SOIL CARBON STOCKS AND MICROBIAL STATUS IN THE SELECTED WOODY ECOSYSTEMS OF TRISSUR DISTRICT, KERALA

by

AISWARYA SOJI JOSEPH

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THESIS

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VELLANIKKARA, THRISSUR – 680656

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DECLARATION

I, Aiswarya Soji Joseph (2016 – 20 – 005) hereby declare that this thesis entitled "**Soil carbon stocks and microbial status in the selected woody ecosystems of Trissur District, Kerala**" is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Place: Vellanikkara	Aiswarya Soji Joseph
Date:	(2016-20-005)

CERTIFICATE

Certified that this thesis entitled "**Soil carbon stocks and microbial status in the selected woody ecosystems of Trissur District, Kerala**" is a record of research work done independently by Miss. Aiswarya Soji Joseph under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

Place: Vellanikkara
Date:

Dr. Kunhamu, TK
Professor and Head
Silviculture and Agroforestry Department
College of Forestry (COF)
Kerala Agricultural University
Vellanikkara, Thrissur
680656

CERTIFICATE

We, the undersigned members of the advisory committee of Miss. Aiswarya Soji Joseph, a candidate for the degree of **B.Sc – M.Sc (Integrated) Climate Change Adaptation** agree that the thesis entitled "**Soil carbon stocks and microbial status in the selected woody ecosystems of Trissur District, Kerala**" may be submitted by Miss. Aiswarya Soji Joseph in partial fulfillment of the requirement for the degree.

Dr. Kunhamu, TK
(Major Advisor, Advisory committee)
Professor and Head
Silviculture and Agroforestry Department,
College of Forestry (COF)
KAU, Vellanikkara, Thrissur

Dr. P. O. Nameer
(Member, Advisory Committee)
Dean
College of Climate Change and
Environment Science (CCCES)
KAU, Vellanikkara, Thrissur

Dr. Santhoshkumar AV
(Member, Advisory Committee)
Professor and Head
Forest Biology and Tree
Improvement Department
College of Forestry (COF)
KAU, Vellanikkara, Thrissur

Dr. K. Surendra Gopal
(Member, Advisory Committee)
Professor and Head
Agricultural Microbiology
Department
College of Agriculture (COA)
KAU, Vellanikkara, Thrissur

(EXTERNAL EXAMINER)

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SYMBOLS AND ABBREVATIONS

BD	Bulk Density
CDM	Clean Development Mechanisms
CFU	Colony Forming Unit
FR1	250-2000µm
FR2	53-250µm
FR3	<53µm
HG	Home Garden
Mg	Megagram
MRT	Mean Residence Time
OHG	Open Home Garden
OTP	Open Teak Plantation
Pg	Petagram
RMP	Recommended Management Practices
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
Tg	Metric ton
TP	Teak Plantation

CHAPTER 1

INTRODUCTION

Anthropogenic activities have trembled the natural climate and brought damages to life, property and environment. The sole benefit of this climatic irregularity is increased productivity but the negative effects are submerging them. The frequencies of extreme events like droughts, floods, heatwaves, forest fires, etc. are constantly expanding all throughout the planet (Albrecht and Kandji, 2003). The indiscriminate exploitation of the nature under the garb of development, has its greatest toll being paid back adding to the miseries of mankind. The elevation of global temperature due to the increased concentration of greenhouse gases has been a topic of discussion for a long time. The three terms climate change, global warming and greenhouse effects are interlinked with each other and became topics of discussion lately. Carbon dioxide, methane, nitrous oxide etc. are a few GHGs that are responsible for these changes, as increased concentrations of these leads to global warming. The warming potential varies for each of them. Despite the fact that carbon dioxide has a lesser warming potential it's too larger concentration often qualifies it as the major contributor to global warming and associated climate change. For instance, carbon dioxide levels have risen from 350 parts per million in the preindustrial era to 412 parts per million as a result of fossil fuel burning, industrial emissions etc. and the global temperature has risen by 0.74° C. There have been an increase of 31% in atmospheric carbon concentration since the preindustrial era from fossil fuel and land use changes (Lal, 2004b).

Various climate policies like Kyoto Protocol, REDD+ program, CDM etc. specifically aim at climate change mitigation and adaptation by reducing carbon dioxide emissions. To lower carbon dioxide levels, several mechanisms such as carbon sequestration, renewable energy development, and biofuel promotion are being developed all over the world. Soil carbon sequestration has been identified as an efficient approach in these climate policies and soils that have higher sequestration potential compared to terrestrial and atmospheric sequestration potential have been found as a cost-effective mechanism. Soil stores carbon in the organic and inorganic pools and the cost for storage seems to be lower with an approximate value of $1 -69/ Mg C (Albrecht and Kandji, 2003). Hence, increasing the capacity of soils to sequester carbon might assist developing nations like India to improve their economic standing. Some mitigation programmes, such as the CDM, award developing countries for the carbon stored beyond their limit. The potential for SOC sequestration can be boosted in a cost-effective manner by increasing tree cover. Even though the importance of trees in carbon storage has been identified, still these carbon sinks are turning out to be sources with increasing deforestation activities. Loss of 1Pg soil C is approximate to release of 0.47ppm carbon into the atmosphere (Holeplass et al. 2004).

Woody ecosystems are known for their carbon sequestration potential both in the biomass and soil. However, there exist considerable variation in the rate at which carbon stored in the biomass and soil. It varies with the kind of tree cover, species diversity, soil chemical and physical properties, carbon and nutrient turnover potential and the like.

In woody ecosystems, carbon accretion to soil is primarily from the aboveground litter and belowground root dynamics. Depending upon various factors like species diversity, management factors, climatic factors etc. the potential of different systems varies. Indian soils have a potential between 39- 49 Tg C/year and sequester 21 billion tons in 1.5m depth (Lal, 2004b). Majority of the woody ecosystems are the major donors of carbon in soil. Forests were found to have the highest carbon sequestration compared to the other agroforestry systems. The potential of different land use systems varies from 0.2- 0.63 % (Maini et al., 2020).

Kerala has a large area covered with monoculture plantations, agroforestry systems like homestead gardens, forests, tree outside forests etc. and all of these have varying sequestration potential. 29% of the state are forests which include both natural and man-managed forests. Teak plantations at different growth stage cover 56510ha in the Kerala state as reported by the Kerala Forest Department. These usually have 50-60years of duration. They sequester carbon in the biomass as well as soil. A typical teak in Kerala have potential to sequester 181.13-ton carbon per hectare during its entire lifespan (Sreejesh et al., 2012). Homegardens, which cover 1.4 million hectares in Kerala, are another prominent agroforestry system. These systems mimic the evergreen forests. They cover 36% of the Kerala state and have a sequestration potential of 101.5 to 127.4 Mg/ ha (Saha et al., 2009).

The soil carbon storage potential in woody ecosystems is primarily decided by the type and the physico-chemical attributes of the soil. Soils rich in nutrients and having congenial biophysical conditions often show higher levels of carbon delivery to the soil. Invariably, soils in woody ecosystems have a prominence in SCS as compared with other land use practices. For instance, studies on the soil CSP on four woody land use types in Kerala showed that the highest carbon storage was attached with forest soils followed by homegardens and rubber plantations (Saha et al., 2010). The non woody paddy field registered the lowest soil carbon stock. The soil microclimate, microbial activity also decides the CSP of soils in addition to the profound influence of associated vegetation.

Among the many factors, the soil texture plays an important role in carbon storage in addition to other physico-chemical attributes. Studies reveal that there exists considerable variation in the quantity and longevity of carbon sequestration among various soil aggregates. Biochemical recalcitrance, chemical stability, and physical protection all help to store carbon in the soil. Soils are made up of diverse fractions, with the lowest fraction having a higher potential for carbon sequestration than the larger fractions. The residence time of carbon in different aggregates varies and also influence the SOC. Woody ecosystems usually store more carbon in the smallest fraction (Saha et al., 2010). Most of the studies concentrate on the SOC but quantitate information of SOC and nutrient storage in soil aggregates are scarce, particularly in Trissur district.

The predominant role of soil microorganisms in enriching the soil properties is established long before. These organisms make the soil more flexible and allow nutrients to be released into the soil. The microbial diversity is found to be higher in woody ecosystems primarily due to the sound carbon and nutrient turnover mechanisms contributed by the deep root systems. It has also been observed that the microbial diversity has significant positive influence on the nutrient and carbon accretion in the soil pools. However, the vegetation type and their diversity play pivotal role in deciding the microbial diversity and their functional efficiency in the soil. Moreover, the diversity is also influenced by the bio-climatic conditions of the soil. The humid agroclimatic of Kerala permit the growth of diverse forms of microorganisms in various land use types especially woody ecosystems. The type and load of the microbial population may also influence the carbon cycle in various wood-based systems in Kerala. However, our understanding on such relationships is seldom reported. Hence there assume considerable importance in identifying the microbial load and diversity in woody ecosystems of Kerala.

In this backdrop, a field study has been designed with the following objectives

1. To assess the soil carbon stock, nutrient content (N, P, K) in various soil size fractions in selected woody ecosystems viz. teak plantation and traditional homegarden.
2. To assess the microbial load and beneficial organisms in selected woody ecosystems of Kerala.

CHAPTER 2

REVIEW OF LITERATURE

2.1 GLOBAL WARMING

The degrading effects of climate change are affecting the environment and the people adversely. The impacts of global warming have brought unprecedented changes in the entire globe. One of the prominent changes by its effect was increased temperature due to the elevated concentration of various GHGs. The concentrations of GHGs like carbon dioxide have been steadily rising at a rate of 1.5 ppmv year^{-1} (3.3 Pg C year^{-1}) in the atmosphere. It increased from 280ppmv in 1750 to 367 ppmv in 1999 (Batjes and Sombroek,1997; Lal, 2004). Around 1.1 Pg C year^{-1} has been released into the atmosphere as a result of land use changes, and 5.5 Pg C year^{-1} was released as a result of fossil fuel combustion. Atmosphere and oceans are acting as sinks for these releases 3.2 Pg C and 2 Pg C respectively per year (Albrecht and Kandji, 2003). Anthropogenic emissions have reached 9.7 Pg C by 2012 (Lorenz and Lal, 2014). Increased agricultural lands have also contributed to this carbon release, accounting for 10-12 percent of all anthropogenic carbon emissions. The cultivated soils have lost two-third of their initial SOC pool (30-40 Mg C year^{-1}) in the last several years. All these factors have demanded the need for the development of sustainable pathways to tackle the problems of climate change.

2.2 WOODY ECOSYSTEMS AND CARBON SEQUESTRATION

Agroforestry has been proved as an effective and cost-effective mechanism to confront climate change by trapping one of the most potent greenhouse gases, carbon dioxide. Carbon sequestration is the process of storing carbon dioxide over lengthy periods of time. Storing carbon has dual benefits it adds carbon to the soil which increases soil fertility as well as it helps to mitigate climate warming (Kan et al., 2020). This carbon storage mechanism also aids to achieve the goals of Kyoto Protocol. Agroforestry gained attention as a mitigation technique under the Kyoto protocol, with annual emissions ranging from 0.29 to 15.21 Mg ha^{-1} (Nair, 2009). Agroforests rank second after forests in terms of their SOC content and hold 25% of global carbon stocks whereas, arable crops have a lower SOC content (Albrecht and Kandji, 2003).

Various Conference of Parties of the UNFCCC proposed strategies aiming at increasing SOC and in COP 21 it was proposed to increase SOC for climate change mitigation and food security advancement, since both are facing a lot of challenges in the current world (Lal, 2004a; Lal et al., 2015). A solution for these insecurities would be the conversion of non-productive areas into agroforests (Albrecht and Kandji, 2003; Nair et al., 2009). About 630 million ha of such lands with the potential to sequester 586,000 Mg C per year by 2040 exists worldwide.

The SOC sequestration potential of agroforestry was also utilized in REDD+ (Reducing Emission from Deforestation and Forest Degradation) for reducing GHGs (Nair, 2012). Carbon trading initiatives like CDM can be brought into action to attract and encourage farmers to practice agroforestry practices(Kumar, 2006). People participating in CDM receive incentives like $50 per Mg Pg^{-1} for storing carbon beyond their limit. These in turn facilitate the improvement of the country's economic status by getting investments from developed nations in exchange for a reduction in GHG emissions.

2.3 SOIL CARBON SEQUESTRATION

Compared to other systems, soils have a larger potential for carbon storage which is double the atmospheric pool and 2.5 times the terrestrial pool (Šimanský and Bajcan, 2014). Soil contains Soil Inorganic (750 Pg) that is directly sequestered carbon and Soil Organic pool (1550 Pg) which is indirectly sequestrated by the first capture by plants and then gained by the soil through decomposition which is stored in deeper soil layers (Nair et al., 2009). The amount of carbon contained in the world's soil varies between 1940 and 3293 Pg C (Batjes and Sombroek, 1997). When compared to terrestrial plants, the top 1m depth stores more than double the amount of carbon (Batjes, 1999). SOC varies from 1200- 1600 Pg in the top 1m and 2376-2456 Pg in 2m depth, owing to contributions from roots and charcoal (Lal et al., 2015). Expansion of woody ecosystems aids in maintaining the SOC.

The sequestration potential varies with tree species, age of the tree, regional climatic conditions etc (Batjes, 1999). For instance, young trees sequester more carbon than matured trees, Fibrous roots contribute to more carbon than taproot species, Tropics have much quicker sequestration than boreal forests. Arid (251 Pg C) has lesser soc than semi-arid (509 Pg C) (Han et al., 2010). Of the total terrestrial SOC stock, 50% is found in Tropical rain forests, 60% in temperate forests, and 85% in boreal forests (Lal, 2005). Soils that are cool and damp, with a lot of clay, give better conditions for enhanced carbon sequestration (Lal et al., 2015). SOC tends to vary globally from 0.4 to 0.8 Pg C per year in croplands, 0.2 to 0.4 Pg C per year in forest and degraded lands, 0.01 -0.3 Pg C per year in grasslands and rangelands and 0.01 -0.03 Pg C per year in irrigated soils, thus world soil sequesters between 0.4 and 1.2 Pg C per year (Batjes, 1999; Maini et al., 2020).

Despite all this, these sources are releasing carbon into the atmosphere due to various anthropogenic interferences. We can minimize rising carbon source emissions from 3.2 Pg C per year to 2-2.6 Pg C per year by re-carbonizing (Lal, 2004b). However, the terrestrial potential reaches 3.8 Pg C/ year (Lal et al., 2015). Although woody ecosystems cover 1,023 million ha, their sequestration is limited due to various site-specific biological, climatic, soil and management characteristics unique to each site (Nair et al., 2009). Woody ecosystems increase above ground and belowground carbon sequestration of soil.

Trees have been shown to have a role in carbon sequestration in soils, vegetation, and biomass products (Nair, 2012). The SOC stock is more in high tree density than in low tree density areas (Saha et al., 2010). Systems like homegardens and agroforests appear to store a huge amount of carbon (Kumar, 2006). Home gardens offer the added benefit of decreasing fuel emissions since they encourage the production of woodfuel (Kumar, 2011). Deforestation in these areas does not cause complete clearance of trees, some of them are always left behind. Teak plantations provide a double advantage by producing timber and storing a significant quantity of carbon in both the trunk and the soil. These systems have a C stock range of 16 to 36 Mg/ha. Teak plantations also have demonstrated their strong carbon sequestration role. These lock carbon for a longer period due to their longer duration (Sreejesh et al., 2012).

2.4 ABOVE GROUND AND BELOW GROUND CARBON DYNAMICS

Soils have an overall sink capacity of 0.4- 0.6 Pg C per year which can be gained over the 50-100 years' time period. The carbon dynamics is a multi-dimensional and interactive process (Albrecht and Kandji, 2003). It is mainly controlled by the rate of carbon transferred into the soil either as fine roots, litter etc or by microbial activity (Batjes, 1999; Nair et al., 2009). The aboveground and belowground soils sequester up to 2.2 Pg C over 50 years in agroforestry systems(Nair et al., 2009).

Above ground, soil carbon sources include litterfall, twigs, plant residues etc. and from these about 1.5 Pg C can be assimilated globally (Nair et al., 2009). But this varies with the region for instance, the tropics have a potential of 2.1×10^9 Mg C year^{-1} while the temperate has a potential of 1.9× 109 Mg C year^{-1} (Oelbermann et al., 2004). The aboveground sinks are usually the topsoil and plant biomass. The belowground carbon is mostly contributed by the root zone which constitutes 30% of tree biomass (Nair et al., 2009). Roots, soil microbes, and the inorganic form of carbon are all sinks for belowground SOC.

Despite the fact that roots provide more carbon to the soil than plants do, but information about fine root dynamics contribution to SOC is scarce. The root zone alone holds 1.5-2 % SOC (Lal et al., 2015). The residence time of root carbon seems to be higher than the shoot carbon. i.e. MRT of root C is 2.4 times MRT of shoot C (Rasse et al., 2005). Humification, aggregation, biomass transfer to deeper strata, inorganic carbon leaching, and other processes all contribute to SOC sequestration in tree-based land use systems. Factors like aggregation strongly influence the SOC concentration in the soil (Sakin, 2012).

2.5. AGGREGATE CARBON SEQUESTRATION

Most studies concentrate on soil carbon as a whole but aggregates have a substantial role in maintaining soil physical structure and chemical properties in various land use systems by sequestrating carbon and protecting it from degradation (Lua et al., 2019; Šimanský & Bajcan, 2014; Zhou et al., 2020). Studying aggregates also gives us a better idea about the SOC dynamics in soil and this process helps to protect loss of carbon for further degradation through formation of organo- mineral complexes (Lal, 2003; Nair, 2012). The abundance of aggregates also defines good soil structure. SOC is protected within the soil aggregates, 90% SOC is stored within the aggregates (Bashir et al, 2016). Aggregates also act as sink and source of carbon which makes its analysis inevitable as its maintenance and elevation of sink capacity is necessary (Chen et al., 2012; Liu et al., 2019). Humic substances and microbial by-products through biotic mechanisms bind SOC in aggregates (Holeplass et al., 2004). SOM is the major cementing agent for stable aggregate formation (Šimanský & Bajcan, 2014). The different aggregates are held together by agents such as fungal hyphae, microbial cells, plant roots exudates and other stabilizing agents at the macroscopic level (Han et al., 2010). These substances regulate the stability of aggregates and combine micro aggregates into macroaggregates. Since the macroaggregates are held by the organic matter they are the highest carbon reservoirs. During various natural and artificial stresses like erosion and tillage activities, these aggregates are scattered and get oxidized which are released into the atmosphere reducing the SOC content in the aggregate particles (Kan et al., 2020). The disruption of macroaggregates causes the removal of labile C fractions as they are easily exposed. With increasing temperatures, these labile fractions are lost rapidly in the artic regions (Lal, 2005). SOC has different components, which vary from labile to stable form with different residence times and different SOC concentrations. The active labile pool has MRTs approximately 1-2 yrs. and SOC 0.09- 0.22 %, slow pool has MRTs ranging approximately 25 years with SOC range 0.15- 0.72%, passive recalcitrant pool having MRT 100-1000 year and SOC 0.83- 4.68% (Maini et al., 2020). The recalcitrant pool gets concentrated with increasing depth (Lorenz and Lal, 2005).

Different land use systems contain different amounts of soil aggregates for instance in forest soils smallest size (<53 μm) is found in higher concentrations but grasslands macroaggregates tend to hold more carbon (Lua et al., 2019). But this alone cannot define the stability of sequestration potential. It is more dependent on the mean residence time (longer MRT longer stability of aggregates) than the land use. Retention time of carbon can vary from immediate release to long term storage. But only long term SOC storage of decades of millennia time helps climate change mitigation (Lal et al., 2015). This shows the importance of analyzing the carbon sequestration potential of soil aggregates in various land use systems even though various other factors have a major controlling role in this sequestration potential. Aggregate scattering shows the extent of physical protection and chemical stabilization in the soil (Lua et al., 2019).

Another major controlling factor in aggregation is land use management. Incorporation of recommended management practices (RMPs) has shown to have average sequestration of 288 Tg C/ year (Lal, 2004b; Lua et al., 2019). These RMPs along with afforestation and reforestation practices helps to increase the sink capacity and have the potential to sequester 14 +/- Pg C in the coming 25 years. These RMPs with 0.58 to 0.80 Pg C potential can reduce 9-12% anthropogenic emissions annually (Batjes, 1999; Lua et al., 2019). Land use changes i.e. conversion of forests tends to disturb the soil physical structure and decrease the aggregation in soil and exposes the carbon encapsulated within the microaggregates and clay and silt fraction (Dondini et al., 2009). These exposed carbon losses its stability and is washed by erosion, wind etc. various practices like tillage reduce the aggregation of soil and reduces the carbon storage in smaller aggregates this is the reason for lower carbon sequestration in croplands compared to undisturbed systems like forests (Gelaw et al., 2015). Erosion induced losses account for 1.14 Pg of C year^{-1} sloping lands 30-40 Mg C ha^{-1}. Sometimes the smaller particles get washed away easier but they have water resistance due to their higher SOC. About 2Pg C per year is lost by deforestation activities by reduction of carbon storage in smaller aggregate fraction. These RMPs change with region depending on the influence of climate change which is more pronounced in high latitude regions than in mid latitude regions (Lal, 2004b). Tropical agroforestry systems sequester between 12- 228 Mg C ha^{-1}. In cultivated lands, SOC can be restored by adopting conservation tillage practices. These soils usually contain 25-75% less SOC than the undisturbed soil. Due to these tillage practices, cultivated soils have higher microaggregate SOC and other systems like grasslands have macroaggregate SOC at higher concentration. Other RMPs that can be adopted including choosing the species with higher sequestration potential, identification of proper crop management systems (Lal et al., 2015). In plantations, RMPs include increasing the rotation length, harvesting, pruning/thinning, controlling natural disturbances, tree species selection. There are various others practices which increases SOC like mulching, crop rotation, fertilizer application etc. But manuring although contributes positively, its effect is not significant in climate change mitigation. These practices can increase SOC sequestration up to 14% (Holeplass et al., 2004). In India if RMPs are adopted the SOC can be increased to 34.9 Pg (Lal, 2003). Macroaggregates are most influenced by the management practices in the land use systems (Kan et al., 2020). Anthropogenic influences also disturb the aggregation and SOC indicating undisturbed forests with higher SOC than with other soils.

