Soil characterisation of rubber ecosystems with special reference to soil organic matter

1. INTRODUCTION

Soil is the one of the precious natural resources on which people rely for their basic needs. It is the medium for plant growth and the suitability of a soil for the optimum growth of plant and sustained production depends on its physical, chemical and biological make up. The only soil component, which influence directly or indirectly the soil physical, chemical and biological properties is organic matter. The quality and quantity of organic matter greatly regulates soil quality. Maintenance of soil quality is essential for sustainable agricultural production. Soil organic matter (SOM) has a key role in soil fertility and productivity. It is the primary sink and source of plant nutrients in natural and managed ecosystems. It plays an important role in the global carbon balance as well. It is highly sensitive and susceptible to changes depending on the land use pattern and associated management practices (Wander, 2004).

SOM can be broadly categorized to labile and recalcitrant pools depending on their decomposition or turnover rates (Six *et al*., 2002). Labile fraction mainly consists of easily oxidizable components such as carbohydrates, sugars, cellulose *etc.*, which are palatable to microbes whereas lignin and tannin type materials falls under the recalcitrant group which are resistant to decay. Identifying and quantifying the suitable indicators that are sensitive enough to reflect the changes in SOM quality and quantity is very important to develop suitable nutrient management strategies for a sustainable nutrient management system. Land use or land management induced changes in soil organic matter status occur much more rapidly in the labile pools, such as particulate organic matter, soluble organic matter or microbial biomass than in the total organic carbon content (Gregorich *et al*., 1994). It has been reported that higher quantity of organic matter need not necessarily maintain or increase crop yield (Ladha *et al*, 2003). Brinson *et al* (1998) reported that the nutrient availability in a system is more influenced by the size of the labile or active SOM fraction rather than the total quantity of SOM. Parton and Ramussen (1994) also reported that the labile component of SOM plays the most important role in the short-term turnover of nutrients.

Plant litter is the major source of organic matter and its decomposition is the primary mechanism by which organic matter is returned to the soil. The decomposition and nutrient release patterns of organic materials are determined by the resource quality, decomposing organisms and environmental conditions (Berg *et al*., 2000).

Chan *et al* (2001) reported that different organic carbon fractions vary in their decomposition pattern and mineralization of soil organic matter plays the major role in available nutrient status in a soil. With changes in the quality and quantity of SOM, the potential of a soil to supply or sequester carbon and nutrients is altered through changes in mineralization – immobilization rates (Janssen and Persson, 1982). Decomposition of organic matter in a soil is mainly governed by soil microbes. However, the decomposition rate varies with the quality and physical availability of substrate that are the energy sources to soil microbes (Raich and Tulekcioglu, 2000). Thus the organic matter decomposition or organic carbon mineralization pattern may vary with the land use type and soil management. Understanding the decomposition kinetics of soil organic matter under different land use systems or management practices can provide useful information on the carbon stabilization potential of the systems as well.

Hevea brasiliensis is the most important commercial source of natural rubber. In India about 7.59 lakhs ha land is under rubber cultivation and about 71% of this area is in Kerala (Rubber Board, 2013). Establishment of legume covers such as *Pueraria phaseoloids or Mucuna bracteata* in immature rubber plantation is a recommended and commonly followed agronomic practice. Intercropping in immature rubber plantation is also a common practice and banana and pineapple are the popular intercrops. Since plant residues are the primary source of SOM, the relative size and composition of SOM in the various rubber based systems may vary. The management practices followed in different rubber based systems are also different. Even though there are many reports available on the effect of cover crop and intercrop on soil properties in rubber growing soils, information on litter quality, labile fractions of organic carbon and soil carbon mineralization in different rubber based systems is limited. Hence the present investigation was carried out with the following objectives :-

1. To determine the quality and decomposition pattern of the three major litter species *viz.*, rubber, *Pueraria* and *Mucuna* in rubber plantation
2. To characterize soil organic matter and soil properties in different rubber based systems
3. To study the carbon mineralization in soil under different rubber based systems and in different soil particle size fractions.

