicinal plants were also grown in mature plantations. Shade tolerant medicinal plants like *Strobilanthus haenianus*, *Adhatoda vasica* and plumbago roses are also being cultivated in rubber plantations. Timber yielding species such as *Terminalia arjuna*, *Albizzia procera* and *Acacia auriculiformia* are being planted in border rows as wind belt in rubber plantations.

We cannot ignore that, ecologically, in comparison to 'natural forest', the 'man made forest' is fragile (as 'man made forest' possess less biodiversity as well as less number of living organisms) and among man made forests/plantations, monoculture is more fragile, but, monoculture is better than no plantation or barren field (Roy *et al.*, 2014) [80]. But, unrestricted expansion of rubber, that too of monoculture should be strictly checked. We also need more realistic approach to promote diversified agro-forestry system, in which rubber be important component, but, not as monoculture (Ziegler *et al.*, 2009) [103].

It is also fact that, under present condition, farmers prefer rubber monoculture with high return over rubber intercropping with lower returns (Aenis *et al.*, 2014; Zhang *et al.*, 2015; Hauser *et al.*, 2015) [2, 102, 40]. It is also labour intensive. Therefore, need of the hour is, permanent integration of highly profitable additional plants or at least be labour extensive to be adopted on a considerable scale (Langenberger *et al.*, 2017) [60]. As in different places, the integration of mini livestock with rubber plantations found to be ecologically compatable and economically viable (Anegbeh, *et al.*, 2017) [4], such endevour can also be undertaken.

Socio-economic impact

Socio-economic improvement and contribution in state GDP in Tripura due to rubber plantations including on transition from shifting cultivation to rubber plantations have been reported by number of researchers (Annonymous, 2007a; Bhowmik, 2006a, 2007; Chouhan and Bhowmik, 2017; Dey *et al.*, 2014; Joshep *et al.*, 2010; Nath *et al.*, 2010; Sarkar, 2010; Joseph and George, 2011; Sinha, 2012; Matauleibi, 2012) [8, 18, 19, 25, 31, 73, 84, 49, 90, 66]. Not only steady and improved income, improved health, improved sanitation, increased education and overall better outlook of the community towards development have been observed as a result of resettlement of jhumias through rubber plantations (Matouleibi, 2012) [66].

Family size has also decreased (Sarkar, 2010) [84]. Now, they have enough food (though mostly purchased from market), they have been able to come out from indebtness and broken

the vicious cycle of poverty (Sarkar, 2010; Krishnakumar and Meenattor, 2003; Matouleibi, 2012) [84, 57, 66]. Improvement in household assets (Sarkar, 2010; Matouleibi, 2012) [84, 66], possessing of concrete house or mud house with GCI sheet roofing, fencing boundary of resident with bamboo splits or GCI sheets, TV, dish antennae, mobile phone, different electrical/electronic gadgets, durable furniture, scooter or bike/motorcycle and even in certain cases car can also be noticed.

Women are able to spend more for cloths and even gold jewellery (Matouleibi, 2012) [66]. Increase in education level in 2nd and 3rd generation, mostly in 3rd generation can be noticed as they invest for that to make them study even at private 'English Medium Schools' and feel that, even if in future rubber crops collapse, their children will have better future (Sarkar, 2010; Matouleibi, 2012) [84, 66]. Basic facilities like drinking water, improved sanitation, better infrastructure are also seen (Matouleibi, 2012) [66]. Reports of decline of village youth joining the extremist organisations (Matouleibi, 2012) [66], even of surrendering of extremists and their involvement in rubber plantations have been found.

In private initiatives, in newer areas of plantations too, scope as absorption as wage labour has increased (Chouhan and Bhaumik, 2017) [25]. Many of the workers having their own small holding also availing that opportunity in their neighbour area in private plantations.

However, the natural rubber being an international commodity, its price is volatile with deep troughs and sharp peaks, which the small and subsistence farmers find difficult to cope with (Mohonkumar, 2014) [68].

Another concern is that, along with economic development, certain negative implications or vices in concern society have arisen which are: women's withdrawal from working outside the house (contrast to shifting cultivation) and their limited role in economy (largely confined to working in the household), dowry demand by groom in marriage (unheard earlier in tribal community, even there was contrast custom in which groom had to serve as labour in the house of bride), devaluation of women's contribution at community/village level, increase of drinking and gambling (Matouleibi, 2012) [66] and other crimes. Even in resettled villages, there are certain left out, possess no title of land and plantations, works as tapper and hence, according to Matouleibi (2012) [66], as a result of rehabilitation of shifting cultivators through rubber plantations, such new class of landless have emerged in the community.