Various other factors are also interlinked with SOC pool. For example, increasing temperature depletes the SOC pol by more than 20% in humid and sub humid regions and up to 15% in arid zone. SOC sequestration in humid regions holds up to 50 Mg C/ ha There is increasing SOC with increasing diversity (Lal, 2004b). With increasing afforestation activities there has been an increase of SOC by 23% and more carbon is stored within the microaggregates (53– 250 µm) and silt and clay (<53 µm). The fine textured soils store more carbon because of their higher residence time and higher concentration. The stability of aggregates is in the order smallest fraction> microaggregates > macroaggregates (Zhou et al., 2020). Thus, the smallest fraction is less prone to disturbances and are mostly associated with C storage. These clay fractions are also more prone to climate change than the sand fraction (Dondini et al., 2009). While considering the MRT, microaggregates appears to have longer residence time than macroaggregates (Falade, 2017). MRT of for macroaggregates, microaggregates, and silt + clay fraction ranges from 1-10, 10-100, 100-1000 years respectively (Nair et al., 2009). Considering the stability and SOC stock, clay and silt fraction have a higher concentration as it is protected from microbial and enzymatic degradation. The small pores of clay lock the carbon and becomes resistant to decomposition (Saha et al., 2010). Stabilization of aggregates are mainly dependent on soil management (Rabbi et al., 2013). Thus evaluating the mineralization and stabilization of aggregates are necessary to know the long-term storage mechanisms of soil carbon (Kan et al., 2020). As the carbon is protected through aggregation inside fine textured, these have significant amount of carbon stocks. During macroaggregate turnover, the stable microaggregates gets released are stored inside the macroaggregates. Another regulating factor is C3 plants store more carbon silt and clay fraction than C4 plants (Nair et al., 2009). It's a complex system with different pools having different turnover times. Still controversies are there whether microaggregates are formed first or whether microaggregates are formed due to the breakage of macroaggregates.

2.6 NUTRIENT SEQUESTRATION IN AGGREGATES

Along with carbon, other nutrients like nitrogen, phosphorus, potassium etc. are also sequestered in the soil aggregates. Total nitrogen is retained in macroaggregates as short-term storage and as long-term storage in the microaggregate fraction (Gelaw et al., 2015). The range of nitrogen in soils range from 92- 140 Pg N. But the nutrients concentration has been declining with increasing cultivation activities (Batjes and Sombroek, 1997). The C:N ratio also influences the SOC dynamics which contributes carbon and nitrogen into the soil (Han et al., 2010).

2.7 MICROFLORA AND SOIL CARBON

SOM gives an entry for microorganisms and makes the soil agile (Maini et al., 2020). These microorganisms have a key role in soil aggregate formation, and control the decomposition process of various plant residues and litter fall are mediated by microbes and they tend to control the degree of aggregation(Lua et al., 2019). They act as controlling agents by forming symbiotic association with roots to influence SOC sequestration (Song et al., 2020). They contribute 2-5% to the total soil carbon pool and these are mostly seen in the rhizosphere and tree region (Talwar and Chatli, 2018). The incorporation of microflora makes it a complex system and analysis of SOC potential difficult as the dynamics of plant residues, soil and soil micro-organisms are the controlling hand within the system other than the anthropogenic influence. The influence of this microbial interaction of microflora with soil aggregation can be found by comparing the sequestration potential of no till soil and disturbed soil. Microorganisms act on the SOM which contains 58% SOC and releases into the soil. By increasing these SOM, it helps to increase the microbial activity which help in the production of substances essential for increasing formation and stabilisation of aggregates. SOM significantly influences the different size of aggregates (Oliveira et al., 2018). The kind of cropping systems influence the number of microorganisms present in the soil and the suitable conditions for microbial activity which in turn affects the aggregate stability (Zhou et al., 2020). Macroaggregates are much exposed compared to the smaller aggregates for the microbial C mineralization (Kan et al., 2020). But increasing the macroaggregates in the soil helps to protect the labile carbon which improves the soil aggregation. These microbes play a key role in SOC mineralization and nutrient cycling and supports in increasing the MRT. Agroforests contribute much suitable conditions for this process, it was noted that microbial SOC was 42% greater in agroforests than a sole crop in India (Oelbermann et al., 2004). Various factors control and makes the microbial contributions towards climate change complex due to the direct and indirect interactions (Liu et al., 2019). Increasing SOC stock in the belowground will increase the microbial activity of soil and root growth. Microbes N fixing trees sequester more stable forms of C.

Hitherto there are only few studies which look into the aggregate dynamics in the soil and our understanding is less about aggregate carbon dynamics (Lua et al., 2019). The mechanisms about C sequestration is still unclear (Kan et al., 2020). Even though trees and soil sequester a large amount of carbon, there has been a huge loss by cutting trees these losses range from 40-537 Pg in the past years (Lal, 2004b). Instead of increasing carbon sources, there should be more focus on increasing carbon sinks as it will only help in controlling the climate of the region. Increasing temperatures have negatively affected by increasing carbon sources. There are several other benefits for increasing carbon sequestration which includes improvement in food, nutritional security, and water quality, advancement of renewable energy sources, biodiversity improvement, element recycling (Lal, 2005). Practices should be adopted to develop the positive carbon budget but increasing complexity of agroforests by inclusion of ruminant animals etc can negatively affect by changing into carbon sources (Albrecht and Kandji, 2003; Montagnini & Nair, 2004). We cannot completely rely on soil carbon sequestration as in some land use systems the SOC sequestration was not significant. We cannot have a general conclusion on how the factors influence the aggregates and its stability, it needs much more research and conclusion. It is crucial to identify the baseline carbon values and how aggregates protect and store SOC for a specific climate and soil type for the various soil aggregate classes (Kan et al., 2020). The biophysical and socioeconomics of SOC issues should be considered in detail. These systems with dual benefits of mitigation and adaptation to climate change are often unexplored. Further, the knowledge about their movement is much scarce (Nair, 2012; Murthy, 2013).

CHAPTER 3

MATERIALS AND METHODS

3.1. STUDY AREA

The study area involves two selected woody ecosystems in Thrissur Forest division, Kerala that include teak plantation and a typical traditional homegarden

Typical homegarden

The selected traditional homegarden is located at Vellanikkara village, Thrissur district, Kerala. The area enjoys warm humid tropical climate with mean annual rainfall 10.225mm with peak rainfall during June August (60%). The mean maximum temperature is 36.6^0C (March) and mean minimum temperature is 23.5^0C (December). The soil in predominantly is reddish brown clayey soils with average soil pH is 5.83. The average soil depth was 80 cm and the deeper layers had stones while the open treeless areas had soil layers even after 80cm.

Teak Plantation area

The teak plantation is located at Pattikad Forest Range in the Thrissur Forest Division (10.538N,76.348E). The teak plantation consisted of trees with mostly of 15-20 years of age and was at a sloping region. The soil was comparatively dry in texture. The management is mainly done by Vaniyampara forest station. Both systems had similar climatic features but the soil was comparatively drier during sample collection.

Figure 1: Soil sample collection in a typical homegarden, Trissur

Figure 2: Soil sample collection in a teak plantation, Trissur

3.2. SOIL SAMPLING AND PREPARATION

3.2.1. Soil collection

Soil samples were collected from homegarden and teak plantation during December and March 2021 respectively. One-meter-deep soil profile was taken randomly from two locations from each of the selected woody ecosystems. Soil samples were collected from each profile from five depth intervals viz. 0-20, 20-40, 40-60, 60-80, 80-100 cm. Similarly, soil profiles were also collected from contiguous treeless open area attached to the two selected woody ecosystem. Hence there were six soil profiles for the study. Triplicate soil samples were taken from all the depth intervals and an undisturbed soil sample was collected from each depth using a core sampler for bulk density calculation.

3.2.2. Soil fractionation

The collected soil samples from the two land use systems were fractionated into three size classes viz. (250- 2000 µm, 53-250 µm, < 53 µm). Soil aggregate fractionation was done by disruptive forces of slaking and wet sieving through three sieve sizes 2000 µm, 250 µm and 53 µm to obtain three fractional size classes using Yoder's Apparatus (Yoder, 1936). Water filled in the drum of apparatus up to a level slightly below the top sieve and the soil was placed on the top of sieves arranged one by one. The apparatus was run for about thirty minutes until soil aggregated into three fractionate size classes. The aggregated soil samples were oven dried at 105 ^{0}C for almost 72hrs. The soils were further powdered and used for carbon and nutrient analysis. In total there were 90 soil samples (6 profiles x 5 depth x 3 size fractions).

3.3. SOIL PHYSICAL PROPERTIES

3.3.1. Bulk density (BD)

Undisturbed soil sample was collected from each depth interval in the soil profile using a core sampler and its volume was calculated by using the formula $\pi r^2 h$ where ‘r’ is the radius of the sampler and ‘h’ is its length. Soil samples collected were oven dried at 105 ^{0}C for 48 hrs for constant weights and oven dry weight was recorded. Bulk density was calculated using the equation:

Bulk density = $mass\ of\ soil \div volume\ of\ soil\ with\ pore\ space$

3.4. SOIL CHEMICAL PROPERTIES

3.4.1. Total soil organic carbon

Carbon percentage was analysed using Walkley and Black titration method to calculate the total soil organic carbon content of each selected woody ecosystems. The carbon stock was calculated using the equation (Anderson and Ingram, 1989):

C storage (Mg C ha^{-1}) = C concentration x BD x Depth
Where,
C storage = C expressed in Mg ha^{-1} in each fraction class for a given depth
C concentration = C in an aggregate (%)
BD = Bulk Density, kg m^{-3}
Depth = Depth of soil profile, cm and
Fraction weight = % weight of the fraction in the whole soil

Total carbon stock was calculated by adding carbon stock of all depths up to one meter depth of the soil.

3.4.2. Carbon content in soil aggregates

Soil carbon content of the fractions were calculated using Walkley and Black titration method (Walkley and Black,1934). One gram of soil was weighed in a 500ml conical flask into which 10 ml of 1 N potassium dichromate and 20 ml concentrated sulphuric acid was added and swirled a little. After 30 minutes, 200 ml of distilled water was added to stop the reaction. Four to five drops of ferroin indicator were added and the solution was titrated with ferrous ammonium solution in which the colour changed from orange to green and then to brown when the end point reached.

3.4.3. Soil total nitrogen

Soil total nitrogen was measured by Macrokjeldahl method. One gram soil was weighed and potassium sulphate and copper sulphate were added in 10:1 ratio. After adding 0.1g Selenium, it was kept aside 24hrs for predigestion by adding 10 ml Concentrated sulphuric acid. The samples were subjected to digestion. After completion of digestion, aliquot was subjected to distillation process which was done by Kelplus instrument in which 1N sodium hydroxide solution was filled. The solution was collected in a conical flask which was already filled with 10 ml of boric acid and mixed indicator solution. The total nitrogen was then estimated by titration with 0.2N sulphuric acid which turned from blue to brown colour.

3.4.4. Soil available phosphorous

Soil available phosphorous was estimated by using spectrophotometer. Five grams of soil was weighed out into a 100ml conical flask and 50ml of Bray No.1 reagent was added. A pinch of charcoal was added and shaken for 5 minutes. The solution was filtered through Whatman No.42 filter paper and extraction was done using ascorbic acid method (Watanabe & Olsen, 1965). In a 25ml standard flask, 5ml of filtrate and 4ml of ascorbic acid mixture. The ascorbic acid mixture was prepared by dissolving 1.056g of ascorbic acid in 200ml of a reagent which contains a solution of ammonium paramolybdate, potassium antimony tartarate and sulphuric acid. The standard flask volume was made up by adding distilled water. The solution turned into blue colour of different intensities in each standard flask and it was analysed using spectrophotometer.

3.4.5. Soil exchangeable potassium

Soil exchangeable potassium was estimated by using flame photometer by taking 1N ammonium acetate for extraction of potassium. Five grams of soil was weighed out into a 100ml conical flask and 25ml of neutral ammonium acetate was added and shaken for 5 minutes. The solution was then filtered through Whatman No.42 filter paper and then exchangeable potassium was estimated by flame photometer.

3.4.6. C: N ratio

The carbon and nitrogen content values measured using Walkley and Black titration and Macrokjeldahl method respectively was used for C:N ratio. It was compared in all aggregates at different depth intervals of the selected woody ecosystems.

3.5. SOIL MICROFLORA ANALYSIS

Soil sample collected from top 0-20cm was used for the microflora analysis of the selected woody ecosystems. Enumeration of microflora and selected beneficiary organisms was done by serial dilution and plate count method on suitable selective media (Johnson and Curl, 1972).

3.5.1. Total bacteria population

Bacterial enumeration was done using 10^{-5} and 10^{-6} dilutions with Nutrient Agar (NA) media. The plate count was taken after 2-3 days by counting the number of bacterial colonies present in the petri dish.

3.5.2. Total fungi population

Fungal enumeration was done using 10^{-3} and 10^{-4} dilutions with Potato Dextrose Agar (PDA) media. The plate count was taken after 5-7 days by counting the number of fungal colonies present in the petri dish.

3.5.3. Total actinomycetes population

Actinomycetes enumeration was done using 10^{-4} and 10^{-5} dilutions with KenKnights and Munaiers Medium (KK) media. The plate count was taken after 7-14 days by counting the number of actinomycetes colonies present in the petri dish.

3.5.4. Total nitrogen fixers, p- solubilizers and k- solubilizers

Nitrogen fixers, p- solubilizers and k- solubilizers enumeration were done using 10^{-5} and 10^{-6} ,10^{-3} and 10^{-4} and 10^{-3} and 10^{-4} dilutions with Jensen, Pikovskayas agar, and Alexsandrow's Broth media respectively. The plate count was taken after 2-7 days by counting the number of nitrogen fixers, p- solubilizers and k-solubilizers colonies present in the petri dish.

3.6. STATISTICAL ANALYSIS

The carbon and nutrient content in each of the soil depth intervals for woody system and its contiguous open control were statistically compared using student t-test. Also, the soil carbon and nutrient contents were compared across the three size fractions for each of the woody ecosystem following one-way analysis of variance (R 4.1.1). The microflora analysis for each population in 0-20 cm depth were statistically compared using one- way analysis of variance.

CHAPTER 4

RESULTS

4.1. SOIL PHYSICAL PROPERTIES

4.1.1. Bulk density

Bulk density value ranged from 1.19 kg m^{-3} to 1.41 kg m^{-3} in the selected woody ecosystems and is depicted in Table 1. The BD showed an increasing trend in most systems. Contiguous open treeless (1.21 kg m^{-3} and 1.26 kg m^{-3}) had higher BD values in 20-40cm and 60-80 cm of homegardens (1.19 kg m^{-3} and 1.2 kg m^{-3}). The consistent increase in BD is clearly seen in open contiguous area of teak plantation and homegarden. Bulk density was highest in teak plantation and comparatively lower in homegarden.

Table 1. Bulk density (kg m^{-3}) of soils under different depths in selected woody ecosystems of Thrissur District, Kerala

Depth (cm)	Bulk density (kg m-3)			
	Homegarden		Teak plantation	
	Woody System	Open	Woody System	Open
0-20	1.23 ^{a} (0.04)	1.19 ^{ab} (0.01)	1.37 ^{ab} (0.04)	1.28 ^{ab} (0.06)
20-40	1.19 ^{a} (0.06)	1.21 ^{ab} (0.0)	1.32 ^{b} (0.01)	1.22 ^{b} (0.1)
40-60	1.19 ^{a} (0.1)	1.14 ^{b} (0.03)	1.41 ^{a} (0.04)	1.35 ^{a} (0.08)
60-80	1.2 ^{a} (0.08)	1.26 ^{a} (0.04)	1.26 ^{c} (0.04)	1.25 ^{ab} (0.05)
80-100	-	1.25 ^{a} (0.05)	1.332 ^{b} (0.03)	1.34 ^{ab} (0.04)
Values in parenthesis are standard values of errors				

4.2. SOIL CHEMICAL PROPERTIES

Numerous soil chemical properties like SOC stock, aggregate SOC, aggregate total nitrogen, aggregate available phosphorus and aggregate exchangeable potassium was analysed. These were compared among different depth of soil up to 1m and the open contiguous plots were also compared during analysis.

4.2.1. *Total soil organic carbon*

Total SOC (%) had a decreasing concentration with depth and the values are tabulated in table 2. The SOC value ranged from 0.09 % in the bottom layer of open treeless area of homegarden to 0.69 % in top 0-20 cm depth of teak plantation to. Teak had higher carbon concentration than homegardens in all soil depths. The open treeless had lower carbon distributed throughout the 1m depth when compared to the woody ecosystems.

Table 2. Total SOC (%) of soils under different depths in selected woody ecosystems of Thrissur District, Kerala

Depth (cm)	SOC (%)			
	Homegarden		Teak plantation	
	Woody System	Open	Woody System	Open
0-20	0.52 ^{a} (0.07)	0.27 ^{a} (0.03)	0.69 ^{a} (0.1)	0.51 ^{ab} (0.15)
20-40	0.38 ^{b} (0.13)	0.19 ^{ab} (0.06)	0.65 ^{a} (0.05)	0.46 ^{ab} (0.04)
40-60	0.26 ^{c} (0.04)	0.21 ^{a} (0.06)	0.4 ^{b} (0.07)	0.69 ^{a} (0.36)
60-80	0.15 ^{d} (0.04)	0.1 ^{b} (0.08)	0.34 ^{b} (0.09)	0.25 ^{b} (0.05)
80-100	-	0.09 ^{b} (0.03)	0.72 ^{a} (0.07)	0.25 ^{b} (0.08)
Fstat	22.14	4.74	27.58	3.23
pvalue	<0.01	0.02	0.01	0.06
cdvalue	0.1	0.1	0.1	0.33
Values in parenthesis are standard values of errors				

The SOC stock was highest in teak (75.04 Mg C ha^{-1}) than homegardens (31.64 Mg C ha^{-1}). The open treeless plots of homegardens (20.8 Mg C ha^{-1}) and teak plantation (75.04 Mg C ha^{-1}) had lower than their respective woody ecosystems. The sequestration potential of soil decreased with increasing depth in all the ecosystems. Teak had higher SOC potential at 80-100 cm depth. The SOC stock was higher in the top 0-40 cm in all land use systems. The percentage increase when compared between the woody ecosystem and its contiguous treeless plots, it was appreciably higher in homegardens. There has been 97% increase in homegardens when compared to its contiguous open in the top 0-20cm soil depth. In 20-40 cm, the percentage increase was slightly lower than top layer but was appreciably with 94%. But in teak plantation even though the open contiguous had lower carbon, the percentage increase when compared to the woody ecosystem was much lower with 0.44 % and 0.57 % in 0-20 cm and 20-40 cm of teak plantation.

Table 3. Total SOC (Mg C ha^{-1}) of soils under different depths in selected woody ecosystems of Thrissur District, Kerala

Depth (cm)	SOC Sequestration Potential (Mg C ha^{-1})			
	Homegarden		Teak plantation	
	Woody System	Open	Woody System	Open
0-20	12.79 ^{a} (0.07)	6.48 ^{a} (0.03)	18.9 ^{a} (0.1)	13.06 ^{ab} (0.15)
20-40	9.04 ^{b} (0.13)	4.64 ^{ab} (0.06)	17.29 ^{a} (0.05)	10.98 ^{ab} (0.04)
40-60	6.18 ^{c} (0.04)	4.79 ^{a} (0.06)	11.28 ^{b} (0.07)	18.63 ^{a} (0.36)
60-80	3.63 ^{d} (0.04)	2.52 ^{b} (0.08)	8.57 ^{b} (0.09)	6.25 ^{b} (0.05)
80-100	-	2.37 ^{b} (0.03)	19.00 ^{a} (0.07)	6.43 ^{b} (0.08)
Total	31.64	20.8	75.04	55.35
Values in parenthesis are standard values of errors				

4.2.1. Carbon content in soil aggregates

The carbon content in different soil aggregate fractions viz., 250-2000µm, 53-250µm, <53 µm were compared along different depths of a typical homegarden and a teak plantation. The results were compared with an open contiguous area also. The results are tabulated in Table 4. There was significant variation in carbon content of different aggregates. The carbon stock of stock of aggregates were calculated from SOC (%) and are depicted in Table 5. The top layer (0-20cm) had higher carbon compared to all layers. The highest SOC (%) was observed in the 0-20 cm depth of <53 µm fraction of homegardens (1.37%)

When comparing the total carbon aggregates, it showed a decreasing trend with depth. It was maximum in silt-clay fraction and minimum in macroaggregate fraction. This trend was observed in all land use systems and its open contiguous. The highest carbon in aggregates was observed in <53 µm fraction of teak plantation. In all fractions teak had higher total SOC stock than homegardens. The major contributors of carbon in <53 µm was 60-100cm soil depth, while in 53-250 µm fraction all depths equally contributed except the 80-100 cm depth. While in homegardens the major contributors to the TSOC were from the top layers than compared to the bottom layers.