2. MATERIALS AND METHODS

2.1. Litter quality and decomposition

The decomposition pattern of three major litter species in rubber plantation *viz.* rubber, *Pueraria* and *Mucuna* were studied through litter bag technique (Bocock *et al*., 1960) at Travancore Rubber Estate, Erumely, near Kottayam in Kerala.

2.1.1 Collection of litter

Freshly fallen litter of rubber, *Pueraria* and *Mucuna* in an area of one square meter from a 12 year-old rubber plantation, 3 year old rubber plantation with cover crop, *Pueraria* and 3 year old rubber plantation with cover crop, *Mucuna* respectively were collected randomly from 12 different points from each field. These samples were oven dried at 70^{o}C and recorded the weight. The average input of these litter species in one square meter was computed for fixing the quantities of litter to be taken in the litter bags.

2.1.2. Litter decomposition

In each situation, 120 nylon litter bags of size 30 cm x 30 cm with a mesh size of 2 mm were used. Litter bags containing 40 g of rubber litter or 35 g *Pueraria* or 35 g *Mucuna* litter were placed randomly in contact with the surface soil in the respective fields and anchored to small pegs. Ten litter bags from each system were retrieved at monthly intervals for a period of one year and brought to the laboratory. The bags were gently rinsed over a fine soil sieve to remove soil and other extraneous material and the residual litter was removed from the bags, oven dried at 70^{o} C to constant weight and weighed. The decay rate coefficient and percentage of nutrients remaining in residual litter were worked out.

2.1.3. Chemical analysis of litter

Oven-dried samples of the fresh litter of the three species and those retrieved at monthly intervals through the litter bags were finely ground and N, P, K, Ca and Mg contents were estimated following standard procedures (Piper, 1966). The biochemical constituents *viz*., cellulose, lignin and polyphenols of the fresh litter were estimated (Anderson and Ingram, 1993).

2.1.4. Decay constant

The decay rate coefficient was calculated using the equation $X/X_o = e^{-kt}$ (Olsen, 1963) where X is the dry weight remaining at time t, X_o is the original dry weight of the litter and k is the decay rate coefficient.

The time required for 50 per cent and 95 per cent loss was estimated using the equations $t_{0.5}=0.693/k$ and $t_{0.95} = 3/k$.

2.1.5. Nutrients remaining in the residual litter

Nutrients remaining in the residual litter were estimated by the equation

Nutrient (%) remaining= $(C/C_0) \times (DM/DM_0) \times 100$ (Bockhelm *et al*., 1991)

Where 'C' is the concentration of the nutrient at time t, 'C_0' is the initial concentration of the nutrient, 'DM' is the dry weight of the litter after time t, 'DMo' is the initial dry weight of the litter.

2.2. Characterization of soil organic matter and soil properties in different rubber based systems

The study was conducted at three locations in Central Kerala. Two locations were selected from the estate sector and one from the small holding sector. The fields in the estate sector were in Harrisons Malayalam Limited, Mundakayam (9^0 31' N, 76^0 52' E) and Travancore Rubber Estate, Erumely, (9^0 27' N, 76^0 52' E). The small holding was at Amayannoor, Kottayam (9^0 37' N, 76^0 36' E).

2.2.1. Site description and management practices

The systems and associated cultural operations in each location are briefed below:

Location 1) Amayannoor:

Four systems *viz.*, a) mature rubber, b) immature rubber with cover crop *Pueraria*, c) immature rubber with banana as inter crop and d) immature rubber with pineapple as inter crop were selected and studied. The selected fields were located in close vicinity. The soils were sandy clay loam in texture and acidic in nature.

a) Mature rubber

The rubber plants were twenty three years of age in the second cycle of cultivation. The area was under mono-crop cultivation of rubber for more than fifty years. The fields were regularly weeded on an annual basis and sparsely grown weeds were noticed. NPK fertilizer was regularly applied by broadcasting method. The soil was tilled only once at the time of planting, pits of size 75 x 75 x 75 cm were made and refilled with top soil mixed with 12 kg of farm yard manure. The rubber plants were planted with a spacing of 6.7 x 3.4 m.