Conclusion and Recommendations

Unlike other places of the globe, where rubber monoculture expanded in large scale replacing natural vegetations, the 'entry-acceptance-expansion' of rubber plantations in Tripura is different.

From this review of studies, it can safely be asserted that, at least in Tripura situation, the rubber plantations have not in any way contributed for negative consequences on the microclimate of the state including in rainfall, stream flow and ground water, thermal climate and soil health. Rather, has shown creditability to improve physical (bulk density, porosity), chemical (nutrient availability) and biological (soil microbe) properties of the soil and in prevention of soil erosion (nutrient/sediment run-off).

In biodiversity front too, as in Tripura, in over all green coverage has been increased (mostly such plantations are on bare land or in denuded forests, that too mostly plantations, or on the lands effected by shifting cultivation, not in substitution of mixed/natural vegetations), as well the rubber plantations has enriched the soil fertility, it has resulted in increase in both above and below ground biodiversity.

In this scenario, as in here, till 2014-2015 only 70,295 hecrers land has been covered under rubber plantations, while on the basis of landscape ecological analysis 1,00,000 hecters land was classified as suitable, rubber plantations can be expanded to rest 29,705 hecters.

However, there are reports that, in recent time, due to economic attraction, some private initiatives are there for substitution of natural vegetation (agro-forestry occupied by horticultural plants); homestead mixed vegetations, other plantations. Even, attempt to encroach forest land illegally for rubber monoculture, replacement of tea with rubber monoculture, and plantations of rubber as single-species on the lands distributed by the Government to the beneficiaries under Scheduled Tribes and other Traditional Dwellers (Recognition of Forest Rights) Act. 2006. As such unrestricted expansion of rubber may cause disturbance in ecology in terms of loss of biodiversity.

Mostly, the rubber plantations in Tripura are monoculture. As a result, there are only standing trees and clear ground with dry leaves, which does not sense true forest. From this review, it appears that, there is scope and potentiality of promotion of intercropping instead of single-species plantations, which may offer further habitats for great variety of both below ground and above ground biodiversity and can minimize the likely risk of imbalances in soil nutrient stock and the susceptibility to disease due to monoculture.

Considering loss of forest cover (both plantations and natural), if any, and other vegetations due to anthropogenic interferences including promotion of monoculture of different crops (including rubber) and taking into consideration of increase in green cover due to plantations (including rubber), 2nd time assessment be made to prepare a scientific map based on landscape ecological analysis.

As a result of globalization, opening up of economy, economic importance cash crop particularly rubber, the entrepreneurs/growers be attracted to raise rubber plantations. This issue be also be possible to address if scientific map based on recent landscape ecological analysis is ready.

There are also risk of deep troughs and sharp peaks of its price as it is international commodity. Appropriate safe guard measures from the Government are needed so that the growers can sustain.

Deterioration of the social fabric and devolution of traditional social values especially among the concerned indigenous populace should not be seen in isolation. Flow of money intermingled with aggressive tide of consumerism as a result of so called globalization is the root cause, against which social movement is needed to be generated.

Taking into above considerations, in concrete following recommendations are made:

1. Expansion of Rubber in Tripura, be promoted only on bare land/denuded forests (both plantations and natural) and/or on land effected by continuous and long time shifting cultivation.
2. Out of 1,00,000 hecters suitable land earmarked for rubber plantations on the basis of landscape ecological analysis, till 2014-15, an area measuring 70,295 hecters

has been covered under rubber plantations. Hence, there is scope to expand rubber plantation further in rest 29,705 hecters. But, instead of single-species plantations, it should be intercropping and integrated with mini livestock. As, beneficiaries, preference should be given to left out jhumias.

3. For existing plantations too, integration of additional and profitable other plants and integration with mini live stock be tried.
4. Development of Tripura specific diversified agro-forestry system, in which rubber be important component, but, not as monoculture is needed through 'Action Research'.
5. In changed scenario, again a land suitability study be conducted on the basis of landscape ecological analysis for long term planning for future promotion of different cash crops including rubber.
6. Awareness generation activities be undertaken extensively among the concerned populace on the risk of monoculture vis-à-vis benefit of intercropping.
7. Awareness generation activities be taken up among the concerned populace to built up social movement to address the issue of deterioration social fabric and devolution of social values.