While comparing the homegardens and its open contiguous areas, the open had comparatively lower in all depths in all fractions, while in teak planation this trend was not consistent. The percentage increase in carbon compared to the open contiguous was higher in homegardens than teak plantation. The percentage in carbon was very much higher in <53 µm fraction of homegardens with 57.25% and 68.48 % increase in aggregate carbon in 60-80cm and 80-100 cm depth respectively.

Table 4: Variation of aggregate soil organic carbon (%) at different depths in different woody ecosystems

Soil Organic Carbon (%)												
Depth (cm)	Fraction											
	250-2000µm				53-250 µm				<53 µm			
	Homegarden	Open	Teak	Open	Homegarden	Open	Teak	Open	Homegarden	Open	Teak	Open
0-20	0.47 ^{c} (0.14)	0.45 ^{b} (0.11)	0.57 ^{b} (0.07)	0.71 ^{b} (0.02)	0.97 ^{b} (0.05)	0.56 ^{b} (0.07)	0.60 ^{b} (0.11)	0.73 ^{b} (0.01)	1.37 ^{a} (0.14)	1.11 ^{a} (0.1)	1.09^{a} (0.06)	0.97 ^{b} (0.06)
20-40	0.35 ^{c} (0.02)	0.34 ^{c} (0.05)	0.48 ^{b} (0.11)	0.52 ^{b} (0.02)	0.70 ^{b} (0.18)	0.43 ^{b} (0.05)	0.59 ^{b} (0.11)	0.56 ^{b} (0.04)	1.15 ^{a} (0.11)	0.94 ^{a} (0.03)	0.84^{a} (0.13)	1.12 ^{a} (0.15)
40-60	0.49 ^{b} (0.10)	0.28^{c} (0.01)	0.44^{b} (0.13)	0.51 ^{b} (0.04)	0.58 ^{b} (0.08)	0.41 ^{b} (0.08)	0.58 ^{b} (0.04)	0.44 ^{b} (0.1)	1.13 ^{a} (0.06)	0.75 ^{c} (0.03)	0.95^{a} (0.05)	1.01 ^{a} (0.06)
60-80	0.43 ^{b} (0.08)	0.23 ^{b} (0.01)	0.47 ^{b} (0.09)	0.42 ^{b} (0.01)	0.44 ^{b} (0.09)	0.37 ^{ab} (0.04)	0.55 ^{b} (0.03)	0.46 ^{b} (0.04)	0.93 ^{a} (0.03)	0.53 ^{a} (0.2)	1.07^{a} (0.12)	0.76 ^{a} (0.04)
80-100	-	0.24 ^{b} (0.05)	0.56 ^{c} (0.28)	0.91 ^{a} (0.07)	-	0.24 ^{b} (0.05)	0.97 ^{b} (0.05)	0.41 ^{b} (0.01)	-	0.5 ^{a} (0.09)	1.23^{a} (0.22)	0.87 ^{a} (0.07)

Values in parenthesis are standard values of errors

Table 5: Variation of aggregate SOC sequestration potential (Mg C ha^{-1}) at different depths in different woody ecosystems

SOC Sequestration Potential (Mg C ha^{-1})												
Depth (cm)	Fractions											
	250-2000μm				53-250 μm				<53 μm			
	Home garden	Open	Teak	Open	Home garden	Open	Teak	Open	Homegarden	Open	Teak	Open
0-20	11.56 ^{c} (0.14)	10.8 ^{b} (0.11)	15.62 ^{b} (0.07)	18.18 ^{b} (0.02)	23.86 ^{b} (0.05)	13.44 ^{b} (0.07)	16.44 ^{b} (0.11)	18.68 ^{b} (0.01)	33.7 ^{a} (0.14)	26.64 ^{a} (0.1)	29.87 ^{a} (0.06)	24.83 ^{b} (0.06)
20-40	8.33 ^{c} (0.02)	8.29 ^{c} (0.05)	12.76 ^{b} (0.11)	12.69 ^{b} (0.02)	16.66 ^{b} (0.18)	10.49 ^{b} (0.05)	15.69 ^{b} (0.11)	13.66 ^{b} (0.04)	27.37 ^{a} (0.11)	22.94 ^{a} (0.03)	22.34 ^{a} (0.13)	27.32 ^{a} (0.15)
40-60	11.66 ^{b} (0.10)	6.38 ^{c} (0.01)	12.4 ^{b} (0.13)	13.77 ^{b} (0.04)	13.80 ^{b} (0.08)	9.35 ^{b} (0.08)	16.36 ^{b} (0.04)	11.88 ^{b} (0.1)	26.89 ^{a} (0.06)	17.1 ^{c} (0.03)	26.79 ^{a} (0.05)	27.27 ^{a} (0.06)
60-80	10.41 ^{b} (0.08)	5.79 ^{b} (0.01)	11.84 ^{b} (0.09)	10.5 ^{b} (0.01)	10.65 ^{b} (0.09)	6.34 ^{ab} (0.04)	13.86 ^{b} (0.03)	11.5 ^{b} (0.04)	22.51 ^{a} (0.03)	13.36 ^{a} (0.2)	26.96 ^{a} (0.12)	19 ^{a} (0.04)
80-100	-	6.34 ^{b} (0.05)	14.78 ^{c} (0.28)	24.38 ^{a} (0.07)	-	6 ^{b} (0.05)	25.61 ^{b} (0.05)	10.98 ^{b} (0.01)	-	13.2 ^{a} (0.09)	32.47 ^{a} (0.22)	23.31 ^{a} (0.07)

Values in parenthesis are standard values of errors

4.2.3. Soil total nitrogen

The soil total nitrogen (%) was calculated in different soil fractions at different soil depths up to 1m depth in the selected woody ecosystems are tabulated in Table 6. Highest soil total nitrogen (%) was observed in the smallest fraction in all land use systems. In homegardens, the soil total nitrogen was distributed uniformly in all soil depths. In teak plantation, the deeper soil depths had lower nitrogen than the top layers.

Macroaggregates and microaggregates fraction did not show much variation in total nitrogen stored in both the land use systems. Homegardens had a higher total nitrogen percentage than teak plantation in all depths except 20-40cm depth in macroaggregates class. The top layers of open contiguous had higher nitrogen (%) in teak plantation of all soil fractions but in the deeper layers the woody ecosystem had higher nitrogen content. Teak plantation (0.294%) and homegarden (0.159%) had higher nitrogen content in the 80-100cm depth in the microaggregate fraction. Smallest fraction had higher than the other two fractions.

Compared to the open, both woody ecosystems had higher nitrogen content in macroaggregate fraction except for the bottom layer of teak plantation. Homegardens had higher nitrogen content than open and can be clearly seen in the macroaggregate and silt- clay fraction.

Table 6: Variation of soil total nitrogen (%) in different woody ecosystem and its open contiguous plots across depth and among different aggregate sizes.

Soil Total Nitrogen (%)												
Depth (cm)	Fraction											
	250-2000μm				53-250 μm				<53 μm			
	Homegarden	Open	Teak	Open	Homegarden	Open	Teak	Open	Homegarden	Open	Teak	Open
0-20	0.26^{a} (0.06)	0.076^{c} (0.01)	0.184^{b} (0.01)	0.183^{b} (0.007)	0.11^{b} (0.03)	0.139^{b} (0.016)	0.162^{b} (0.02)	0.178^{b} (0.011)	0.283^{a} (0.15)	0.348^{a} (0.03)	0.313^{a} (0.03)	0.353^{a} (0.081)
20-40	0.15^{b} (0.02)	0.129^{b} (0.09)	0.287^{a} (0.03)	0.156^{c} (0.009)	0.152^{b} (0.02)	0.117^{b} (0.012)	0.227^{b} (04)	0.232^{b} (0.041)	0.422^{a} (0.11)	0.304^{a} (0.02)^{a}	0.306^{a} (0.04)	0.313^{c} (0.023)
40-60	0.244^{b} (0.04)	0.0882^{b} (0.005)	0.135^{b} (0.03)	0.147^{c} (0.015)	0.13^{c} (0.03)	0.145^{b} (0.06)	0.16^{b} (0.02)	0.179^{b} (0.017)	0.362^{a} (0.02)	0.285^{a} (0.01)	0.336^{a} (0.08)	0.267^{a} (0.013)
60-80	0.215^{b} (0.02)	0.137^{b} (0.016)	0.126^{c} (0.01)	0.148^{b} (0.03)	0.16^{c} (0.01)	0.159^{b} (0.31)	0.165^{b} (0.04)	0.134^{b} (0.06)	0.312^{a} (0.04)	0.267^{a} (0.01)	0.329^{a} (0.02)	0.256^{a} (0.004)
80-100	-	0.1^{b} (0.004)	0.142^{c} (0.01)	0.2^{a} (0.001)	-	0.06^{b} (0.04)	0.293^{b} (0.01)	0.204^{a} (0.008)	-	0.232^{a} (0.04)	0.142^{a} (0.04)	0.25^{a} (0.04)
Values in parenthesis are standard values of errors												

4.2.4. Soil available phosphorous

Fractionate soil available phosphorous (kg ha^{-1}) in different soil depths of woody ecosystems has been depicted in Table 7. The total soil available phosphorus in soil aggregates did not show much variation. In all other fractions except <53 µm fraction, homegardens had higher available phosphorus than teak plantation. But in 0-20cm and 40-60 cm depth teak had higher concentration in <53 µm. In homegardens, the distribution of available phosphorous was almost similar with slightly higher values in top layers in macroaggregate fraction. It was comparatively lower in open contiguous areas. In homegardens, it showed a decreasing trend and then increases. The teak plantation, the top layers had lower values than the bottom layers. In teak, the open had higher values in top layers but with increasing depth, the concentration of available phosphorous decreased. Except in the bottom layers, open contiguous plots had higher available phosphorus than homegarden in <53 µm fraction.

Table 7: Variation of soil available phosphorus (kg ha^{-1}) in different woody ecosystem and its open contiguous plots across depth and among different aggregate sizes.

Soil Available Phosphorus (kg ha^{-1})												
Depth (cm)	Fraction											
	250-2000μm				53-250 μm				<53 μm			
	Homegarden	Open	Teak	Open	Homegarden	Open	Teak	Open	Homegarden	Open	Teak	Open
0-20	50.75^{a} (14.58)	32.07^{a} (2.57)	13.7^{b} (3.37)	19.52^{a} (2.21)	57.78^{a} (9.4)	14.48^{b} (5.26)	9.33^{c} (3.32)	31.09^{a} (13.52)	7.78 (1.3) b	19.2 (0.95) b	28.71 (1.35) a	16.94^{a} (2.05)
20-40	22.47^{a} (2.98)	55.44^{a} (3.87)	15.4^{b} (9.53)	26.32^{b} (4.22)	19.39^{a} (7.83)	58.2^{a} (3.96)	12.84^{b} (7.07)	47.24^{a} (6.71)	23.07^{a} (21.7)	2.35^{b} (0.34)	27.47^{a} (3.46)	18.48^{b} (3.4)
40-60	27.79^{a} (6.35)	46.77^{b} (2.96)	38.41^{a} (9.90)	53.94^{a} (7.43)	32.79^{a} (4.36)	60.52^{a} (6.78)	9.71^{b} (6.70)	51.37^{a} (5.81)	17.58^{b} (1.62)	1.79^{c} (0.22)	41.52^{a} (6.88)	54.17^{a} (2.43)
60-80	29.98^{b} (18.27)	51.26^{a} (11.11)	31.52^{a} (20.46)	19.08^{b} (11.64)	56.07^{a} (8.95)	45.21^{a} (1.86)	37.36^{a} (10.81)	50.25^{a} (3.67)	36.57^{b} (8.72)	20.55^{b} (1.84)	23.08^{a} (1.70)	13.27^{b} (3.15)
80-100	-	52.97^{b} (11.2)	26.16^{a} (12.37)	11.37^{b} (3.01)	-	82.62^{a} (13.58)	25.98^{a} (4.48)	32.72^{a} (3.48)	-	20.05^{c} (1.79)	7.19^{b} (0.54)	16.03^{b} (2.52)
Total	130.99	238.51	125.19	130.23	166.03	261.03	95.22	212.67	84.93	43.89	127.97	118.89
Values in parenthesis are standard values of errors												

4.2.5. Soil exchangeable potassium

Soil exchangeable potassium in different soil aggregates at different depths is shown in Table 8. While comparing the potassium stock, open had slightly higher than the woody ecosystems. Any specific trend in soil exchangeable potassium was not seen between the soil aggregates. In most systems, it showed a decreasing trend with depth. Between the two systems, teak had higher soil exchangeable potassium. The open had comparatively lower value in both woody ecosystems. In 53-250µm, the woody ecosystems had higher exchangeable potassium than their open contiguous areas. In <53 µm fraction, homegardens had higher exchangeable potassium than teak plantation. In teak planation, the middle layer had comparatively higher exchangeable potassium, in both open and woody ecosystem.

Table 8: Variation of soil exchangeable potassium (kg ha^{-1}) in different woody ecosystem and its open contiguous plots across depth and among different aggregate sizes.

Soil Exchangeable Potassium (kg ha^{-1})												
Depth (cm)	Fraction											
	250-2000μm				53-250 μm				<53 μm			
	Homegarden	Open	Teak	Open	Homegarden	Open	Teak	Open	Homegarden	Open	Teak	Open
0-20	205.52 ^{b} (80.12)	717.54 (11.21) c	257.79 ^{a} (27.60)	142.24 ^{a} (1.12)	213.54 ^{b} (112.07)	945.28 ^{a} (59.04)	270.10 ^{a} (21.03)	129.17 ^{b} (3.42)	422.8 ^{a} (113.50)	869.12^{b} (13.4)	109.33 ^{b} (0.42)	72.52 ^{c} (1.4)
20-40	179.95 ^{c} (13.24)	126.19 ^{c} (25.84)	215.41 ^{a} (53.87)	132.16 ^{b} (8.07)	298.85 ^{b} (14.17)	245.35 ^{b} (22.09)	249.01 ^{a} (48.72)	173.23 ^{a} (6.75)	496.16 ^{a} (116.57)	534.86 ^{a} (15.16)	123.11^{b} (9.03)	70.77^{c} (3.06)
40-60	172.48 ^{b} (35.92)	137.01 ^{c} (14.27)	152.88 ^{b} (35.89)	123.95 ^{b} (3.42)	238.18 ^{b} (27.83)	161.28 ^{b} (6.23)	206.82 ^{a} (43.56)	137.76 ^{a} (2.96)	447.25 ^{a} (156.76)	330.96 ^{a} (0.56)	112.14 ^{c} (6.05)	77.56^{c} (0.84)
60-80	15.08 ^{c} (23.81)	130.29 ^{c} (20.17)	176.77 ^{b} (10.44)	353.54 ^{a} (5.74)	186.85 ^{b} (12.95)	157.17 ^{b} (8.4)	231.09 ^{a} (26.45)	182.56 ^{b} (2.96)	382.48 ^{c} (10.87)	287.84 ^{a} (1.12)	113.68 ^{c} (2.50)	75.6^{c} (0.56) ^{c}
80-100	-	217.41 ^{b} (11.99)	169.49 ^{b} (16.93)	316.21 ^{a} (13.07)		210.19 ^{b} (13.07)	258.35 ^{a} (119.44)	153.41 ^{b} (7.0)		595.84 ^{a} (258.02)	105.14 ^{b} (25.93)	101.38^{c} (0.52)
Total	573.03	1328.44	972.34	1068.1	937.42	1719.27	1215.37	622.72	1748.69	2618.62	563.4	397.83
Values in parenthesis are standard values of errors												

4.2.6. C: N ratio

The C:N ratio was highest in the top layer in homestead and had a decreasing trend except in 250-2000 µm (macroaggregate) fraction. The microaggregate fraction had higher C:N ratio compared to the other two fractions in woody ecosystems. In most layers, the open contiguous had lower C:N ratio. The apparent change in C:N ratio is clearly seen in the microaggregate fraction of homegarden and contiguous open. Open treeless had only 4.1 while the homegarden had 9.4 in the top 0-20 cm. Similarly in the teak, the apparent difference is clearly seen in 20-40 cm of microaggregate fraction with 5 in woody ecosystem and 2.5 in the contiguous open. In the other fractions and soil depths, open have lower C:N ratio, but the difference is not significant. But in few layers like 0-20cm of the macroaggregate fraction, the woody ecosystem had higher C:N ratio than the contiguous open. In the top 0-20cm, homegardens (9.4,6.4) had higher C:N ratio than teak planation (3.7,3.5) in microaggregate and silt-clay fraction respectively. This is true in the most of soil layers. While teak had higher C:N ratio in macroaggregate fraction.

Table 9: Variation of soil C: N ratio in different woody ecosystem and its open contiguous plots across depth and among different aggregate sizes.

C: N ratio												
Depth (cm)	Fraction											
	250-2000µm				53-250 µm				<53 µm			
	Homegarden	Open	Teak	Open	Homegarden	Open	Teak	Open	Homegarden	Open	Teak	Open
0-20	2^{b} (0.12)	6^{a} (0.13)	3.1^{a} (0.04)	3.9^{a} (0.03)	9.4^{a} (0.23)	4^{b} (0.02)	3.7^{a} (0.06)	4.1^{a} (0.03)	6.4^{a} (0.40)	3.2^{b} (0.05)	3.5^{a} (0.03)	2.8^{b} (0.07)
20-40	2.5^{b} (0.06)	3.6^{a} (0.24)	1.7^{b} (0.04)	3.4^{a} (0.03)	4.7^{a} (0.08)	3.7^{a} (0.06)	5^{a} (0.16)	2.5^{b} (0.04)	2.9^{b} (0.08)	3.1^{a} (0.01)	2.8^{b} (0.08)	3.6^{a} (0.02)
40-60	2^{b} (0.05)	3.4^{a} (0.03)	3.5^{a} (0.16)	3.4^{a} (0.02)	4.5^{b} (0.14)	3.4^{a} (0.21)	3.7^{a} (0.03)	2.3^{b} (0.03)	3.1^{b} (0.03)	2.6^{a} (0.003)	2.9^{a} (0.06)	3.7^{a} (0.02)
60-80	2^{b} (0.05)	1.7^{a} (0.02)	3.7^{a} (0.08)	2.9^{a} (0.06)	2.7^{a} (0.06)	2.3^{a} (0.05)	3.4^{a} (0.07)	3.5^{a} (0.05)	3^{a} (0.04)	2^{a} (0.07)	3.3^{a} (0.03)	2.9^{a} (0.01)
80-100	-	2.4^{a} (0.06)	4^{a} (0.2)	4.5^{a} (0.04)	-	5.6^{a} (0.44)	3.4^{a} (0.03)	2^{c} (0.01)	-	2.2^{a} (0.03)	3.8^{a} (0.06)	3.6^{b} (0.05)
Values in parenthesis are standard values of errors												

4.3. SOIL MICROFLORA OBSERVATIONS

Soil microflora observations were done for the top 0-20cm depth, and the colony forming unit per ml for different microflora were found to be higher in homegardens than teak planation except for the K solubilizers population. The results were also compared with their open contiguous plots.

4.3.1. Total bacteria population

The homegardens (193.3 × 10^6 cfu g^{-1}) had higher cfu g^{-1} than teak plantation (5.33× 10^6 cfu g^{-1}) considering the total bacteria population. The open contiguous plots had lower population compared to the woody ecosystems.

4.3.2. Total fungi population

Teak (22.67 × 10^4 cfu g^{-1}) had lower population of fungi when compared to homegardens (144 × 10^4 cfu g^{-1}) and open had lower compared to tree-based areas.

4.3.3. Total actinomycetes population

The cfu g^{-1} was higher for homegardens (224 × 10^4 cfu g^{-1}) compared to the teak plantation (25 × 10^4 cfu g^{-1}) and open contiguous areas.

4.3.4. Total nitrogen fixers, p- solubilizers and k- solubilizers

The number of K- solubilizers was higher in teak (8× 10^4 cfu g^{-1}) compared to homegardens (1.67× 10^4 cfu g^{-1}). But the nitrogen fixers population and P-solubilizers were higher in homegardens (139.34× 10^6 cfu g^{-1} and 174.67 × 10^4 cfu g^{-1}) compared to teak plantation (13× 10^6 cfu g^{-1} and 23.34 × 10^4 cfu g^{-1}). It was lower in the respective treeless regions.