b) Immature rubber with *Pueraria* cover crop

The rubber plants were three years old and belong to the third cultivation cycle. The area was under continuous rubber cultivation for more than fifty five years. Luxuriant growth of the legume - *Pueraria* existed. Other cultural operations were similar as in the previous case of rubber (mature phase) except that Mg fertilizer was also applied for the last three years.

c) Immature rubber with banana intercrop

The rubber plants were two years old and belong to the third cultivation cycle. The area was under continuous rubber cultivation for more than fifty four years. Chemical fertilizer (NPK) was applied to rubber and banana plants separately. In addition, Mg was applied to rubber plants. The rubber plants were planted as in the previous cases. The field was tilled manually in the inter row area of rubber plants for planting banana. Organic manure was applied to banana (10 kg $plant^{-1}$) at the time of planting.

d) Immature rubber with pineapple intercrop

The rubber plants were two years old and belong to the third cultivation cycle. The area was under continuous rubber cultivation for more than fifty four years. During land preparation, the entire planting area was tilled by mechanical devices. Chemical fertilizer inputs were there separately for rubber and pineapple plants. In addition, Mg was applied to rubber plants. Organic manure (25 tons $ha^{-}1$) was also applied to pineapple as basal dose.

Location 2. Harrisons Malayalam Limited, Mundakayam:

Four systems *viz.*, a) mature rubber, b) immature rubber with cover crop *Mucuna*, c) immature rubber with banana as inter crop and d) immature rubber with pineapple as inter crop were selected and studied. The selected fields were located in close vicinity. The soils were sandy clay loam in texture and acidic in nature.

a) Mature rubber

The rubber plants were twenty years of age in the second cycle of cultivation. The area was under mono-crop cultivation of rubber for more than fifty years. The fields were regularly weeded on an annual basis and sparsely grown weeds were noticed. NPK fertilizer was regularly applied by broadcasting method. The soil was tilled only once at the time of planting, pits of size 75 x 75 x 75 cm were made and refilled with top soil mixed with 12 kg of farm yard manure. The rubber plants were planted with a spacing of 6.7 x 3.4 m.

b) Immature rubber with *Mucuna* cover crop

The rubber plants were three years old and belong to the third cultivation cycle. The area was under continuous rubber cultivation for more than fifty five years. Thick, luxuriant growth of the legume – *Mucuna* existed. Other cultural operations were similar as in the previous case of rubber (mature phase) except that Mg fertilizer was also applied for the last three years.

c) Immature rubber with banana intercrop

The rubber plants were two years old and belong to the third cultivation cycle. The area was under continuous rubber cultivation for more than fifty four years. Chemical fertilizer (NPK) was applied to rubber and banana plants separately. In addition, Mg was applied to rubber plants. Organic manure was applied to banana (10 kg plant^{-1}) at the time of planting. The rubber plants were planted as in the previous cases. The field was tilled manually in the inter row area of rubber plants for planting banana.

d) Immature rubber with pineapple intercrop

The rubber plants were two years old and belong to the third cultivation cycle. The area was under continuous rubber cultivation for more than fifty four years. During land preparation, the entire planting area was tilled by mechanical devices. Chemical fertilizer inputs were there separately for rubber and pineapple plants. In addition, Mg was applied to rubber plants. Organic manure (25 tons ha^{-}1) was also applied to pineapple as basal dose.

In all the fields there was copper fungicide application.