References

1. Abraham M, Abraham CT. Weed flora of rubber plantations in Kerala. Indian J Natural Rubber Res. 2000;13:86-91.
2. Aenis T, Hofmann-Souki S, Nagel UJ, Tang L, Wang J. Rubber cultivation and livelihood – A stakeholder analysis in Xishuangbanna, South West China. Humbold-Universitat zu Berlin, 2014. Available from: URL:http://ecdoc.hu-berlin.de/oa/books/reZf1RwMqPrk/PDF/29jESAnTG1Y2.pdf.
3. Allen RB, Platt KH, Coker REJ. Understorey species composition patterns in *Pinus radiate* D. Don plantation on the central North Island Volcanic plateau, New Zealand. New Zealand J For. Sci. 1995;25:301-317.
4. Anegbeh PO, Esekhade TU, Abolagba EO, Ogwuche P, Afolabi KD, Balogun FE. Analysis of profitability of mixed farming in rubber-based agro-forestry system in Nigeria. Direct Res. J of Agricul. And Food Sci. 2017;5(1):26-34.
5. Annamalainathan K, Satheesh PR, Jacob J. Rubber plantation as a potential sink for atmospheric carbon dioxide: An ecosystem flux approach. In: IRRDB Workshop on Climate Change and Rubber, Rubber Research Institute of India and IRRDB, Kottayam, India, 2010.
6. Anonymous. State of Environment Report-2002, Tripura State Pollution Control Board, Agartala, Tripura, 2002.
7. Anonymous. Enumeration of shifting cultivators in Tripura. Forest Department, Government of Tripura, 2007.
8. Anonymous. Tripura Human Development Report (Ed. Swaminathan, M.). Government of Tripura, 2007a.
9. Anonymous. Drivers of deforestation? Facts to be considered regarding the impact of shifting cultivation in Asia. Asian Indigenous Peoples Pact (AIPP) and International Work Group for Indigenous Affairs (IWGIA), 2012, 11.
10. Anonymous. Environment consequences of rubber plantations in Kerala (NRPPD Discussion Paper 44), Department of Commerce, Ministry of Commerce and Industry, Government of India, 2015.
11. Aweto AO. Physical and nutrient status of soils under rubber (*Hevea brasiliensis*) of different ages in south-western Nigeria. Agricultural Systems. 1987;23(1):63-72.
12. Balagopalan M. Changes in the distribution of organic carbon and different forms of nitrogen in soils under natural forests and teak plantations. In: Proc. VII Kerala Science Congress, 1995, 110-112.
13. Bera A, Namasudra P. Impact of shifting cultivation on the environmental changes in Gumti River basin, Tripura. Int. J Reent. Scientific Res. 2016;7(6):11771-11774.
14. Bahuguna VK. Rubber cultivation in Tripura. In: Natural rubber in Tripura: base line data and future planning (Ed. Bahuguna, V. K.). Tripura Rubber Mission, Government of Tripura, 2006, 17-18.
15. Bhattacharya S. From Jhuming to Tapping. Directorate of Research, Department of Welfare for Scheduled Tribes, Government of Tripura, 1992, 85.
16. Bhattacharjee B. Tripurar Jalbayu O Prakriti (In Bengali).Moumita, Agartala, Tripura, India, 2002, 80.
17. Bhowmik I. Rehabilitation of jhum cultivators through rubber plantations: problems and prospects. In: ICHR Seminar, Tripura University, Agartala, 2006.
18. Bhowmik I. Status report on rubber plantations in Tripura. In: Natural Rubber in Tripura: baseline data and future planning (Ed. Bahuguna, V.K.). Tripura Rubber Mission, Government of Tripura, Agartala, India, 2006a, 41-52.
19. Bhowmik I. Socio-economic profile of the shifting cultivators of Tripura. In: ITTO Pre-Project Workshop, Agartala, 2007.
20. Brahma B, Nath AJ, Das AK. Managing rubber plantations for advancing climate change mitigation strategy. Current Science. 2016;110(10):2015-2019.
21. Chakraborty NK, Pal TK, Dey SK, Varghese YA. Flora of Rubber and other plantation in Tripura. Indian J Natural Rubber Res. 2002;13:86-91.
22. Chakraborty K, Sudhakar S, Sarma KK, Raju PLN, Das AK. Recognizing the rapid expansion of rubber plantation—a threat to native forest in parts of northeast India. Current Science. 2018;114(1):207-213.
23. Cheng C, Wang R, Jiang J. Variation of soil fertility and carbon sequestration by planting *Hevea brasiliensis* in Hainan Island, China. J Environmenttal Sciences. 2007;19(3):348-352.
24. Chaudhuri PS, Nath S, Paliwal R. Earthworm population of rubber plantations (*Hevea brasiliensis*) in Tripura. Tropical Ecology. 2008;49(2):225-234.
25. Chouhan P, Bhoumik I. Labour Market Conditions of Natural Rubber Plantations in Tripura. Social Change and Development. 2017;14:55-69.
26. Datta M, Bhattacharya BK, Saikia H. Soil fertility – A case study of shifting cultivation sites in Tripura. J Indian Soc. Soil Sciences. 2001;49(1):104-109.
27. Debnath J, Ahmed I, Das N. Impact of anthropogenic activities on channel characteristics: A case study of Muhuri River, Tripura, North-East India. Arch. Appl. Sci. Res. 2015;7(7):27-36.