Table 10. Microflora observation of different land use systems in 0-20cm depth

Microflora population (cfu g^{-1})				
Microflora Population	Systems			
	Homegarden (Woody)	Homegarden (Open)	Teak Plantation (Woody)	Teak Plantation (Open)
Total bacteria	$193.3 \times 10^{6\,a}$ (44.95)	$107.34 \times 10^{6\,b}$ (6.43)	$5.33 \times 10^{6\,c}$ (1.15)	$8.67 \times 10^{6\,c}$ (0.57)
Total Fungi	$144 \times 10^{4\,a}$ (17.43)	$89.4 \times 10^{4\,b}$ (18.9)	$22.67 \times 10^{4\,c}$ (3.05)	$8 \times 10^{4\,c}$ (2)
Total Actinomycetes	$224\times 10^{4\,a}$ (26.23)	$144\times 10^{4\,b}$ (13.85)	$25\times 10^{4\,c}$ (3.6)	$11 \times 10^{4\,c}$ (1)
Total Nitrogen Fixers	$139.34 \times 10^{6\,c}$ (14.19)	$142 \times 10^{6\,c}$ (13.85)	$13 \times 10^{6\,b}$ (4.35)	$8 \times 10^{6\,b}$ (1)
Total P-solubilizers	$174.67 \times 10^{4\,a}$ (42.77)	$124 \times 10^{4\,b}$ (19.28)	$23.34 \times 10^{4\,c}$ (10.41)	$12.66 \times 10^{4\,c}$ (2.08)
Total K- solubilizers	$1.67 \times 10^{5\,bc}$ (0.57)	$0.34 \times 10^{5\,c}$ (0.58)	$6.67 \times 10^{5\,a}$ (2.08)	$2.67 \times 10^{5\,b}$ (0.57)
Values in parenthesis are standard values of errors				

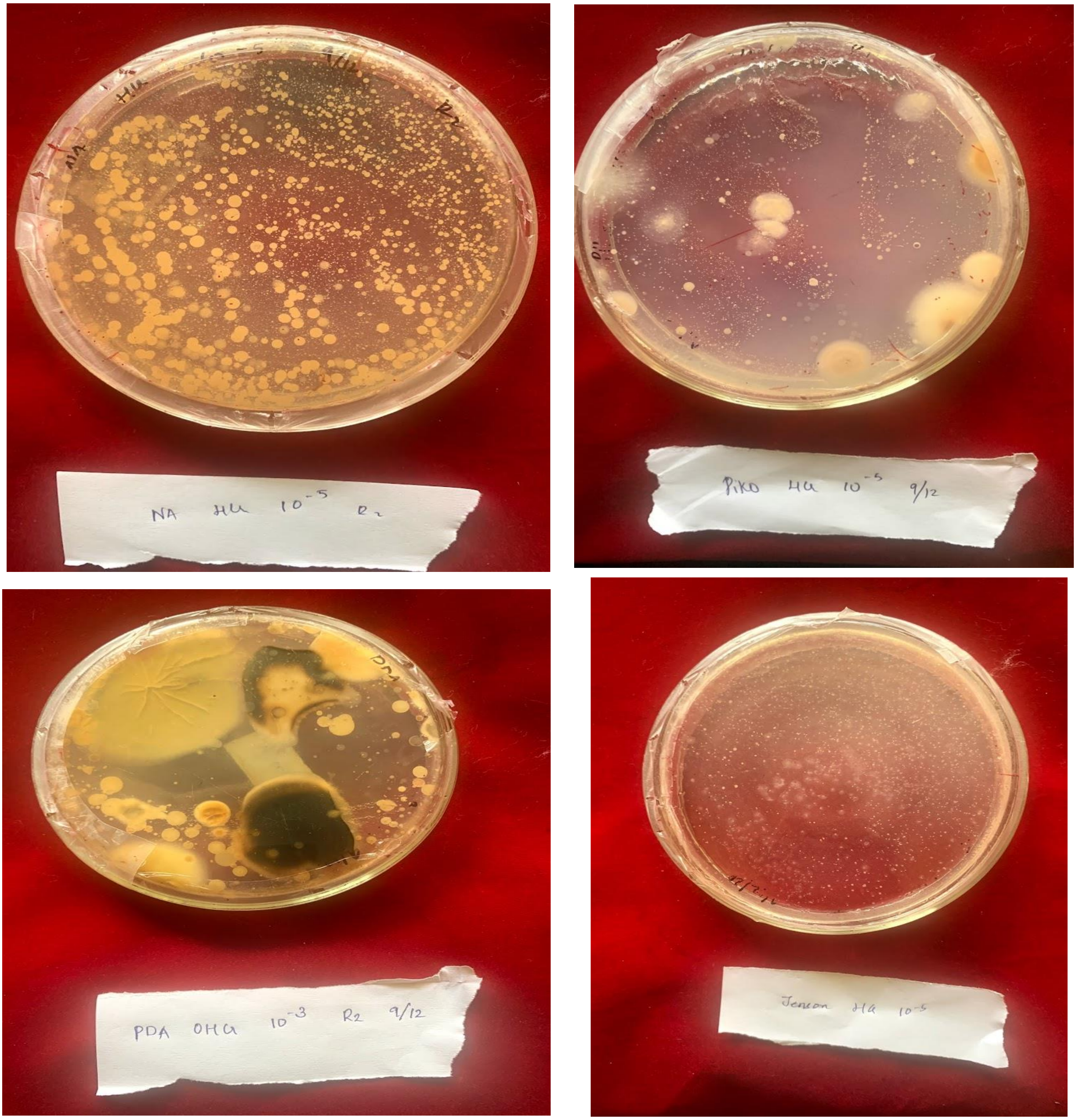


Figure 3: Microflora populations in different medias of the selected woody ecosystems, Trissur.

CHAPTER 5

DISCUSSION

The study was done to analyse the carbon stock of different aggregate sizes in a traditional homestead and a teak plantation. The nutrient and microflora population were also estimated. It was compared with their open contiguous area up to 1m depth. The results are discussed below.

5.1. SOIL PHYSICAL PROPERTIES

5.1.1. Bulk density

Bulk density value varies with management practises like tillage, the moisture content of soil etc. which influences the soil compaction, organic matter content, available nutrients, porosity etc. (Chaudhari et al., 2013; Singh & Sahoo, 2015).

Bulk density, which represents the hardness of soil had slight and consistent increasing trend with depth (Table 1). The reason for the apparent changes in BD is due to changes in the organic matter content. Organic matter has an inverse relation with bulk density (Sakin, 2012). The relation is clearly seen in homegardens which had lower bulk density values. Homegardens which mimics natural forests are rich in species diversity. These different species contribute organic matter into the soil through litter fall and fine root dynamics in the belowground (Han et al., 2010). Low bulk density allows easier movement of plant roots for better nutrient uptake. With increasing depth, there was consistent increase in BD due to the low availability of organic matter sources (Asok and Sobha, 2014). This trend is clearly seen in homegardens but in teak, it was not prominent. But in open, BD had higher values due to the absence of carbon sources in treeless areas. One of the major limitations of my study was low number of pits taken for comparison with the contiguous open due to the COVID pandemic situation and time limit of the wok. Another significant for the deviation in trend could be the management practices in teak plantation. Teak is a monoculture crop and hence it very less species diversity when compared to the homegardens. In homegardens, most species have deep rooted fibrous roots while in stum teak, the roots are mainly distributed in the top 0-40 cm depth. Root proliferation in the soil influences the BD. With increasing depth, it has decreased contributing to higher BD values at deeper depths.

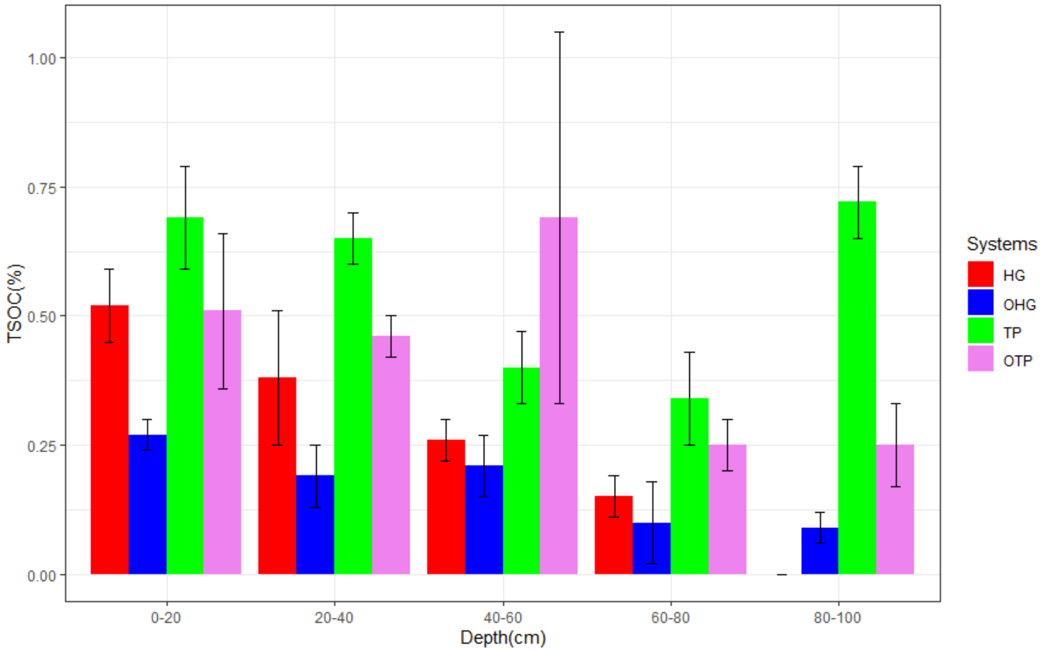
5.2. SOIL CHEMICAL PROPERTIES

5.2.1. Total soil organic carbon

The main sources of carbon in soil are litter and root dynamics and it is influenced by many biotic and abiotic factors. Deep rooted trees have higher sequestration potential and due to this the sequestration potential of woody ecosystems vary substantially with species diversity. Another influencing factor is the species diversity and management practices of the system. The carbon sources are easily available in top layers and hence the TSOC values are very much higher in the top 0-40cm depth (Lorenz and Lal, 2005). But with increasing depth the only contributing carbon sources are the fine root dynamics. Due to this, in all systems a decreasing trend in TSOC was observed with soil depth. When comparing the woody ecosystem with its controls, the control had lower TSOC due to the absence of carbon sources in treeless areas. In most studies, a similar trend was observed. For instance, Manjuanatha et al (2015) also observed similar observations.

The percentage increase in carbon was very much higher homegarden when compared to its control. In 0-20 cm depth there has been 97% increase in homegardens while in teak the percentage increase was only 44%. This is mainly due to high species diversity of homegardens as well as presence of deep-rooted plants (Saha et al., 2010). The teak had only similar kind of plants in which root zone is limited to the top 40cm. The management practices such as tillage, mulching, etc. influences the SOC concentration. Since teak have life time compared to annual crops in homegardens, it had higher SOC stock as it accumulates carbon during its 50-60years age (Falade, 2017)..

Figure 4: Variation of Total soil organic carbon (%) of different woody ecosystems and its contiguous open treeless at different depths



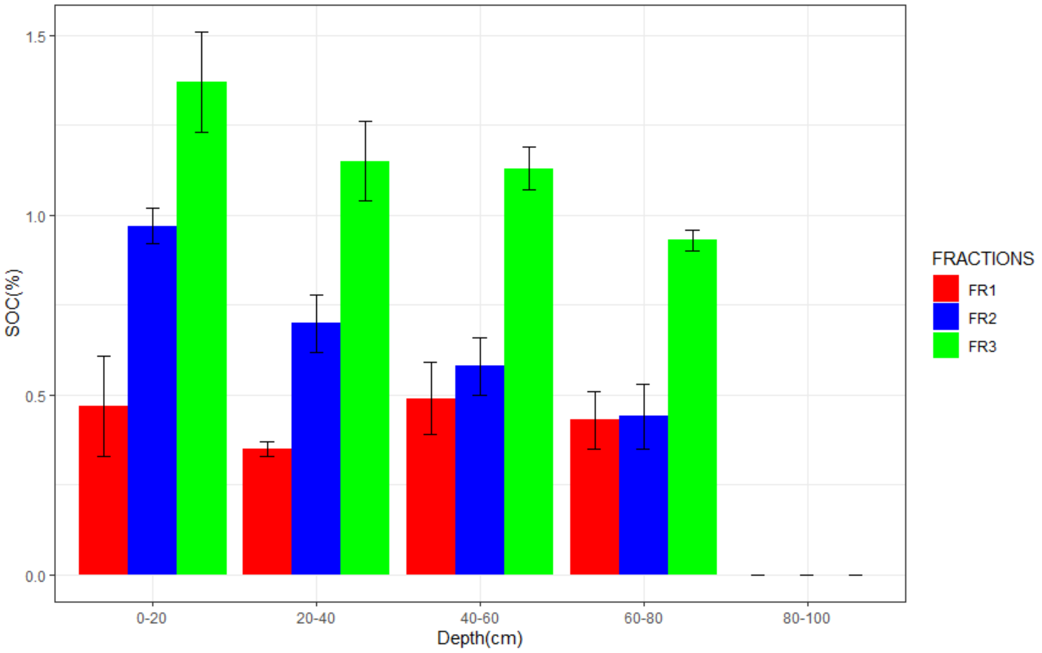
5.2.2. Carbon content in soil aggregates

Carbon content in different soil aggregates varied consistently with depth and fraction sizes. These had a decreasing trend with increasing soil depth (Kan et al., 2009) The smallest fraction had highest carbon content in all land use systems (Saha et al., 2010; Lua et al., 2019). It had a decreasing trend with aggregate size, it was in the order silt and clay (<53 µm) > microaggregates (53-250 µm) >macroaggregates (250-2000 µm). This is due to the encapsulation of silt and clay particles inside the larger aggregate fractions which protects the SOC stored from microbial degradation (Dondini et al., 2009 ; Albrecht and Kandji. 2003). Another reason for the higher accumulation of carbon in the smallest fraction and in the woody ecosystem is that the trees contribute more carbon to the stable fraction (Lorenz and Lal, 2014; Nair et al., 2009). But many studies showed a contradicting trend in which the macroaggregate class had higher SOC stock than the smallest fraction. Tisdall and Oades (1980b) and Saroa and Lal (2001) had opposite results and hence a general trend cannot be concluded. The reason behind these results was that many smaller aggregates stick together to form a macroaggregate and hence the carbon content will be higher in the largest fraction class. There are two results for the fractionate carbon content. But studies by Christensen, De Jonge et al and Li et al's had similar results to the present study i.e., increased SOC with decreasing aggregate size (Zhou et al., 2020). A contradicting result were observed in which, any significant differences between the aggregates was seen and the reason for this was the absence of baseline values for carbon (Kan et al., 2009). There are so many climatic and management practices which influence the variation in aggregate SOC. We need to understand the variations in the storage of SOC in aggregate in the specific conditions.

SOC is dependent on various soil and management factors. The SOC influences the productivity of soil and it also helps in mitigating the climate change by its long-term storage. Considering the two land use systems, teak plantation had higher SOC than homegardens. Homegardens are subjected to soil disturbances like weeding, manuring, tillage practices etc. which reduces the SOC stored (Gelaw et al., 2015). Another reason which could attribute to the lower SOC would be the presence of shallow root systems in homegardens, as it usually contains mostly short duration crops which are removed after their economic lifespan (Saha et al., 2010). But both the systems have almost similar SOC which proves the potential of woody ecosystems in capturing the carbon in the soil. The open had comparatively lower SOC in homesteads, as it was relatively treeless and the main source of carbon is mainly from tree litter and its roots. The value of SOC varied from 0.23 % in 250-2000 µm fraction in the bottommost layer of open contiguous area in homegardens to 1.37% in <53 µm fraction in the top most layer.

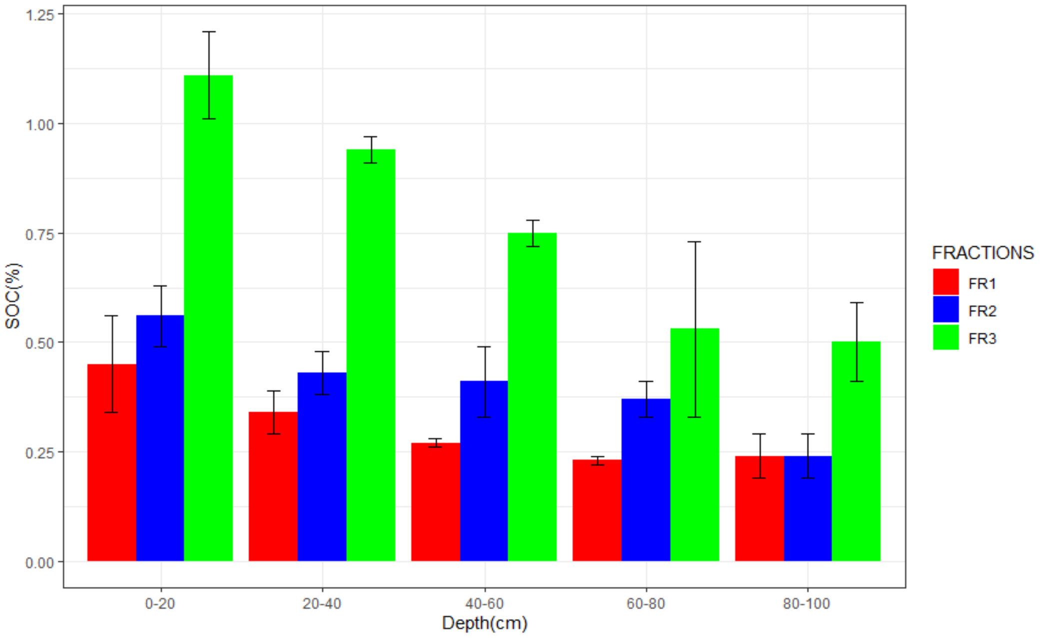
All these findings suggest that the smallest aggregate size fraction had the highest SOC and the SOC varies profoundly with land use systems and with fraction size. Another conclusion is the decreasing SOC concentration with increasing depth.

Figure 5: Variation in soil organic carbon percentage of different aggregate sizes at different soil depths of a typical homegarden.



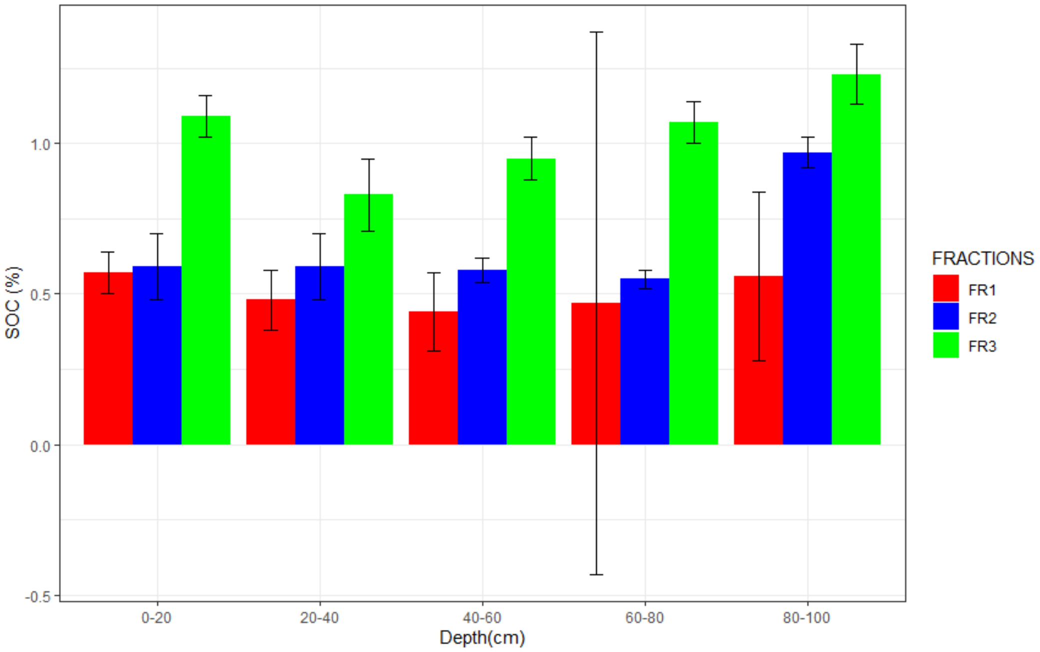
FR1: 250-2000, FR2: 53-250, FR3: <53 µm

Figure 6: Variation in soil organic carbon percentage of different aggregate sizes at different soil depths of contiguous open homegarden.



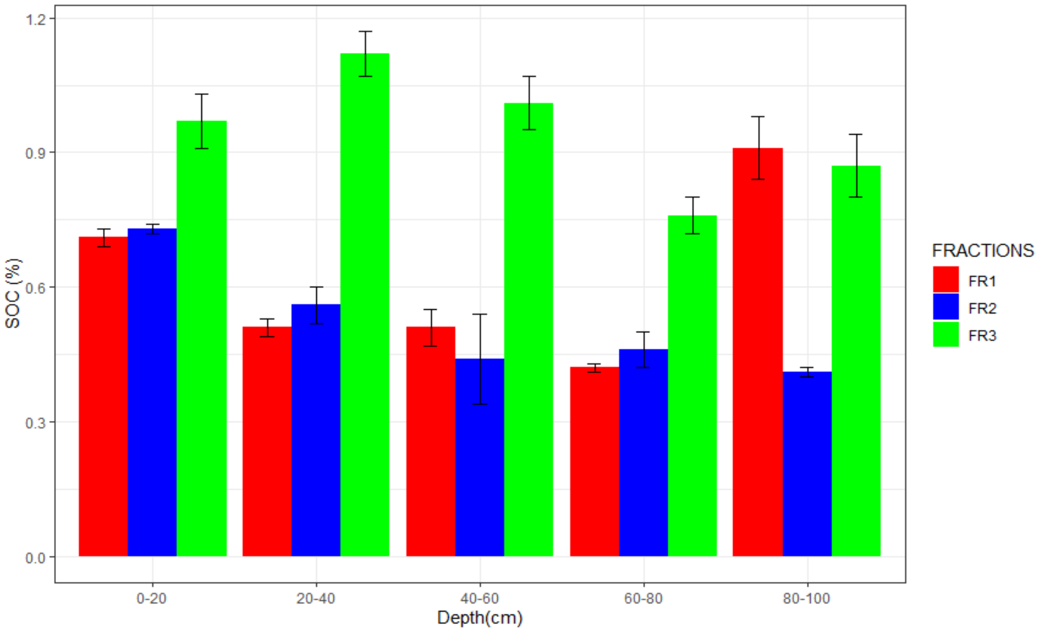
FR1: 250-2000, FR2: 53-250, FR3: <53 µm

Figure 7: Variation in soil organic carbon percentage of different aggregate sizes at different soil depths of teak plantation.