Location 3. Travancore Rubber Estate, Erumely:

Three systems *viz.,* a) mature rubber, b) immature rubber with cover crop *Pueraria* and c) immature rubber with cover crop *Mucuna* were selected and studied. The selected fields were located in close vicinity. The soils were sandy clay in texture and acidic in nature.

a) Mature rubber

The rubber plants were twelve years of age in the third cycle of cultivation. The area was under mono-crop cultivation of rubber for more than sixty years. The fields were regularly weeded on an annual basis and sparsely grown weeds were noticed. NPK fertilizer was regularly applied by broadcasting method. The soil was tilled only once at the time of planting, pits of size 75 x 75 x 75 cm were made and refilled with top soil mixed with 12 kg of farm yard manure. The rubber plants were planted with a spacing of 6.7 x 3.4 m.

b) Immature rubber with *Pueraria* cover crop

The rubber plants were three years old and belong to the third cultivation cycle. The area was under continuous rubber cultivation for more than fifty five years. Luxuriant growth of the legume - *Pueraria* existed in the field. Other cultural operations were similar as in the previous case of rubber (mature phase) except that Mg fertilizer was also applied for the last three years.

c) Immature rubber with *Mucuna* cover crop

The rubber plants were three years old and belong to the third cultivation cycle. The area was under continuous rubber cultivation for more than fifty five years. Thick, luxuriant growth of the legume - *Mucuna* existed in the field. Other cultural operations were similar as in the case of rubber (mature phase) except that Mg fertilizer was also applied for the last three years.

There was copper fungicide application in these fields.

2.2.2. Collection of soil samples

Soil samples (0-10 cm) were collected on a random basis from all the systems in each location. Five sites in each system in locations 1 and 2 *viz.,* at Amayannoor and at Mundakayam and ten sites at location 3, *viz.,* Erumely were identified and soil samples were collected from each site. Three samples were collected from each sampling site and composited.

The field moist samples were brought to the laboratory and a portion was sieved through a 2mm sieve and used for the estimation of water soluble carbon (WSC) and hot water extractable carbon (HWEC). The remaining portions were air dried, sieved (2mm) and used for other analyses.

2.2.3. Soil analysis

Following soil properties were estimated in each soil sample.

A) Soil physical properties

Particle size analysis

Texture of the soil was determined by international pipette method (Jackson, 1958)

Bulk density

Bulk density was determined by core sampling method (Black, 1965)

Particle density

Particle density was estimated by displacement method (Black,1965)

Porosity

Porosity was calculated using the formula St = 100(1-Db/P) Where 'St' is the total porosity, 'P' is the particle density and 'Db' is the bulk density.

Water stable aggregates

Water stable aggregates were determined by following the method as described by Kemper and Koch (1966).

A) Soil chemical properties

Soil reaction (pH)

Soil was equilibrated with water (1:2.5 soil solvent ratio). The pH of the suspension was determined electrometrically on a direct reading pH meter with combined calomel – glass electrode.

Cation exchange capacity

Cation exchange capacity (CEC) was estimated using neutral normal ammonium acetate (Black,1965).

Total carbon and nitrogen

Total carbon and nitrogen were estimated by dry combustion method using an automated elemental analyser (Leco Truspec CN). The total carbon estimated in 2mm soil was organic carbon (OC) as the soils were acidic in nature and no inorganic forms of carbon was present in any of the soil studied.

Available phosphorus

Available phosphorus extracted using Bray II extractant and estimated by chloromolybdic stannous chloride reduction method (Jackson, 1958).

Available potassium, calcium and magnesium

Soil samples were extracted with neutral normal ammonium acetate solution. Potassium was estimated by flame photometry and calcium and magnesium by atomic absorption spectrophotometry.

2.3 Characterization of soil organic matter

2.3.1. Physical fractionation

Particle size fractionation of soil was carried out by dispersion followed by wet sieving and sedimentation (Cambardella *et al*., 2001). Soil (10 g) was dispersed in 30 ml 0.5% sodium hexa metaphosphate by shaking for 16 h on an end –over-end shaker at 140 rev min^{-1}. After dispersion, the suspension was wet- sieved to separate the 2.00- 0.250 mm, 0.250 - 0.053 mm and < 0.053mm fractions. All the fractions were dried at 65^0C. Carbon and nitrogen in the size separates were estimated by dry combustion method using an automated elemental analyser (Leco Truspec CN).