28. Dey SK. Geo-environmental status of the river gumti, Tripura., Tripura State Pollution Control Board, Agartala, 2014, 68.
29. Dey SK. Biodiversity in Rubber Plantations. Planters Chronicle, August issue, 2011.
30. Dey SK, Pal TK, Nazeer MA, Jacob J. Performance of popular *Hevea* clones under tea intercropping system in Tripura climate condition. Indian J Hill Farming. 2014;27(1):17-21.
31. Dey SR, Munidinamani SM, Basavaraja H, Kulkarni GN, Banakar B, Hegde RV. Economics of rubber plantations in Tripura. Karnataka J Agric. Sci. 2014;27:160-164.
32. Devakumar AS, Sathik MBM, Jacob J, Annamalainathan K, Prakash PG, Vijaykumar KR. Effect of atmospheric and soil drought on growth and development of *Hevea brasiliensis*. J Rubb. Res. 1998;1(3):190-198.
33. Dhamodaran TK. Status of rubber wood processing and utilisation in India: a country report. In: Workshop on Promotion of Rubber Wood Processing in the Asia Specific Region, Sanya, Hainan, China, 2008.
34. Eappen T, Rao DVKN, Karthikakullyamma M, Sarma AC., Dey SK, Varghese YA, *et al.* Influence of plantation crops on soil properties in Tripura. Natural Rubber Research. 2005;18(1):67-80.
35. Fox J, Castella J, Ziegler AD, Westley SB. Rubber plantations expand in Mountainous Southeast Asia: What are the consequences for the environment. East West Centre, Asia Pacific Issues. 2014;114:1-8.
36. Guardiola-Claramonte M, Troch PA, Ziegler AD, Gimbelluca TW, Vogler JB, Nullet MA. Local hydrologic effects of introducing non-native vegetation in a tropical catchment. Ecohydrology. 2008;1:13-22. DOI: 10-1002/eco.3.
37. Guardiola-Claramonte M, Troch PA, Ziegler AD, Gimbelluca TW, Vogler JB, Nullet MA. Hydrologic effects of the expansion of rubber (*Hevea brasiliensis*) in a tropical catchment. Ecohydrology. 2010;3:306-314.
38. Guo LB, Gifford RM. Soil carbon stocks and land use change: a meta analysis. Global Change Biology. 2002;8(4):345-360.
39. Hartley MJ. Rationale and methods for conserving biodiversity in plantation forests. For. Ecol. Manage. 2002;155:81-95.
40. Hauser I, Martin K, Germer J, He P, Blagodatskiy S, Liu H, *et al.* Environmental and socio-economic impacts of rubber cultivation in the Mekong region: challenges for sustainable land use. CAB Reviews. 2015;10:027. DOI: 10.1079/pavsnnr201510027.
41. Hunter Jr ML (ed.). *Maintaining Biodiversity in Forest Ecosystems*, Cambridge University Press, Cambridge, 1999, 716.
42. Jacob J. Rubber tree, man and environment. In: Natural Rubber: Agro management and Crop Processing (Eds. George, P.L. and Jacob, C.K.), Rubber Reasearch Institute of India, Kottayam, 2000, 509-610.
43. Jacob J. Carbon sequestration capacity of natural rubber plantations. In: IRRDB Symposium on Challenges for National Rubber in Globalisation, Chiang Mai, Thailand, 2003.
44. Jacob J, Chaudhury D, Thapliyal AP, Mandal D, Singh RP. Meti S, *et al.* Ecological impact of Ntural Rubber, Teak and Jarul Plantations. In: Proc. of Symposium (PLACROSYM) on Plantation Crop Research & Development in the New Millennium, Hyderabad, 2002, 365-369.