FR1: 250-2000, FR2: 53-250, FR3: <53 µm

Figure 8: Variation in soil organic carbon percentage of different aggregate sizes at different soil depths of open contiguous teak plantation.



FR1: 250-2000, FR2: 53-250, FR3: <53 µm

Figure 9: Variation of soil organic carbon (%) in <53µm at different soil depths in different land use systems

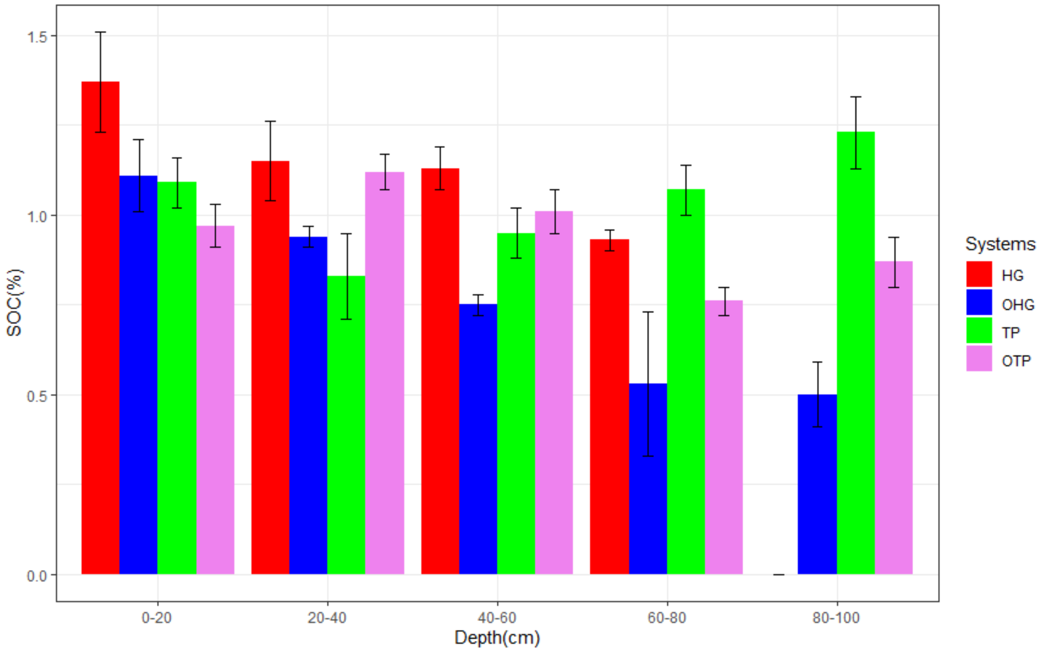


Figure 10: Variation of soil organic carbon (%) in 53-250µm at different soil depths in different land use systems

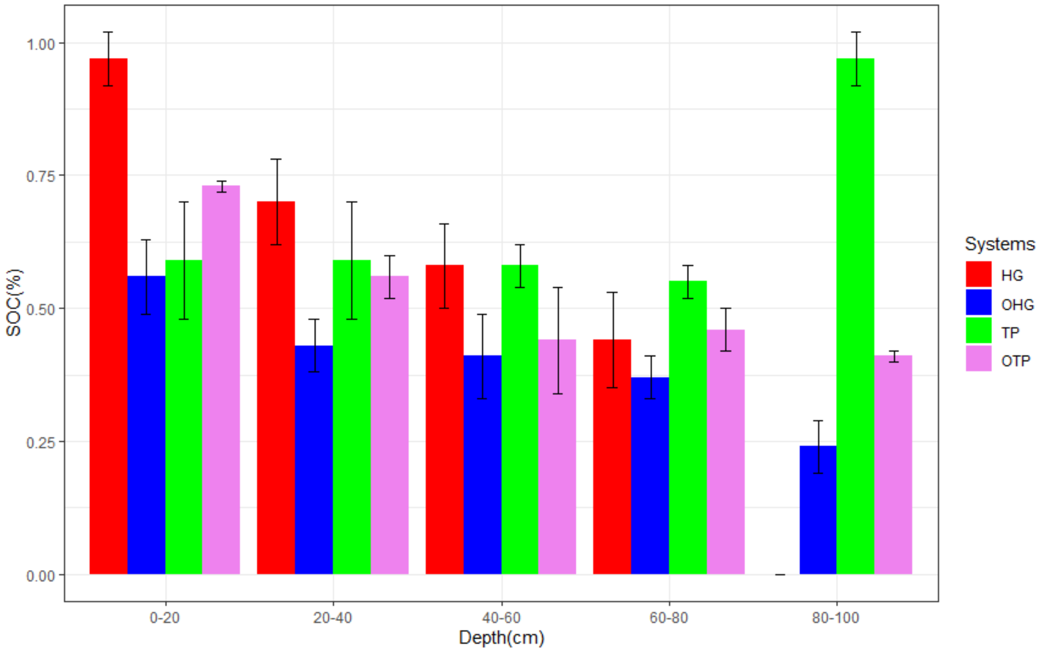
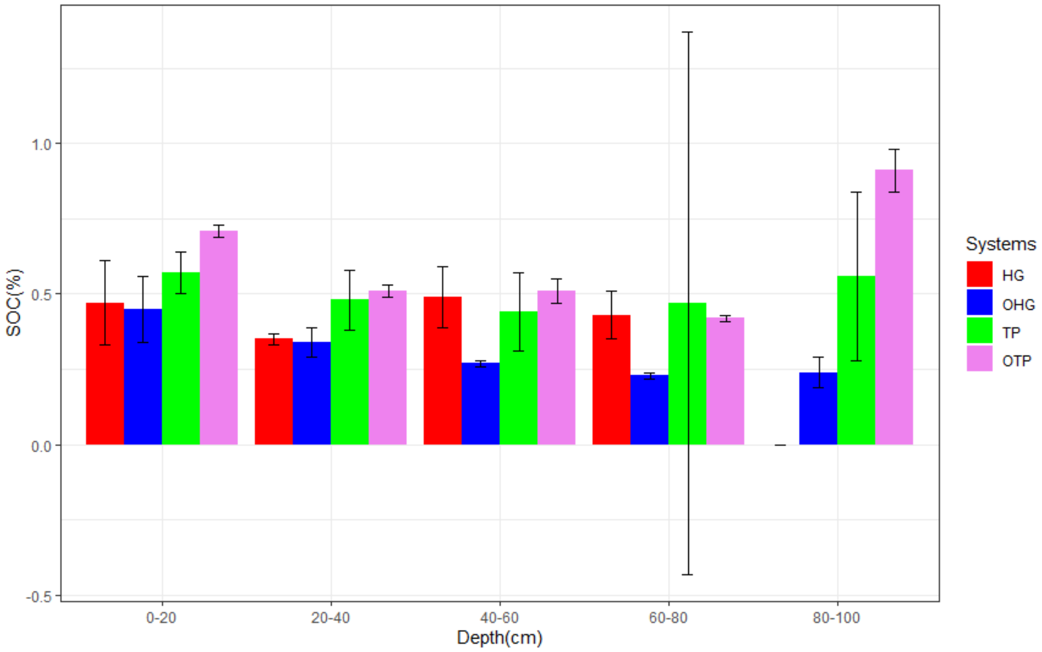


Figure 11: Variation of soil organic carbon (%) in 250-2000µm at different soil depths in different land use systems



5.2.3. *Soil total nitrogen*

Soil total nitrogen had similar values in both land use systems. Except in some layers, teak had higher total nitrogen concentration. Its value varied from 0.6 of 80-100 cm depth in open contiguous plot in microaggregate fraction to 0.422 % in <53 µm in 20-40 cm depth of homegarden. Sarora and Lal (2001) had an contridicting results in which increasing aggregate size had higher nitrogen storage (Holeplass et al., 2004) Addition of litter in to the soil increases the nitrogen stored and the smaller fraction have longer sequestration potential (Gelaw et al., 2015; Holeplass et al., 2004). The soil nitrogen is influenced by many controlling factors like manuring, etc. The nitrogen in soil is very much susceptible to erosion, leaching and are soluble in water. Hence, the reason for lower nitrogen content in open treeless areas could the inability of soil to hold nitrogen in the absence of roots. Initially a decline in nitrogen was observed is due to the leaching of nitrogen (Isaac & Nair, 2006). Another reason for this initial decrease could be due to the presence of more roots in the upper layers which results in greater absorption of nutrients. Homegardens which have high species diversity tends to have more roots in the deeper layers compared to teak plantation whose roots are limited to the top 40cm. Since roots are distributed evenly in homegardens, there is only slight variation in soil total nitrogen with soil depth. Trees with longer lifespan helps to hold nutrients in the deeper soil layers due to the presence of stronger roots, this attributes to the lower concentration in the deeper layers of treeless areas (Saha et al., 2009). But in the top layers, since the plant absorb nitrogen from the soil, contiguous open have higher nitrogen concentration. In general, there has been an increasing soil total nitrogen concentration with soil depth.

Figure 12: Variation in soil total nitrogen percentage of different aggregate sizes at different soil depths of a typical homegarden.

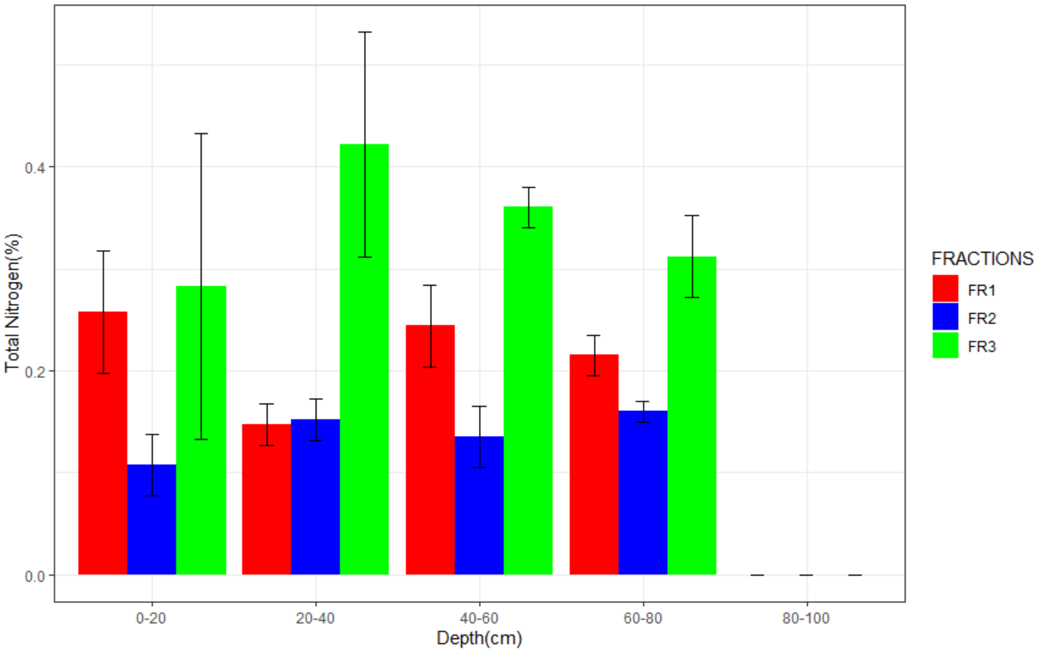


Figure 13: Variation in soil total nitrogen percentage of different aggregate sizes at different soil depths of open contiguous homegarden.

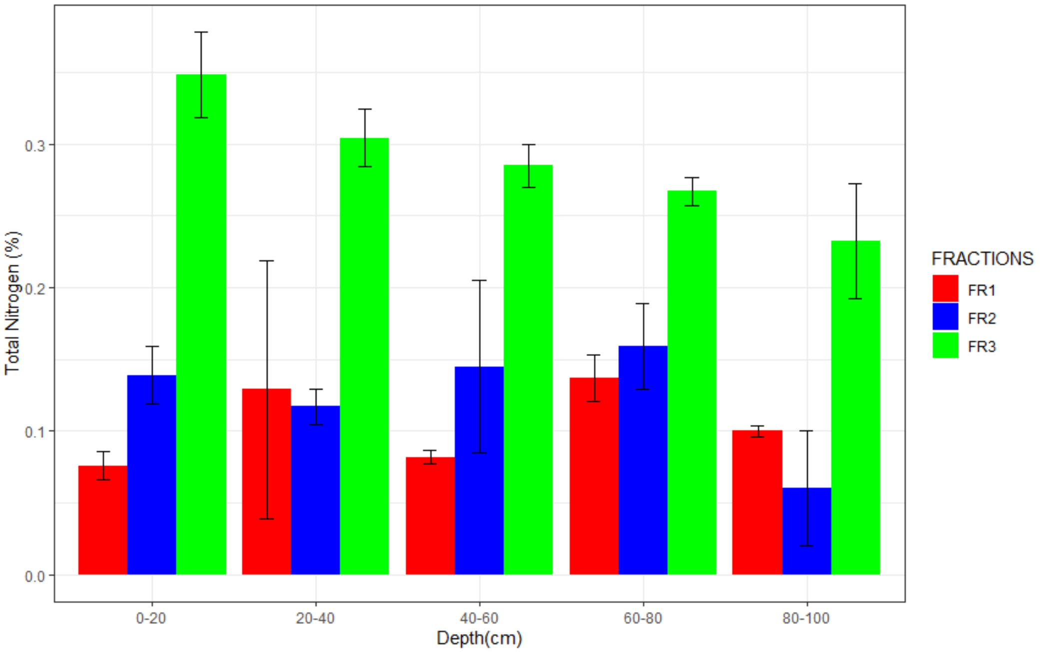
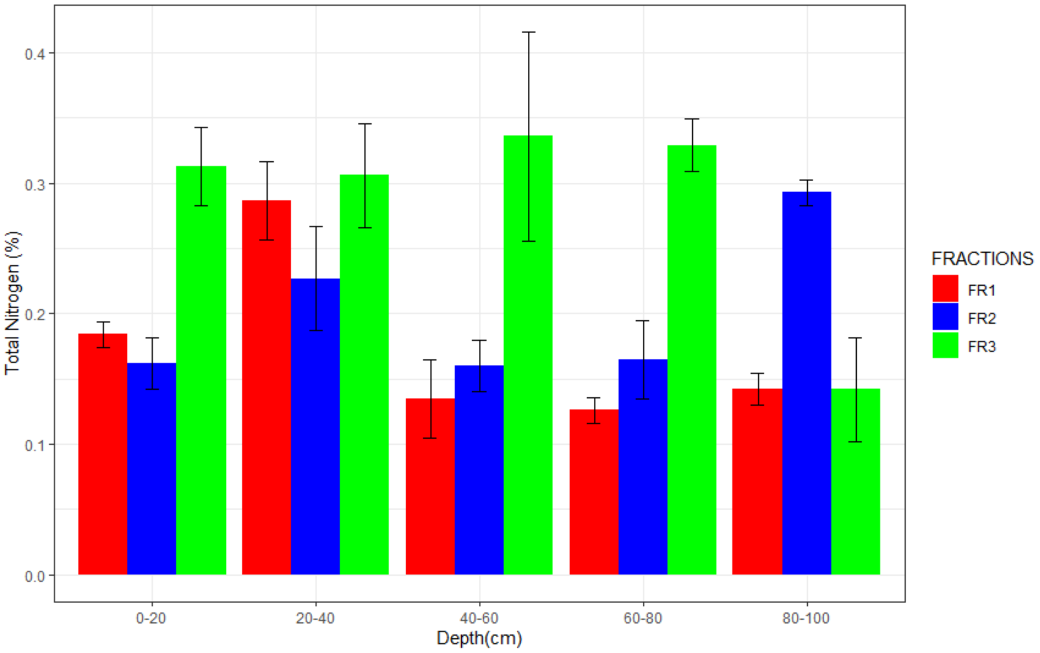


Figure 14: Variation in soil total nitrogen percentage of different aggregate sizes at different soil depths of teak plantation.



FR1: 250-2000, FR2: 53-250, FR3: <53 µm

Figure 15: Variation in soil total nitrogen percentage of different aggregate sizes at different soil depths of open contiguous teak plantation.

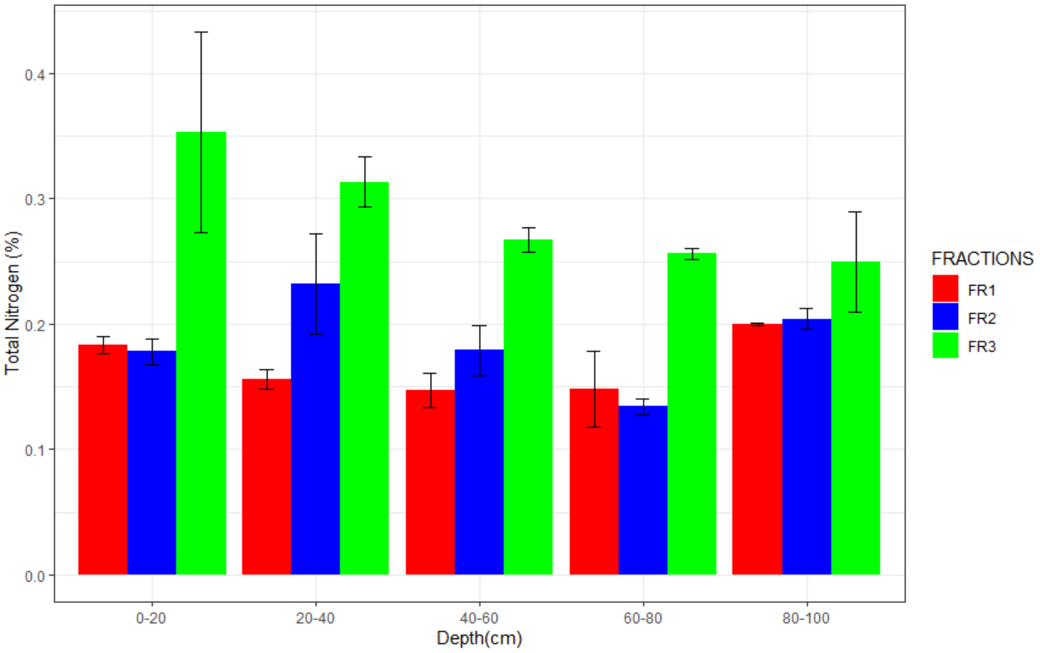


Figure 16: Variation of soil total nitrogen (%) in <53µm at different soil depths in different land use systems

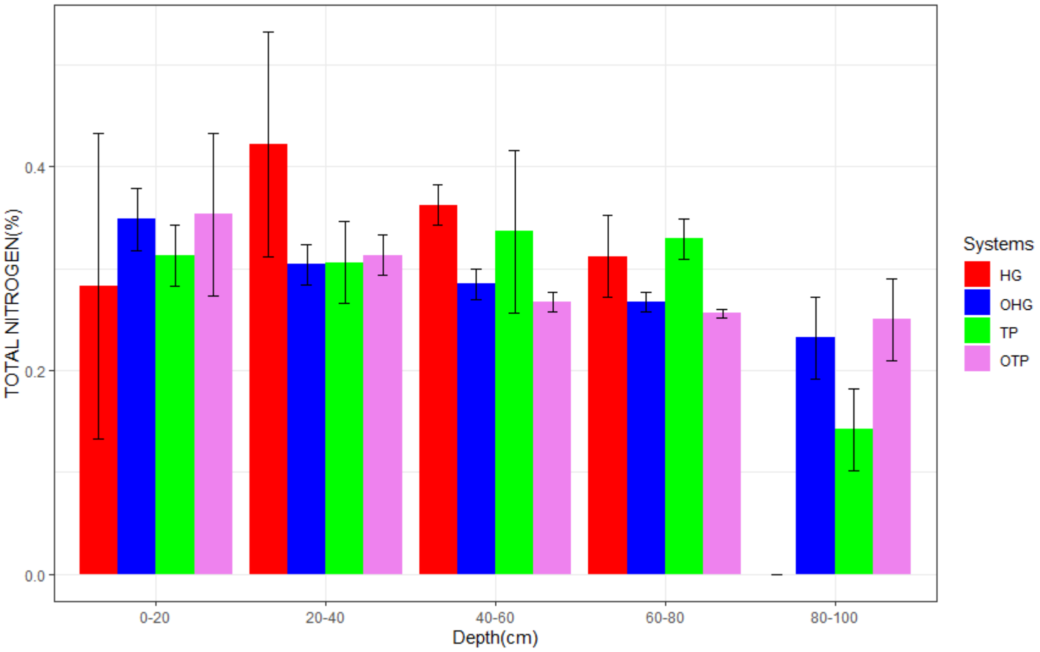


Figure 17: Variation of soil total nitrogen (%) in 53-250µm at different soil depths in different land use systems