2.3.2. Chemical fractionation

Water soluble carbon (WSC)

Field moist soil samples (2mm) were extracted with distilled water in the ratio 1:3 for 30 minutes on an end-over –end shaker and centrifuged for 20 miinutes at 8000 rpm. The supernatant was filtered and the extract was estimated for water soluble carbon by dichromate oxidation method (Ghani *et al*., 2003).

Hot water extractable carbon (HWEC)

10 g field moist, sieved (2mm) soil was mixed with 30 ml distilled water in polypropylene centrifuge tube and shaken on a horizontal shaker for 30 minutes.

Then the tubes were capped and left in an 80^0C hot-water bath for 16 hours. The tubes were then shaken for 10 minutes on a horizontal shaker and subsequently centrifuged at 8000 rpm for 20 minutes. The supernatant was used to determine HWEC by dichromate oxidation method (Ghani *et al*., 2003).

Permanganate oxidizable soil carbon (POSC)

Soil was extracted with 20mM KMnO4 in the ratio1:10 for 30 minutes and centrifuge for 5 minutes at 2000 rpm. Two ml of the aliquot made upto 50 ml and the absorbance measured at 560 nm using **s**pectrophotometer (Modified method of Blair *et al.*, 1995) .

2.3.3. Spectrosopic characterisation- UV/Vis spectroscopy

Humic substance was extracted from the soil with 0.05M $NaHCO_3$ and the absorbance was measured at 254, 365, 465 and 665 nm using a UV-Vis spectrophotometer (UV-1601, Shimadzu). E_2/E_3 and E_4/E_6 ratios were worked out. (E_2, E_3, E_4, and E_6 are the absorbances at 254, 365. 465 and 665 respectively)

2.3.4. *Spectrosopic characterisation* - FTIR spectroscopy

2mm sieved soil samples were powdered in an agate mill and mixed thoroughly with KBr (FT-IR grade). FT-IR spectra of the pelletized KBr samples were recorded with a spectrometer (Varian 660-IR FTIR spectrometer) (Ellerbrock *et al.*, 1999a). All spectra were corrected to reduce the effect of mineral contents, using the subtraction method (Bio Rad, 1996a).

2.4. Soil carbon mineralisation (Incubation experiment)

Carbon mineralisation of soil samples collected from different systems from Amayannoor and Mundakkayam were studied by quantifying the CO_2 evolution from soils incubated for different time intervals, as described by Ladd *et al* (1995). Soil samples (20 g, 2mm) were moistened to 60% field capacity and incubated at 28^oC in air -tight plastic containers for 60 days and replicated five times. Evolved CO_2 was allowed to get absorbed in 10 ml of 1M NaOH kept in a beaker placed inside the container. The beakers were taken out at regular intervals *viz.*, 7, 15, 30, 45, 60 days and titrated with 0.5 M HCl. The containers were opened for ten minutes every third day to allow gas exchange. The amount of CO_2-C evolved was calculated using the formula, CO_2-C evolved (mg/100 g soil) = (A-B) x N x 6 where A and B are the volume of HCl consumed for titrating 10 ml of NaOH in control and sample respectively and N is the normality of HCl .

The soil samples (2 mm) were fractionated to different physical size fractions (2– 0.25 mm, 0.25 - 0.053 mm and < 0.053 mm) and the different size fractions were also incubated to study the carbon mineralization.

2.4. Statistical Analysis

One-way ANOVA was carried out for all data on soil properties in SPSS version 10.0. Duncan's Multiple Range Test (DMRT, $p < 0.05$) was used to separate the means when differences were significant. Pearson linear correlations between the parameters were conducted with SPSS version 10.0.

3. RESULTS AND DISCUSSION

3.1. Litter quality and decomposition pattern

Among the three litter species studied, rubber litter had the highest lignin and polyphenol contents, intermediate in cellulose content and lowest in nitrogen and phosphorus contents. *Pueraria* litter had the highest cellulose and phosphorus, intermediate nitrogen and the lowest lignin and polyphenols contents. The highest nitrogen, intermediate phosphorus, lignin and polyphenols and the lowest cellulose contents were recorded in *Mucuna* litter.