45. Jiang J, Wang R. Hydrological eco-service of rubber plantations in Hainan Island and its effect on economic development. J Environmental Sciences. 2003;15(5):701-709.
46. Jones KP. Natural rubber as a green commodity: part. II Rubber Development. 1994;47(3):37-41.
47. Jones KP. Rubber and the environment. In: Joint Workshop of the International Rubber Study Group (IRSG) and secretariat of the United Nations Conference on Trade and Development (UNCTAD) on opportunities and constraints for the internalization of environmental costs and benefits into the price of rubber. IRSG and UNCTAD, 1997.
48. Joseph KT. Soil Conservation. In: The State of Natural Conservation in Malaysia (Ed. Kiew, R.). Malayan Nature Society, Kuala Lampur, 1991, 209-221.
49. Joseph J, George TK. Income inequality among beneficiaries under natural rubber block planting scheme in Tripura: a preliminary assessment. Natural Rubber Research. 2011;24(2):203-210.
50. Joseph J, George TK, Dey SK. Report on the socio-economic impact of Natural Rubber cultivation under the block planting in Tripura. Rubber Research Institute of India, Kottyam, Kerala, 2010, 39.
51. Karthikakutty Amma M, Suresh PR, Valsa G, Aiyer RS, Mathew M. Comparative evaluation of soil organic matter status of rubber growing soils in relation to forest ecosystem. In: VII Kerala Science Congress, 1995, 100-101.
52. Karthikakutty Amma M, Suresh PR, Aiyer RS, Aiyer RS, Valsa G. Effects of continuous cultivation of rubber (*Hevea brasiliensis*) on total and available nitrogen status of soil. In: VIII Kerala Science Congress, 1996, 80-82.
53. Kox HL. Ecological advantages of NR latex production. Nature Rubber. 2000;17(1):4.
54. Krishnakumar AK, Eappen T, Rao N, Potty SN, Sethuraj MR. Ecological impact of rubber (*Hevea brasiliensis*) plantation in North East India. 1. Influence on soil physical properties with special reference to moisture retention. Indian J Nat. Rubb. Res. 1990;3:53-63.
55. Karmakar P, Ghosh R, Saha AK, Das P. Aeromycoflora of mixed forest and rubber plantation sites of Tripura. J Mycological Res. 2016;54(3):431-434.
56. Krishnakumar AK, Potty SN. Nutrition of *Hevea.* In: Natural Rubber: Biology, Cultivation and Technology (Eds. Sethuraj, M.R. and Mathew, N.M.). Elsvier, Amsterdam, 1992, 239-262.
57. Krishnakumar AK, Meenattoor RJ. Restoration of denuded lands in the north eastern India through rubber plantations. *Leisa India*, December, 2003, 23-24.
58. Krishnakumar AK, Gupta C, Choudhury D, Meenattoor RJ. Rubber (*Hevea brasiliensis*) plantation in Tripura: some ecological considerations with reference to microclimate. In: National Seminar on Resource Management, Agartala, Tripura, 1991.
59. Krishnakumar AK, Gupta C, Sinha RR, Sethuraj MR, Potty SN, Eappen T, *et al.* Ecological impact of rubber (*Hevea brasiliensis*) plantations in North East India.2.