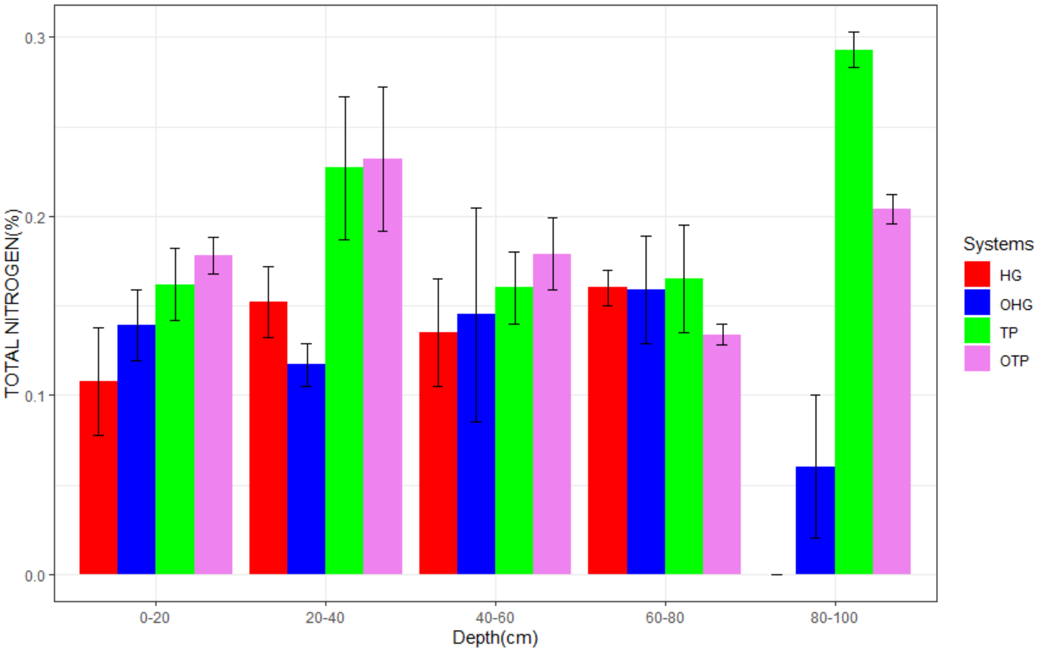
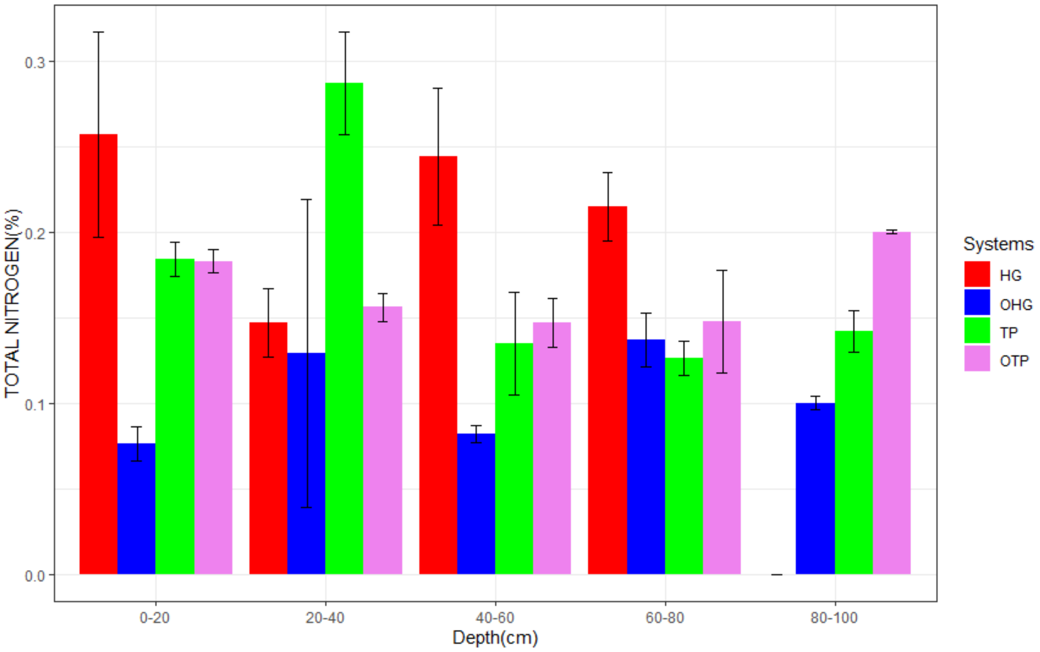


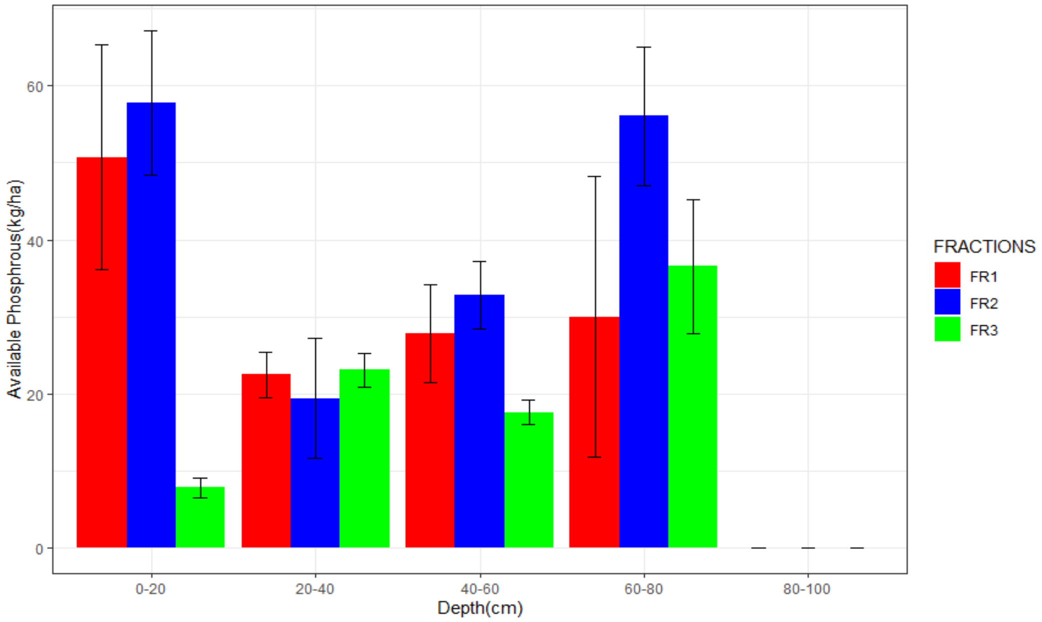
Figure 18: Variation of soil total nitrogen in 250-2000µm at different soil depths in different land use systems



5.2.4. Soil available phosphorus

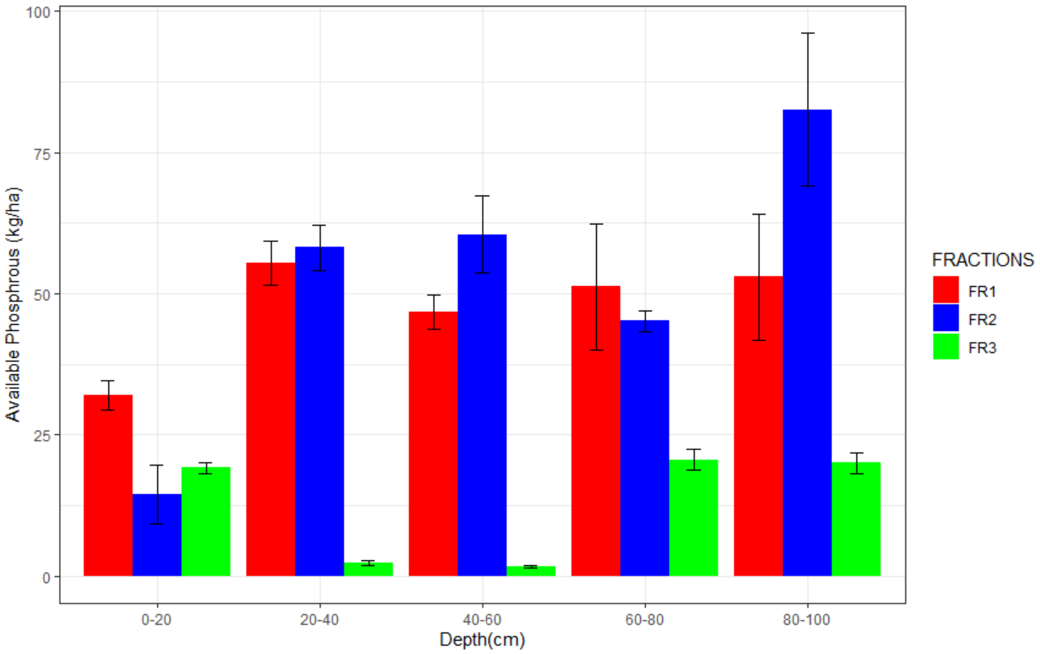
Available form of phosphorous is comparatively less in soil, even though plants assimilate it from the soil. Aggregates in soil influence the nutrient sequestration and dynamics, these are also influenced by management practices (Lu et al., 2018). In homegardens, the concentration of available phosphorous was comparatively higher compared to teak planation. This could be due to availability of available phosphorous through artificial means such as manuring in homegardens. The main source of nutrient addition into the soil is from litter and fruit crops releases more nutrients than other tree species. Compared to other nutrients like nitrogen and potassium, phosphorus is added in comparatively smaller amount into the soil (Isaac & Nair, 2006). The initial decline of phosphorus and then its gradual increase was observed throughout the 1m soil depth. This could be due to the absorption of available phosphorus by plant roots in the top layers. With increasing soil depth, root proliferation decreases causing lesser absorption of available nutrients by plant roots. Stum teaks usually have their fibrous roots distributed in the top 40 cm for greater absorption of nutrients. This leads to greater concentration of available phosphorus in the top layers of contiguous open when compared to the woody ecosystems. This is the influence of management implications undertaken in teak plantation. Homegardens which are rich in species diversity contains deep rooted plants which absorbs the available nutrients present in the soil (Dawud et al., 2016). In the treeless areas, the sources of nutrients are less as well as the absorption of nutrients are also less. Unlike woody ecosystem, absence of deep-rooted plants causes higher concentration of available phosphorus. Another source of phosphorus in deeper layers is from rocks mother material present in deeper layers which contributes nutrients in both treeless and woody ecosystem. No specific trend among the aggregates has been found. Another factor was the limitation in number of pits taken for soil analysis as a single pit may not represent the entire area.

Figure 19: Variation in soil available phosphorus (kg ha^{-1}) of different aggregate sizes at different soil depths of typical homegarden



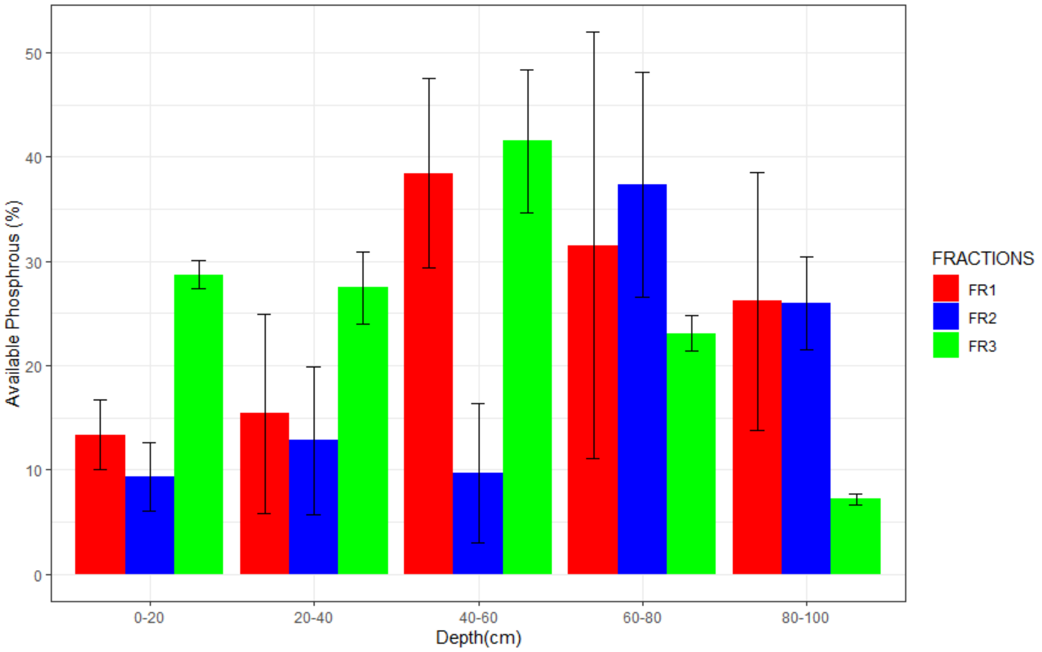
FR1: 250-2000, FR2: 53-250, FR3: <53 µm

Figure 20: Variation in soil available phosphorus (kg ha^{-1}) of different aggregate sizes at different soil depths of open contiguous homegarden.



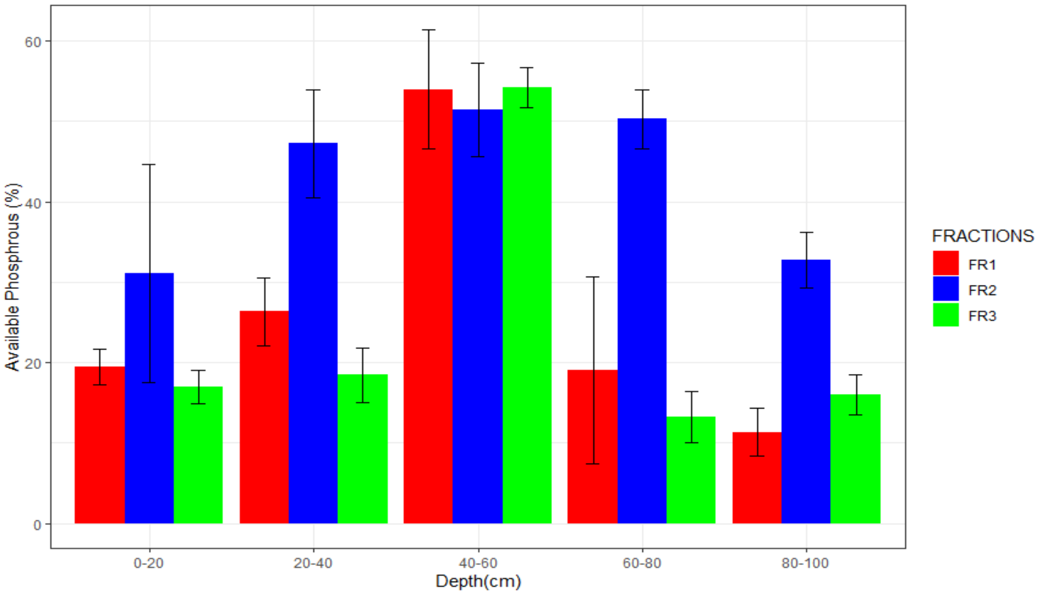
FR1: 250-2000, FR2: 53-250, FR3: <53 µm

Figure 21: Variation in soil available phosphorus (kg ha^{-1}) of different aggregate sizes at different soil depths of teak plantation



FR1: 250-2000, FR2: 53-250, FR3: <53 µm

Figure 22: Variation in soil available phosphorus (kg ha^{-1}) of different aggregate sizes at different soil depths of open contiguous teak plantation



FR1: 250-2000, FR2: 53-250, FR3: <53 µm

Figure 23: Variation of soil available phosphorus (kg ha^{-1}) in <53µm at different soil depths in different land use systems

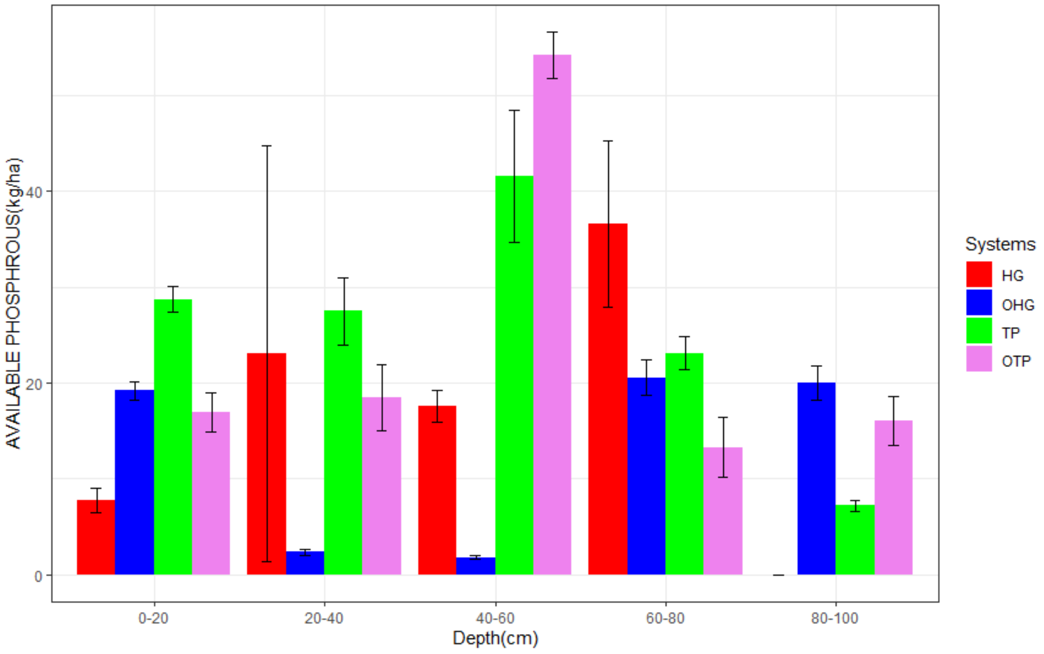


Figure 24: Variation of soil available phosphorus (kg ha^{-1}) in 53-250µm at different soil depths in different land use systems

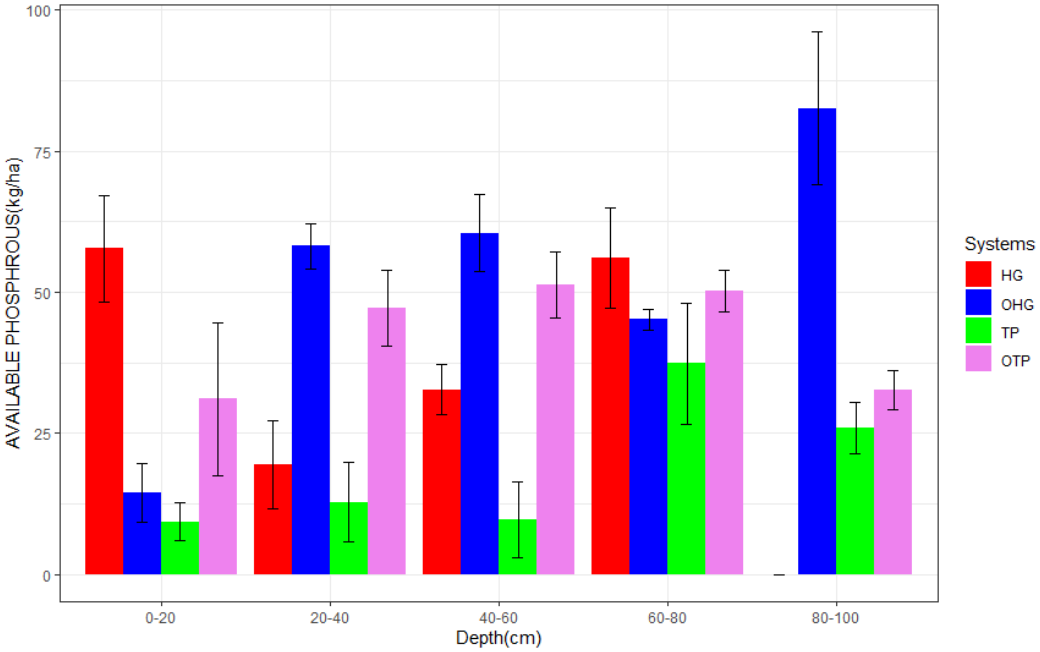
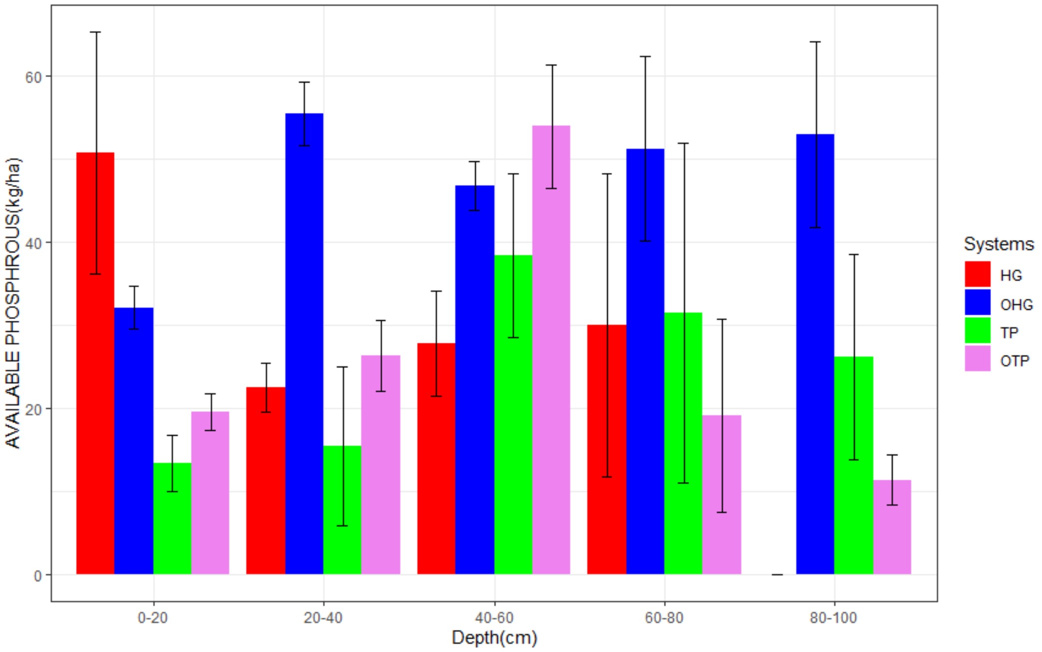