The rate of decomposition of litter from the three species was in the order *Pueraria* > *Mucuna* > rubber. The half life values were 2.7, 3.3 and 3.6 months for *Pueraria, Mucuna* and rubber respectively. Cellulose, phosphorus and nitrogen contents in litter showed a significant positive correlation with loss of weight of litter where as lignin, polyphenols and calcium contents in litter showed a negative correlation. It was observed that about 98 per cent of the nutrients (N, P, K, Ca and Mg) in *Pueraria* were released within a year. The reasons for faster decomposition of *Pueraria* than the other two litter species could be due to the higher cellulose and lower lignin and polyphenols contents.

3.2. Characterization of soil organic matter and soil properties

***3.2.1. Location 1*. Amayannoor**

3.2.1.1. Soil physical properties

Bulk density was not affected by the different land use systems. Particle density was significantly lower in immature rubber with pineapple system than the other three systems, which were comparable. Immature rubber with *Pueraria* system recorded significantly higher porosity than the other systems. It was observed that the land use or the associated management practices affected water stable aggregates and it significantly decreased in the order immature rubber with banana > immature rubber with *Pueraria* > immature rubber with pineapple > mature rubber system.

3.2.1.2. Chemical properties

There was significant difference in pH between systems and it decreased in the order immature rubber with banana (5.06) > immature rubber with *Pueraria* (4.91) = mature rubber (4.88) > immature rubber with pineapple (4.79). Organic carbon (OC) status varied significantly among the systems and was highest in immature rubber with *Pueraria* and lowest in immature rubber with pineapple. Immature rubber with banana and mature rubber systems showed comparable OC status. Total nitrogen in immature rubber with *Pueraria* and mature rubber systems was comparable and higher than the other two systems. CEC also was highest in immature rubber with *Pueraria* followed by immature rubber with banana. CEC of mature rubber was lowest and it was comparable to that of immature rubber with pineapple system. There was variation in available nutrient status also.

3.2.1.3. Characterization of soil organic matter

Physical fractions

Physical fractionation of the soil separates the soil (2 mm) into three size fractions *viz.* macro sized (0.250-2.0 mm), micro sized (0.053-0.250 mm) and silt + clay (< 0.053mm) fractions. It was observed that the distribution of soil particle size fraction was different in different systems. In all the systems the micro sized fraction was less than the other two size fractions. Marked difference was observed in carbon content of different size fractions. Irrespective of the systems, the carbon content of the size fractions increases with decrease in size. It was observed that on an average 77 per cent of the soil carbon was associated with the silt+ clay fraction.

Chemical fractionation

WSC and HWEC were significantly higher in immature rubber with *Pueraria* and in immature rubber with banana systems than the other two systems. POSC in the various systems decreased in the order immature rubber with *Pueraria* > mature rubber = immature rubber with pineapple > immature rubber with banana.

Spectroscopic characterization

Characterization by UV-Vis spectroscopy

The E_4/E_6 values and E_2/E_3 values of different rubber based systems at Amayannoor decreased in the following order: immature rubber with *Pueraria* > immature rubber with pineapple > immature rubber with banana > mature rubber indicating more condensation in mature rubber system compared to immature systems.

Characterization by FTIR spectroscopy

The relative absorption at 1050 cm^{-1} (C-O stretching of carbohydrates, polyssacharides) was highest in immature rubber with *Pueraria* and lowest in mature rubber. The relative absorption at 1630 cm-1 (C=O vibrations of carboxylates and aromatic vibrations) of the different systems decreases in the order mature rubber > immature rubber with banana > immature rubber with pineapple > immature rubber with *Pueraria* indicating more aromaticity in mature rubber system than the immature systems.

3.2.2. Location 2.Mundakayam

3.2.2.1. Soil physical properties

Bulk density of the immature rubber with *Mucuna* and immature rubber with banana systems were significantly lower than the rubber-pineapple and mature rubber systems. Also rubber-*Mucuna* and rubber-banana systems had higher porosity. No marked difference was noticed in particle density among the systems. Water stable aggregates also were significantly higher in immature rubber with banana and lower in immature rubber with pineapple system.