Soil properties and biomass recycling. Indian J Nat. Rubb. Res. 1991a;4(2):134-141.
60. Langenberger G, Cadisch G, Martin K, Min S, Waibel H. Rubber intercropping: a viable concept for the 21st century. Agroforestry System. 2017;91(3):577-596.
61. Li H, Aide TM, Ma Y, Liu W, Cao M. Demand for rubber is causing the loss of high diversity rain forest in SW China. Biodivers. Conserv. 2007;16(6):1731-1745. DOI: 10.1007/s10531-006-9052-7.
62. Li HY, Aide TM, Liu W. Past, present and future land use in Xishuangbanna, China and the implications for carbon dynamics. Forest Ecol. Management. 2008;255(1):16-24. DOI: 10.1016/j.foreco.2007-06-051.
63. Majumder A, Datta S, Choudhury BK, Majumder K. Do extensive rubber plantation influences local environment? A case study from Tripura, Northeast India. Current World Environment. 2014;9(3):768-779.
64. Mandal D, Pal TK. Rubber plantation in North East India and its influence on soil properties and ecosystem—an appraisal. In: State level seminar on frontier areas of Chemistry to commemorate 150th Birth Anniversary of Acharya P.C. Roy. Department of Chemistry, Tripura University and Tripura State Council for Science and Technology, 2010.
65. Mandal D, Pal TK. Rubber plantations in North East India and its influence on soil properties and ecosystem – An Appraisal. In: Bulletin, Tripura Chemical Society. 2011;10:72-76.
66. Matouleibi S. How wonderful is the wonder crop? Block rubber plantation and indigenous tribal women in Tripura. Research paper submitted for Master of Arts in Development Studies, International Institute of Social Studies, The Hague, The Netherland, 2012.
67. Meher-homji VM. The link between rainfall and forest clearance, case studies from West Karnataka. Trans. Inst. Indian Geography. 1980;2:59-65.
68. Mohankumar S. Political Economy of Natural Rubber Cultivation in Tripura. IDSJ (Institute of Development Studies) Working Paper 172, Jaipur, India, 2014, 1-15.
69. Moreira A, Moraes LAC, Fageria NK. Potential of rubber plantations for environmental conservations in Amazon region. Bioremediation, Biodiversity and Bioavailability. 2009;3(1):1-5.
70. Mukherjee B, Nath RC, Dasgupta MK. Plant parasite nematode communities in rubber nurseries and plantations in Tripura. Indian J Nematol. 2000;30(2):170-174.
71. Nataraj KN, Jacob J. Clonal differences in photosynthesis in *Hevea brasiliensis* Mull. Arg. Photosynthetica. 1999;36(1-2):89-98.
72. Nath S, Chaudhuri PS. Human-induced biological invasions in rubber (*Hevea brasiliensis)* plantations of Tripura (India) – *Pontoscolex corthrurus* as a case study. Asian J Exp. Biol. Sci. 2010;1(2):360-369.
73. Nath TK, Inoue M, De Zoysa M. Rubber planting for forest rehabilitation and enhancement of commercial livelihood: a comparative study in three south asian countries. In: 18th Commonwealth Forestry Conference, Edinburgh, 2010.
74. Pal TK, Dey SK, Varghese YA. Medicinal plants in rubber plantations in Tripura, North East India. Rubber Board Bulletin. 2006;28(2):4-8.
75. Paribalam P. Role of Rubber Board in Tripura. In: Natural Rubber in Tripura: Baseline Data and Future Planning (Ed. Bahuguna, V.K.). Tripura Rubber Mission, Government of Tripura, Agartala, India, 2006, 41-52.
76. Philip V, Rao DVKN, Varghese M, Vinod KK, Pothen J, Krishnakumar AK. Spatial distribution of roots and nutrients in soil under rubber plantations in Tripura. Indian J Natural Rubber Research. 1996;9(2):106-111.
77. Qui L. Where the rubber meets the garden. Nature. 2009;457:246-247. DOI: 10-1038/457246a.
78. Rahaman WA. Natural rubber as a green commodity – Part. 1. Rubber Developments. 1994;47:13-16.
79. Raj S, Roy D. Impact of rubber cultivation in Tripura: Some scientific facts. Tripura Times (13-07-2012), Agartala, 2012.
80. Roy ML. Rubber Chas: Bastutrantrik Bitarka – Tripura Prasanga (In Bengali). Jnan Bichitra, Agartala, Tripura, 2014, 128.
81. Roy ML, Saha S, Roy M. Ecological impact of rubber plantations: Tripura perspective. Int. J Curr. Sci. 2014;6(11):103310340.
82. Roy M, Saha S, Roy ML. Transition from shifting cultivation to rubber cultivation in Tripura: socioeconomic and ecological impact. The Clarion. 2015;4(2):64-74.
83. Saha R, Choudhury RS, Somasundaran J. Soil health management under hill agro-system in northeast India. Applied and Environmental Soil Science, Article ID696174, 2012, 9. DOI: 10.1155/2012/696174.
84. Sarkar S. Revolution of jhumia's life through rubber plantation: a case study of Dhalai District, Tripura. Forestry, Environment, Plantation Crops & Permaculture Constancy & Research, 2010.
85. Sarkar S. Rubber plantation: A new hope for rural tribals in Tripura. International J Plant Sciences. 2011;6(2):274-276.
86. Sailajadevi T. Has the climate changed in NE India? In: International Workshop on Climate Change and Rubber Cultivation: R & D priorities, Rubber Research Institute of India, Kottayam, India, 2010.
87. Sethuraj MR. Impact of natural rubber plantations on environment. In: Natural Rubber: An Eco- friendly Material, Rubber Board, Kottayam, 1996, 55-59.
88. Sethuraj MR, Jacob J. Rubber and the Environment. In: Second meeting of the Expert Group, Project on Promotion of Natural Rubber as an Environment Friendly Raw-materials and a Renewable Resource, Cochin, India, 1997.
89. Sinha AK. Prospect of rubber plantation in NE region with special reference to the state of Tripura. In: Seminar-cum-workshop on 'saving soil and croplands', Soil Conservation Development, Assam, Guwahati, 2007.
90. Sinha AK. Rubber plantations in Northeast India: hopes vs. concerns. The Tripura Foundation, 2012, 3.
91. Sinha AK. Rubber plantations in Northeast India, hopes vs. concerns. The Tripura Foundation, 2014. Retrieved from: http://www.thetripurafoundation.org/art-rubber-north-east-hopes-vs-concern (Accessed on 24-06-20-13).
92. Soman MK, Krishnakumar K, Singh N. Decreasing and trend in the rainfall of Kerala. Current Science. 1988;57:7-12.