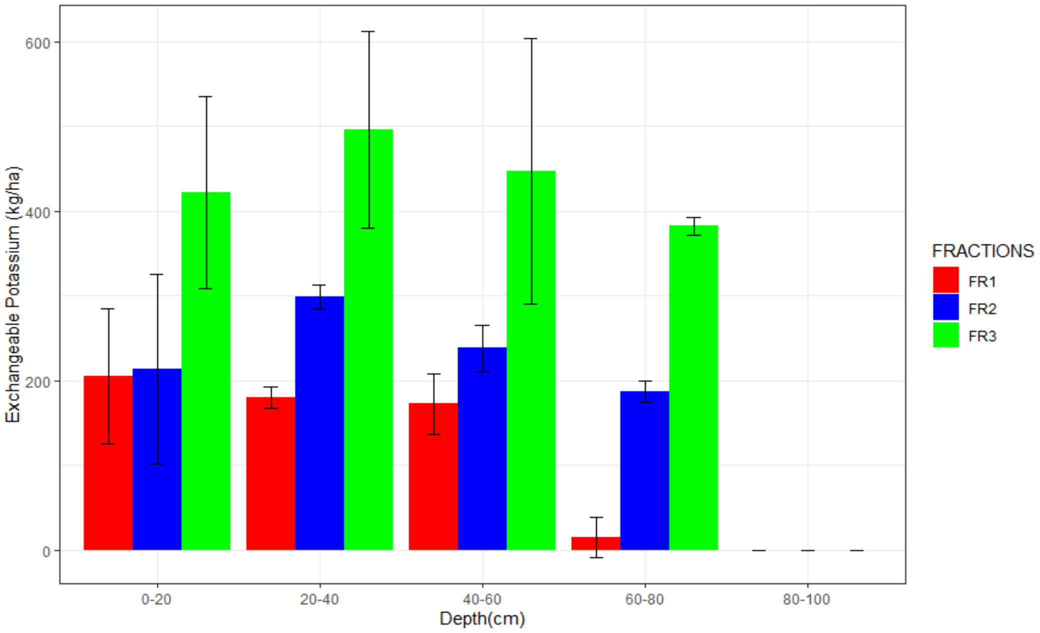
Figure 25: Variation of available phosphorus (kg ha^{-1}) in 250-2000µm at different soil depths in different land use systems



5.2.4. Soil exchangeable potassium

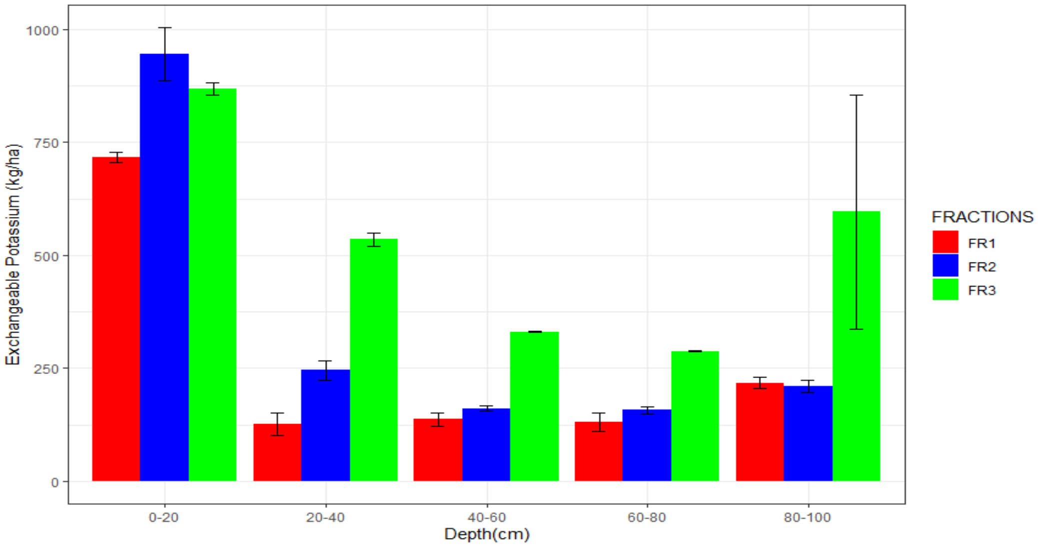
Decomposition and production of litter in woody ecosystems controls the biogeochemical nutrient cycling in soil. Analysing the distribution of potassium in different soil fractions is necessary as it released in to the soil in a continuous and slow, which limits its availability in the soil. The vertical distribution of potassium didn't exhibit any particular trend (Alam et al., 2021). The exchangeable potassium in top layers were comparatively lower than the sub surface layers due to the depletion of nutrients by trees in the soil. Hence the woody ecosystems had lower exchangeable potassium than the contiguous open in the top layers. Teak which is a monoculture plantation absorbs lesser nutrients than homegardens which contains higher diversity species (Kumar, 2006). Available nutrients are absorbed by the different types of tree species present in homegardens constituting a lower nutrient concentration in homegardens than teak plantation. Since teak has its root limited to the top layers, the absorption by them decreases leading higher values in the middle layers in woody ecosystems. Only a single pit was taken to represent the contiguous open, which limits the results.

Figure 26: Variation in soil exchangeable potassium (kg ha^{-1}) of different aggregate sizes at different soil depths of a typical homegarden.



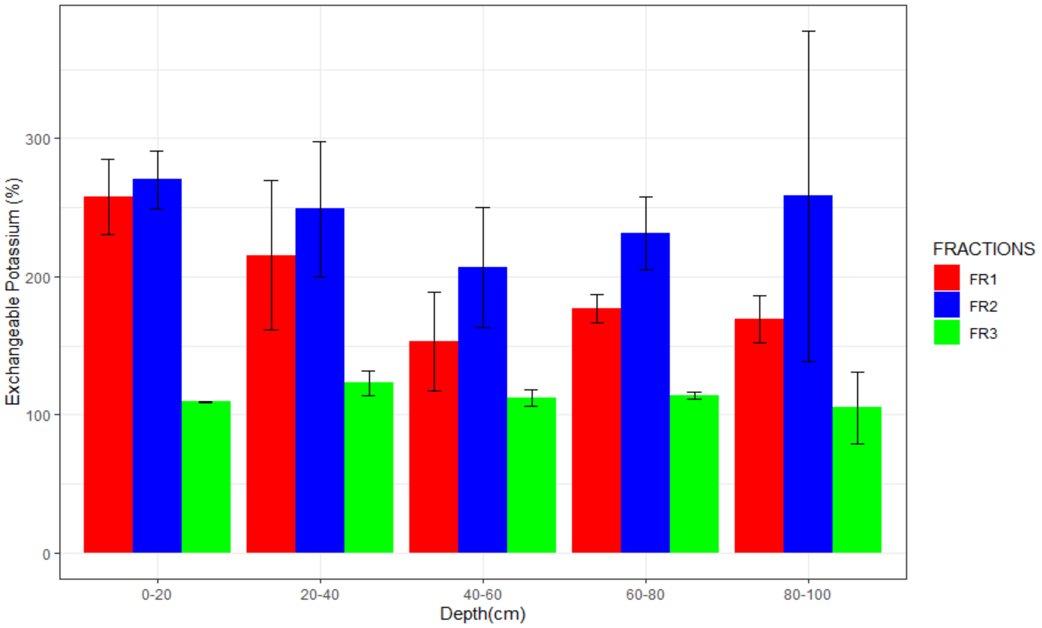
FR1: 250-2000, FR2: 53-250, FR3: <53 µm

Figure 27: Variation in soil exchangeable potassium (kg ha^{-1}) of different aggregate sizes at different soil depths of open contiguous homegarden.



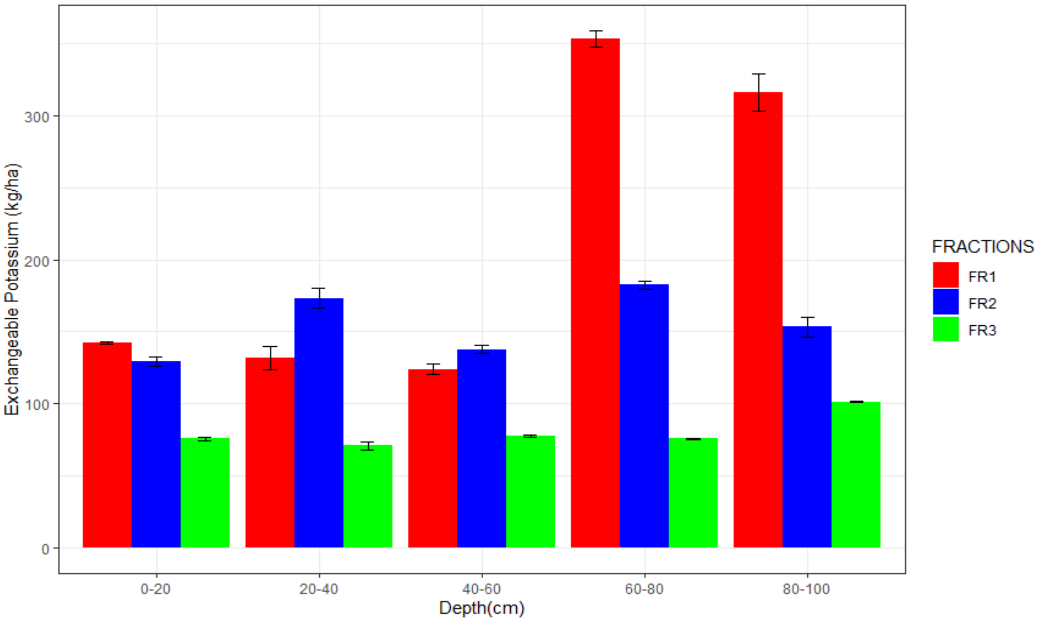
FR1: 250-2000, FR2: 53-250, FR3: <53 µm

Figure 28: Variation in soil exchangeable potassium (kg ha^{-1}) of different aggregate sizes at different soil depths of teak plantation.



FR1: 250-2000, FR2: 53-250, FR3: <53 µm

Figure 29: Variation in soil exchangeable potassium (kg ha^{-1}) of different aggregate sizes at different soil depths of open contiguous teak plantation.



FR1: 250-2000, FR2: 53-250, FR3: <53 µm

Figure 30: Variation of soil exchangeable potassium (kg ha^{-1}) in <53µm at different soil depths in different land use systems

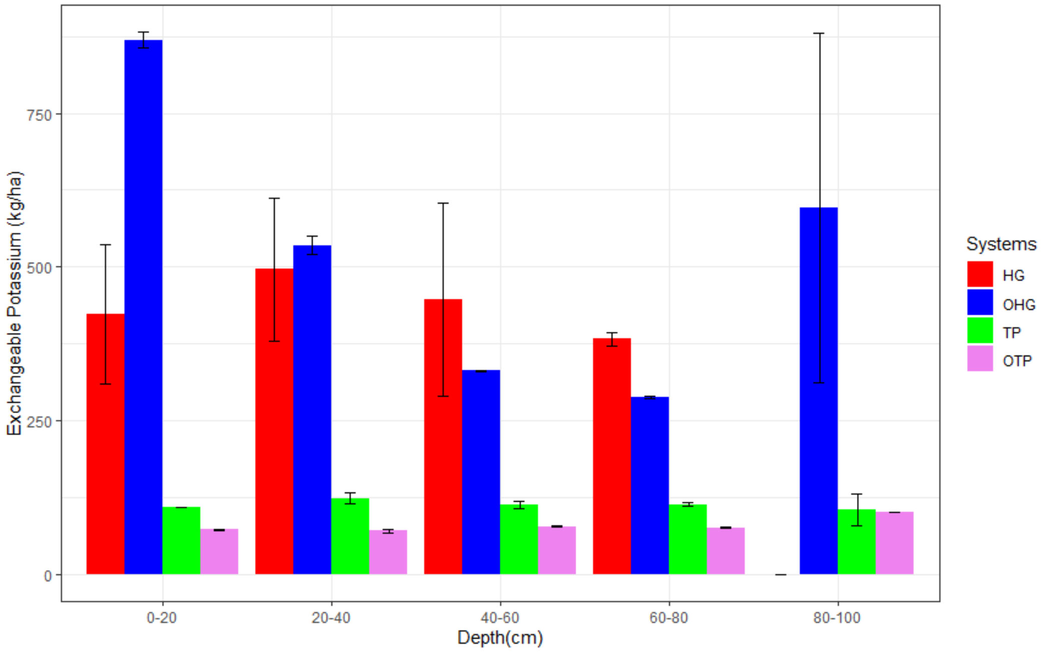


Figure 31: Variation of soil exchangeable potassium (kg ha^{-1}) in 53-250µm at different soil depths in different land use systems

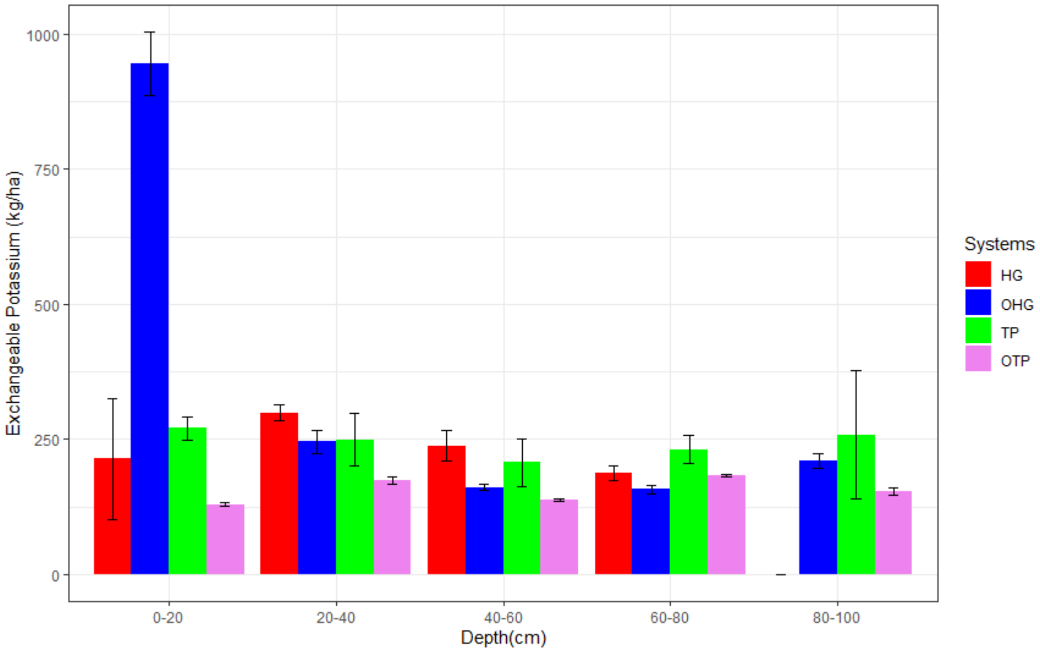
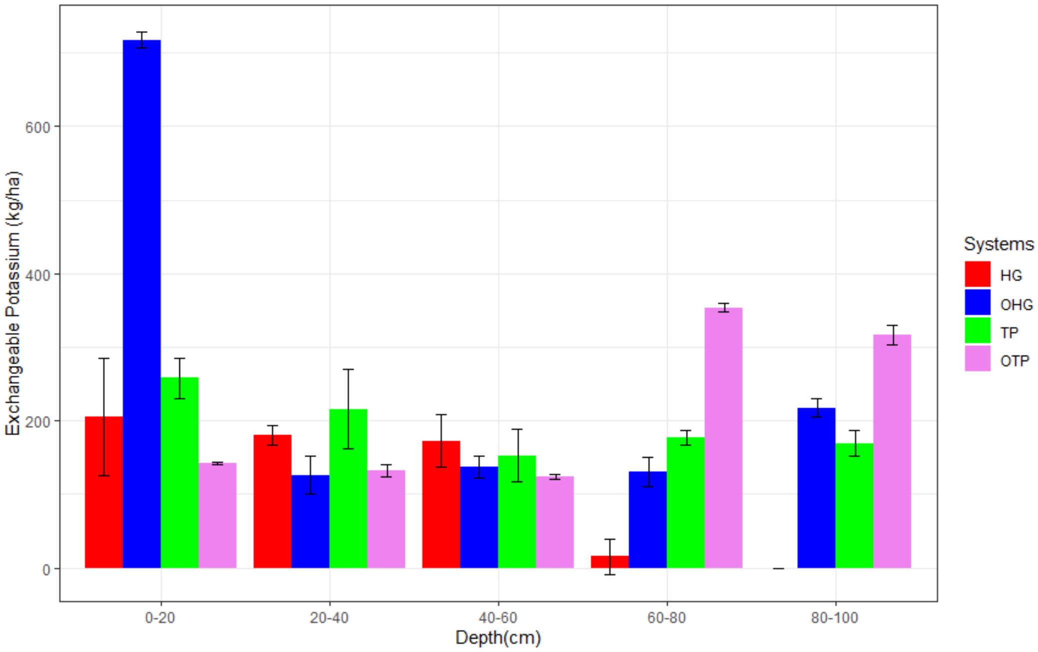


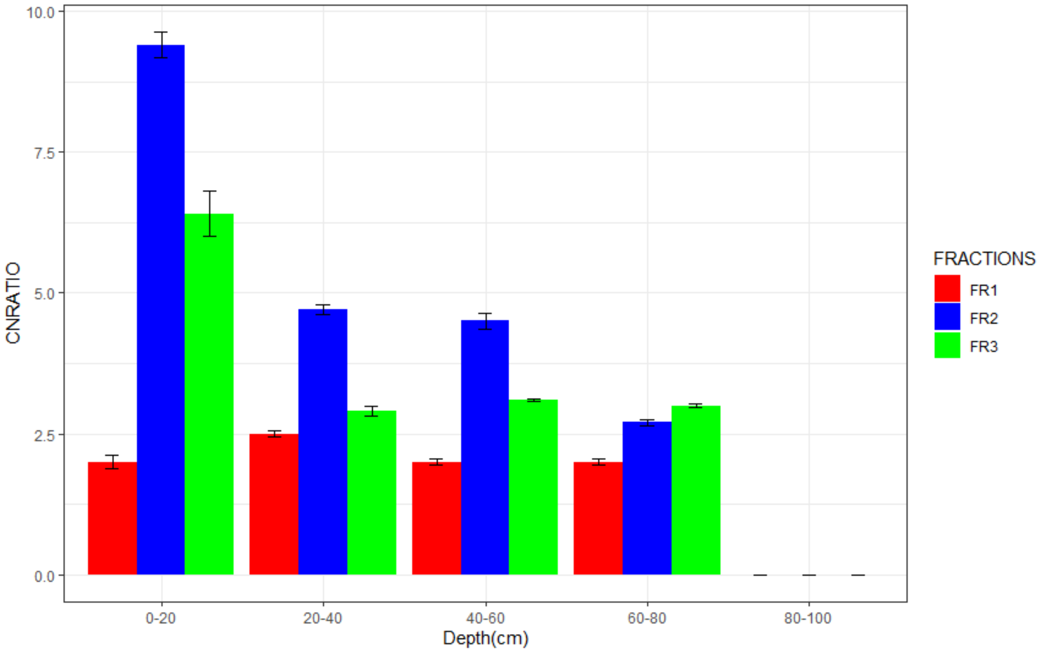
Figure 32: Variation of soil exchangeable potassium (kg ha^{-1}) in 250-2000µm at different soil depths in different land use systems



5.2.6. C: N ratio

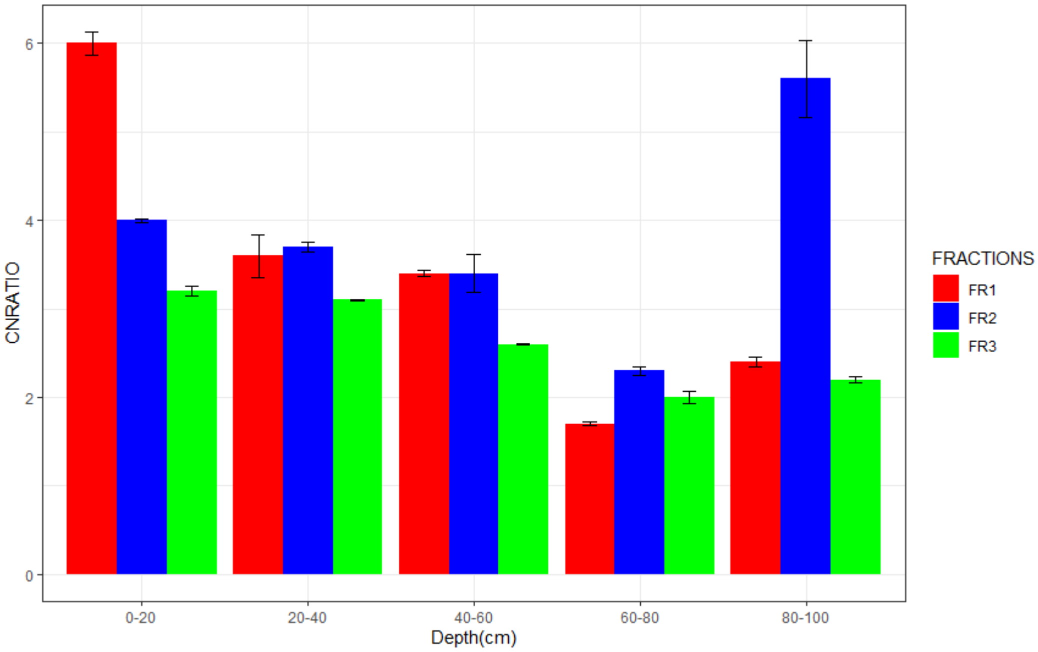
Carbon and nitrogen concentration are higher in the top layer due to their release into the soil from litter decomposition. It also influences the carbon dynamics in the soil (Han et al., 2010). The higher ratio is an indicator of fertility and better soil development. This has contributed to the higher C:N ratio in the top layer. The higher C:N ratio of homegardens than teak plantation is due to their higher species diversity in homegardens (Dawud et al., 2016).