3.2.2.2. Soil chemical properties

All the systems are strongly acidic in reaction. Acidity in the various systems decreased in the order immature rubber with banana (4.92) > immature rubber with pineapple (4.70) > immature rubber with *Mucuna* (4.65) > mature rubber (4.44). OC was significantly higher in immature rubber with *Mucuna* and lower in mature rubber. Same trend was observed in CEC also. Available nutrient status also showed variation between systems.

3.2.2.3. Characterization of soil organic matter

Physical fractionation

The distribution of soil particle size fractions was different in different systems at Mundakayam also. Irrespective of the systems, the micro sized fraction was less than the other two size fractions. Carbon content of the three size fractions vary markedly and here also it decreases in the order silt + clay fraction > micro sized fraction > macro sized fraction. It was found that on an average 75 per cent of the soil carbon was associated with the silt + clay fraction.

Chemical fractionation

WSC was significantly higher in immature rubber with banana system and other systems were comparable. HWEC was significantly lower in immature rubber with pineapple than the other three systems, which were comparable. The different systems showed marked variation in POSC.

Spectroscopic characterization

Characterization by UV-Vis spectroscopy

E_4/E_6 values and E_2/E_3 values of the various systems decreased in the order, immature rubber with banana > immature rubber with pineapple > immature rubber with *Mucuna* > mature rubber. This indicates high degree of condensation of aromatic humic constituents in mature rubber system compared to immature systems.

Characterization by FTIR spectroscopy

At Munakayam, the relative absorption at 1050 cm^{-1} (C-O vibrations of carbohydrates, polyssacharides) decreased in the order immature rubber with banana > immature rubber with pineapple > immature rubber with *Mucuna* > mature rubber. The relative absorption at 1630 cm^{-1} (C=O vibrations of carboxylates and aromatic vibrations) of the different systems varied in the order, mature rubber > immature rubber with *Mucuna* > immature rubber with pineapple > immature rubber with banana indicating more aromaticity in mature rubber system than the immature systems.

3.2.3. Location 3. Erumely

3.2.3.1. Physical properties

Bulk density in the mature rubber and immature rubber with *Pueraria* systems were comparable and significantly lower than that of immature rubber with *Mucuna.* No significant difference in particle density of the systems noticed. Mature rubber system recorded significantly higher porosity than the other two systems, which were comparable. Similar trend was observed in water stable aggregates also.

3.2.3.2. Chemical properties

Soil acidity was more in immature rubber with *Pueraria* system than the other two systems. Organic carbon status in the three systems differ in the order mature rubber > immature rubber with *Pueraria* > immature rubber with *Mucuna*. Total nitrogen also showed similar trend. The three systems showed variations in their available nutrient status.

3.2.3.3.Characterization of soil organic matter

Physical fractionation

The distribution of soil particle size fraction was different in different systems. However, in all the systems the micro sized fraction was less than the other two size fractions. It was found that carbon content in size fractions increases with decreasing size.

Chemical fractionation

WSC in immature rubber with *Pueraria* and immature rubber with *Mucuna* systems were comparable and significantly higher than that in mature rubber system. HWEC was also highest in immature rubber with *Pueraria* system. POSC showed significant difference between systems.

Spectroscopic characterization

Characterization by UV-Vis spectroscopy

Mature rubber system recorded a lower E_4/E_6 value and E_2/E_3 value than that in the immature systems with cover crop and it decreased in the order, immature rubber with *Pueraria* > immature rubber with *Mucuna* > mature rubber. This indicates more humification in mature rubber system than in immature systems.

Characterization by FTIR spectroscopy

Immature rubber with *Pueraria* system showed a lower absorption in the aromatic region and a higher absorption in the carbohydrate region than the other two systems which are almost similar.