93. Sivkumaran S, Kheong YF, Hassan J, Rahman A. Carbon sequestration in rubber: implication and economic models to fund continued cultivation. In: Proceeding of Indonesian Rubber Conference and IRRD Symposium, 2000, 79-102.
94. Tang Z, Zhang Y, Sony Q, Liu W, Deng X, Tang J, *et al*. Rubber Plantations act as water pumps in tropical China. Geophys. Res. Lett. 2011;38:L24406. DOI: 10.1029/2011/GL050006.
95. Thomas KA, Panikkar AON. Indian rubber plantation industry: Genesis and development. In: Natural Rubber: Agromanagement and Crop Processing (Eds. George, P.J. and Kuruvilla, C.), Rubber Research Institution of India, Kottayam, 2000, 1-9.
96. Thomas EW, Dolman PM, Edwards DP. Increasing demand for natural rubber necessitates a robust sustainability initiative to mitigate impacts on tropical biodiversity. Conserv. Lett. 2015;8(4):230-241.
97. Uhl C. Factors controlling succession following slash-and-burn agriculture in Amazonia. Journal of Ecology. 1987;75:377-407.
98. Van Keer K. On-farm agronomic diagnosis of transitional upland rice Swidden cropping system in northern Thailand. Ph.D. Thesis, Fuculteit Landbouwk, 2003.
99. Venkatachalam P, Geetha N, Sangeetha P, Thulaseedharan A. Natural rubber producing plants: an overview. African Journal of Biotechnology. 2013;12(12):1297-1310.
100. Wan AR, Jones KP. Natural rubber as a green commodity. In: Natural Rubber: An Ecofriendly Material, Rubber Board, Kottayam, India, 1996, 1-17.
101. Wauters JB, Coudert S, Grallien E, Jonard M, Ponette Q. Carbon stock in rubber tree plantations in Western Ghana and Mato Grosso (Brazil). Forest Ecology and Management. 2008;255:2347-2361.
102. Zhang L, Kono Y, Kobayashi S, Hu H, Zhou R, Qin Y. The expansion of smallholder rubber farming in Xishuangbanna, China: A case study of two Dai villages., Land Use Policy. 2015;42:628-34.
103. Ziegler AD, Fox JM, Xu J. The Rubber Juggernaut. Science. 2009;324(5930):1024-1025.
104. Ziegler AD, Bruun TB, Guardiola-Claramonte M, Giambelluca TW, Lawrence D, Nguyen T. Environmental consequences of the demise in Sweden agriculture in SE Asia: geomorphological process. Human Ecol. 2009a;37(3):361-373. DOI: 10.1007/s10745-009-9258-$_x$.