Figure 33: Variation in soil C: N of different aggregate sizes at different soil depths of typical homegarden



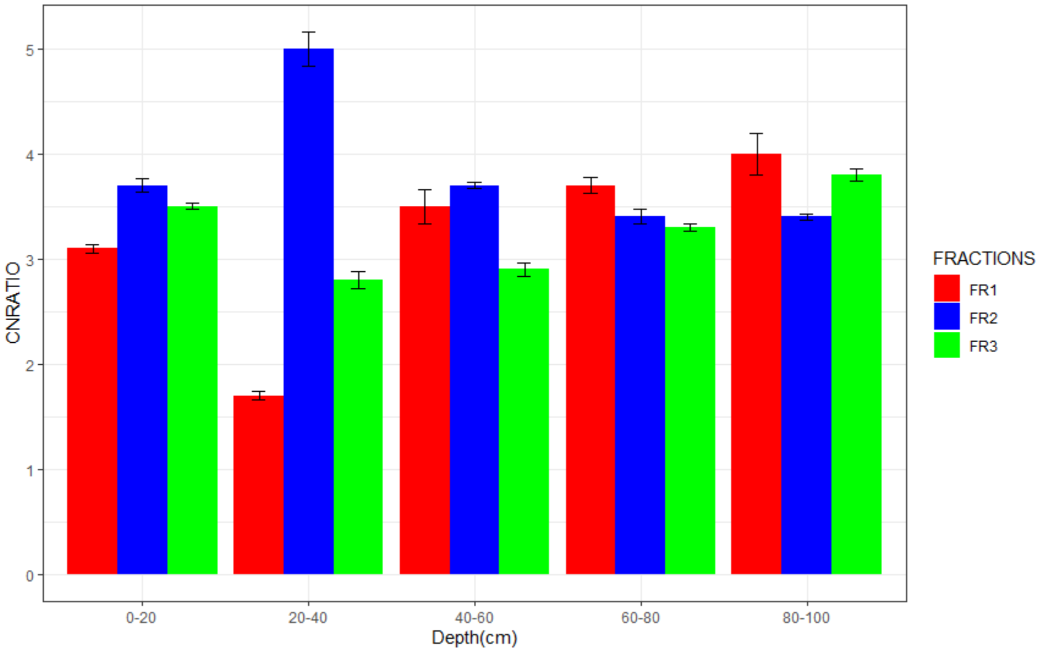
FR1: 250-2000, FR2: 53-250, FR3: <53 µm

Figure 34: Variation in soil C: N of different aggregate sizes at different soil depths of open contiguous homegarden



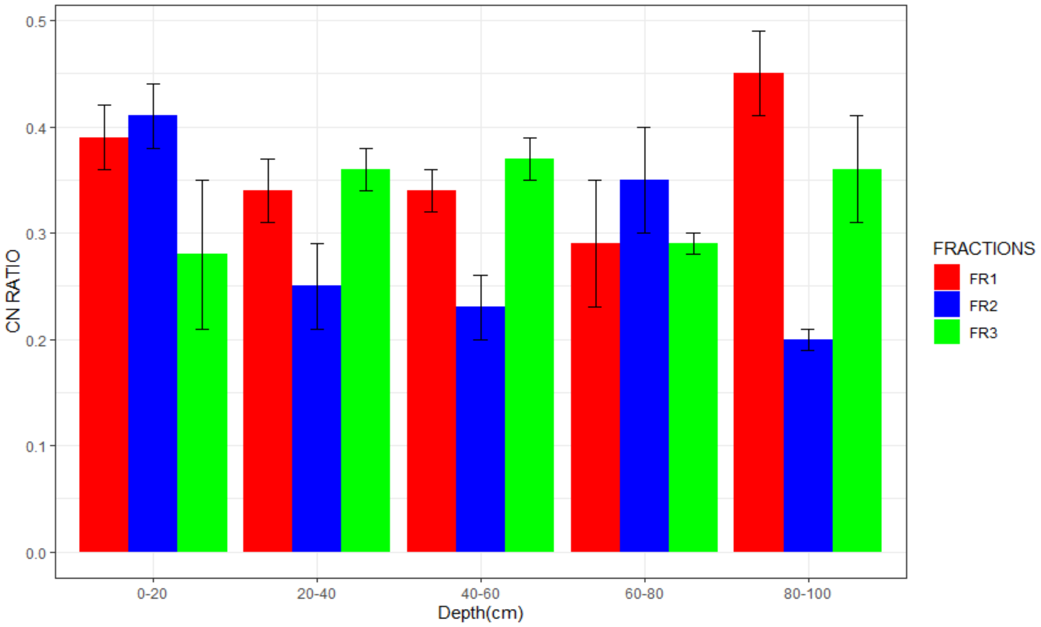
FR1: 250-2000, FR2: 53-250, FR3: <53 µm

Figure 35: Variation in soil C: N of different aggregate sizes at different soil depths of teak plantation.



FR1: 250-2000, FR2: 53-250, FR3: <53 µm

Figure 36: Variation in soil C: N of different aggregate sizes at different soil depths of open contiguous teak plantation.



FR1: 250-2000, FR2: 53-250, FR3: <53 µm

Figure 37: Variation of C: N in <53µm at different soil depths in different land use systems

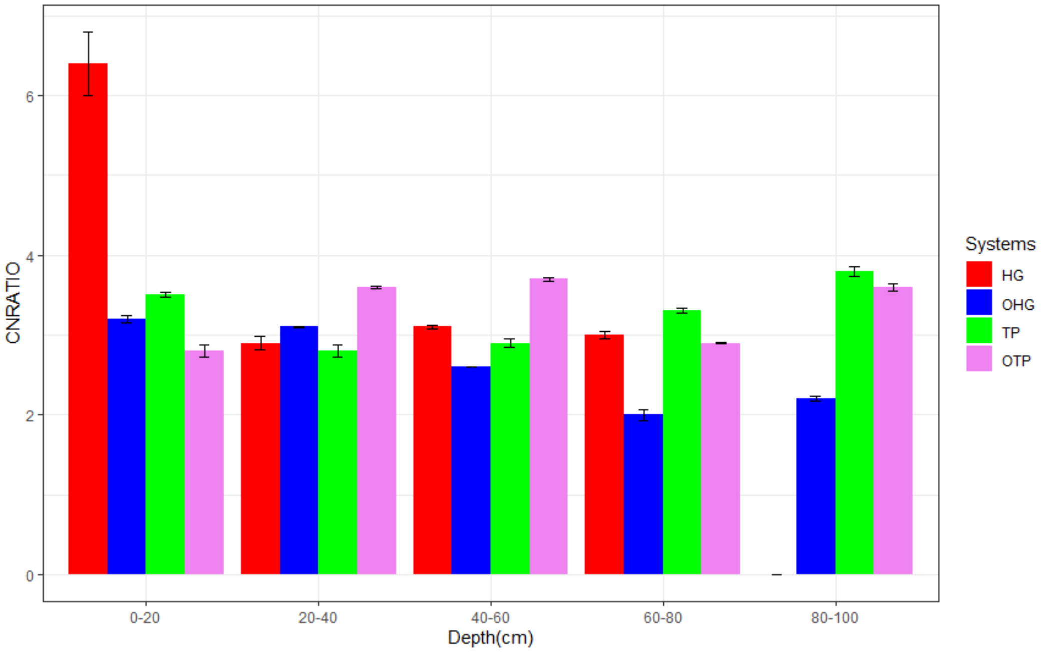


Figure 38: Variation of C: N in 53-250µm at different soil depths in different land use systems

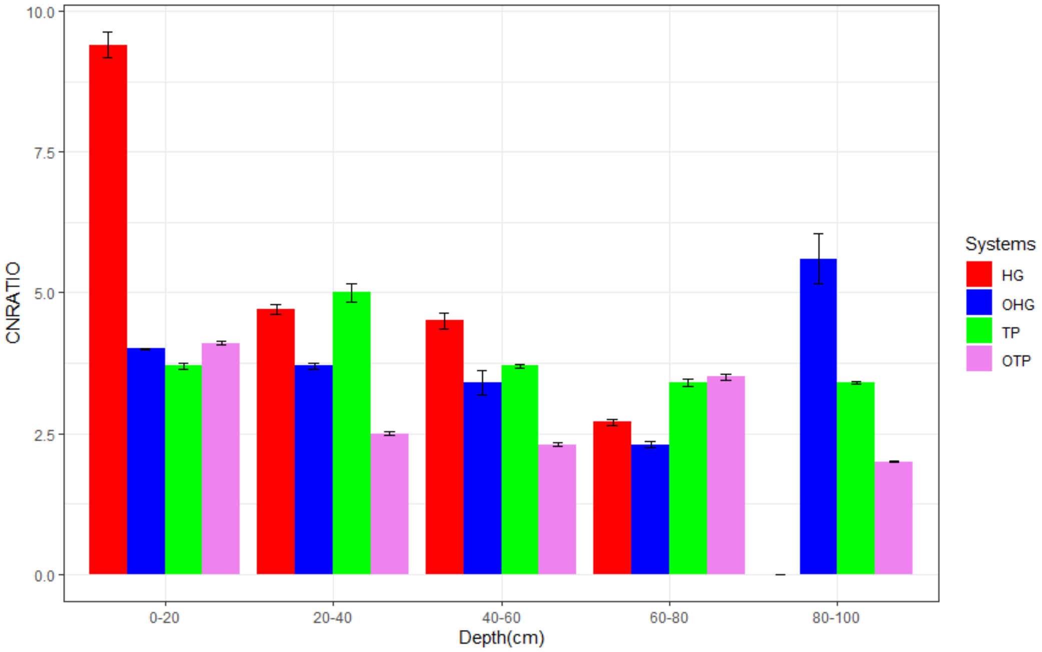
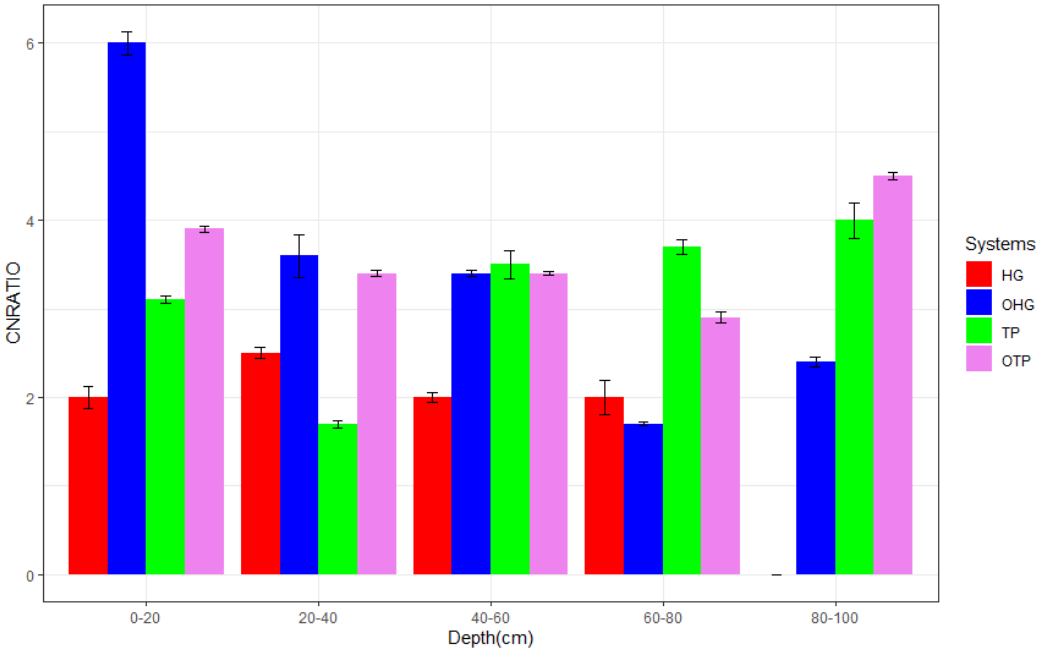


Figure 39: Variation of C: N in 250-2000µm at different soil depths in different land use systems



5.3. SOIL MICROFLORA OBSERVATIONS

Soil microflora are very much active in the top 1m and near the roots of trees. These organisms release the nutrients in to the soil through decomposition and increases the productivity of soils. They have a requisite part in the agglomeration of soils and its presence indicates soil fertility. The small pores in soil aggregates promotes its activity and the in the rhizosphere region moisture conditions are maintained to a limit by the roots present (Talwar and Chatli, 2018). They are much susceptible to changing climate and vary with a slight change in habitat conditions.

5.3.1. Total bacteria population

The bacterial population in the soil is influenced by both biotic and abiotic factors in the soil (Gopal and Kurien, 2015). The population of bacteria was higher in homegardens compared to teak plantation. The soils of teak plantation had comparatively drier conditions when compared to homesteads which could be the reason for lower bacterial population. The species diversity and the microclimate of the region influences the population if microflora in the region. For instance, higher moisture levels like humid climate promotes the growth of microflora by providing suitable conditions to thrive (Talwar and Chatli, 2018).

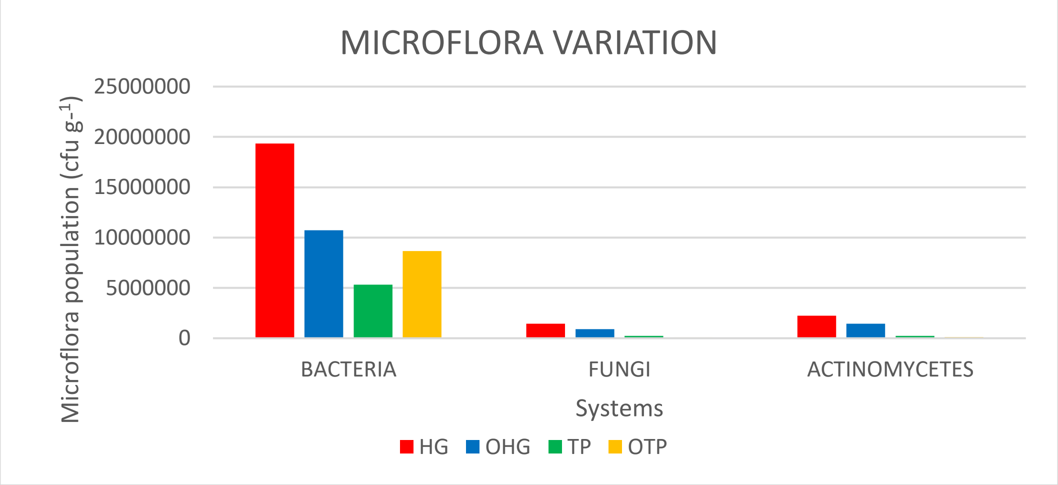
5.3.2. Total fungi population

Soil promotes fungal population than other environments. Around 1.5 million fungi population are estimated worldwide and they play a crucial role in soil formation, improving fertility and many other positive benefits are found. The amount of root hair and nutrient status of the soil influences the microflora population (Gopal & Kurien, 2013). The lower concentration of fungi population in teak would be due to low amount of root hairs compared to homegardens which contains many deep-rooted species.

5.3.3. Total actinomycetes population

The diversity of species present also influences the population of microflora in the soil A typical homegarden in Kerala usually holds a diverse array of species which include coconut, areca nut, mango tree etc. (Gopal & Kurien, 2015). Homegardens which contain more species diversity had higher actinomycetes population compared to teak plantation. The treeless areas had lower than the woody ecosystem (Patidar et al., 2017).

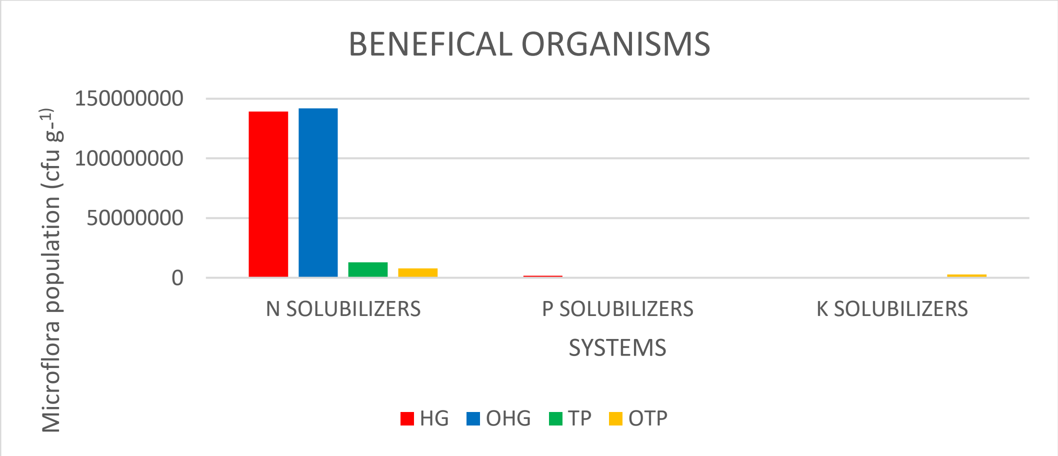
Figure 40: Variation of different beneficial organisms in different woody ecosystems and its open contiguous plots.



5.3.4. Total nitrogen fixers, p- solubilizers and k- solubilizers

The population was higher in woody ecosystems than treeless areas. These nitrogen fixers play a crucial role in maintain the nitrogen pools in soil (Talwar and Chatli, 2018).The higher microbial population near rhizosphere region is due to its association withs roots, the suitable micro-climate of the region and higher litter deposition in woody ecosystems (Patidar et al., 2017).

Figure 41: Variation of different beneficial organisms in different woody ecosystems and its open contiguous plots.



CHAPTER 6

SUMMARY AND CONCLUSION

Soil carbon sequestration which is recognised as efficient and cost-effective mechanism in climate change mitigation focussed mostly on the total potential of soils. When the potential of different aggregates is taken into consideration, soils have much more potential to store carbon but this often remains unexplored. This study focuses on analysing the potential of carbon and nutrient storage in different soil fractions. Carbon and nutrient dynamics in soil is also controlled by the various microbes in the soil which in turn controls soil aggregation. The study also focused on analysing the population of different soil microbes.

In this study, soil samples were collected from two different land use systems- a teak plantation and a homestead. Soils were also collected from open contiguous treeless plots as controls. These soils were fractionated into different fraction sizes (250-2000 µm, 53-250 µm, <53 µm) using Yoder's apparatus. The aggregate carbon and nutrient analysis of these samples were done by following standard procedures. For carbon, the estimation was done using Walkley and Black method. Soil total nitrogen estimation was done by Macrokjeldahl method. soil available phosphorus and exchangeable potassium was analysed using spectrophotometer and flame photometer respectively. The population of various microflora was analysed by serial dilution and plate count method.

Carbon and nutrients varied profoundly with depth, land use system and the soil size. The smallest fraction which was found in least amount had highest carbon and nitrogen stored. Teak plantation (75.04 Mg C ha^{-1}) had higher carbon concentration than homegardens (31.64 Mg C ha^{-1}). But the total nitrogen concentration was higher in teak plantation than homegardens. The open contiguous plots had lower concentration compared to the woody ecosystems as the availability of litter and root for decomposition was less.

All the microflora populations were higher in homegardens except the K-solubilizers which was higher in teak. The open treeless plots had lower beneficial organisms than treeless areas in all populations of microflora. The reasons attributing to these would be the drier conditions in teak plantation. Microbes thrive abundantly in cool and damp conditions than drier habitats.

The significant role of trees in climate change mitigation, has been well understood from this study entitled “Soil carbon stocks and microbial status in the selected woody ecosystems of Trissur district, Kerala” The results emphasise the need for increasing tree cover as it increases aggregation which increases the storage potential in soil. The higher concentration of carbon in the smallest fraction shows that the potential to store carbon varies in different aggregates. Soils have higher potential for carbon sequestration when aggregates are examined.

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ABSTRACT

Soil aggregates which maintain the soil structure plays a significant role in protecting the carbon stored from degradation. As the ecosystem is experiencing the negative effects of the enhanced climate change. Analysing the potential of carbon and nutrient sequestration in different soil fractions demonstrated their remarkable part in climate change mitigation using soil carbon storage mechanism. Woody ecosystems act as a sink for carbon and helps storing it in the aggregates. Even though the macroaggregates are found in larger proportion they have relatively smaller carbon and nitrogen storage potential. The smallest soil fraction which is protected from further microbial degradation has the highest carbon and nitrogen stored compared to the all-other soil fractions. The role of trees in storing carbon in finer fractions seems credible. Teak plantation and homesteads had profoundly higher carbon compared to their open treeless areas. The carbon stock was higher in teak plantation than homegardens. There wasn't any particular trend for nutrient stored in soil fractions. Since teak had a relatively drier conditions than homegardens, the microbial status was low in teak plantation. The treeless areas had lower microbial population than both the woody ecosystems. Hence enhancing tree cover improves soil aggregation that results in enhancement of carbon storage in them. It also provides the suitable habitat for the microbes to thrive which plays a significant role in carbon and nutrient cycling. Proper land use management practices are needed as disturbances such as tillage leads to breakage of aggregates and exposes the carbon encapsulated within it. These can lead to huge losses of carbon by erosion and releases more carbon in to the atmosphere inducing climate change.