3.3. Soil carbon mineralisation (Incubation study)

3.3.1. Amayannoor

In the initial phase of incubation there was a rapid release of CO_2 in all the systems studied which was followed by a slow release. When the evolution of CO_2 for sixty days were considered, it was highest in immature rubber with *Pueraria* system followed by immature rubber with banana system, immature rubber with pineapple and the mature rubber system. It was found that, there was significant difference in total carbon mineralized per unit weight of soil carbon between systems during the incubation period. The rate of carbon mineralization (mg CO_2-C g^{-1} soil C day^{-1}) was in the following order, immature rubber with *Pueraria* (0.55) > immature rubber with banana (0.45) = immature rubber with pineapple (0.42) > mature rubber (0.37).

Presence of more water soluble carbon might have enhanced the carbon mineralization in the immature rubber with *Pueraria* system than the other three systems. The higher mineralization rate in the immature rubber with pineapple system compared to the mature rubber system might be due to the effect of tillage in the pineapple intercropped field. WSC and HWEC showed significant positive correlation with carbon mineralization rate.

3.3.2. Mundakayam

The mineralisation pattern showed that in these systems also initially there was a rapid release of CO_2, followed by a slow phase. The cumulative CO_2 evolution from the different systems during the incubation period was in the order, immature rubber with banana > immature rubber with pineapple > mature rubber > immature rubber with *Mucuna.* The rate of carbon mineralization (mg CO_2-C g-1soil C day-1) was in the following order, immature rubber with banana > immature rubber with pineapple = mature rubber > immature rubber with *Mucuna.* The low pH and recalcitrant nature of the litter might have contributed to the slow decomposition of soil organic matter in mature rubber and immature rubber with *Mucuna* systems.

Carbon mineralization in particle size fractions

The decomposition rate of soil carbon varied with particle size. Irrespective of the land use / management practices, carbon associated with the largest sized fraction decomposed faster than the other smaller size fractions. As the macro sized fraction consists of partially decomposed litter, it is more susceptible to microbial attack than the carbon in the silt + clay fraction which is bonded with mineral matrix.

SUMMARY

- The three major litter species in rubber plantation *viz*. rubber, *Pueraria* and *Mucuna* vary in quality, decomposition rate and nutrient release. Rubber litter had significantly higher content of lignin and poly phenols and lower contents of nitrogen and phosphorus than *Pueraria* and *Mucuna*. *Pueraria* litter had significantly higher cellulose, phosphorus and lower lignin and polyphenols than the other two litter species. Nitrogen and calcium were higher and cellulose was lower in *Mucuna* litter. The rate of decomposition of the three litter species decreased in the order *Pueraria* > *Mucuna* > rubber.

- Carbon content in the soil particle size fractions increased as size decreased in all the systems in all the locations.

- Major portion of carbon in soil is associated with < 0.053mm (silt + clay) fraction.

- In general, immature rubber with *Pueraria* system showed better physico – chemical properties and more labile carbon than the other systems studied.

- UV-Vis and FTIR spectroscopic characterisations indicated more condensation or humification in mature rubber system than the immature systems.

- Incubation study indicated that different rubber based systems were significantly different in soil carbon decomposition. Among the different systems, rate of

carbon decomposition at Amayannoor was in the order, immature rubber with *Pueraria* > immature rubber with banana = immature rubber with pineapple > mature rubber. Among the different systems at Mundakaym, the rate of carbon decomposition was in the order, immature rubber with banana > immature rubber with pineapple =mature rubber > immature rubber with *Mucuna*.

- Carbon mineralization is positively influenced by water soluble carbon and pH.
- Irrespective of the land use/management practices, carbon associated with the largest sized fraction decomposed faster than the other smaller size fractions.

CONCLUSION

The study revealed that vegetation and management practices in rubber plantation influenced the quantity and quality of soil organic matter. The higher labile carbon pool and faster decomposition of organic matter in immature rubber with *Pueraria* system indicated its higher nutrient supplying potential compared to other systems studied. Immature rubber with *Mucuna* system having higher carbon status and slow organic matter decomposition favours carbon storage. In the growing phase of rubber, establishment of *Pueraria* is more favourable than other vegetation. The slow soil carbon mineralization in mature rubber plantation indicates its carbon sequestration potential.