

**MICROBIAL BIOMASS CARBON STOCKS AT HOME GARDEN
AGROFORESTRY SYSTEM IN PARTS OF WESTERN GHATS**

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BENGALURU**

2018

**MICROBIAL BIOMASS CARBON STOCKS AT HOME GARDEN
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Thesis submitted to

The University of agricultural sciences, Bengaluru

In partial fulfillment of the requirements

For the award of the degree of

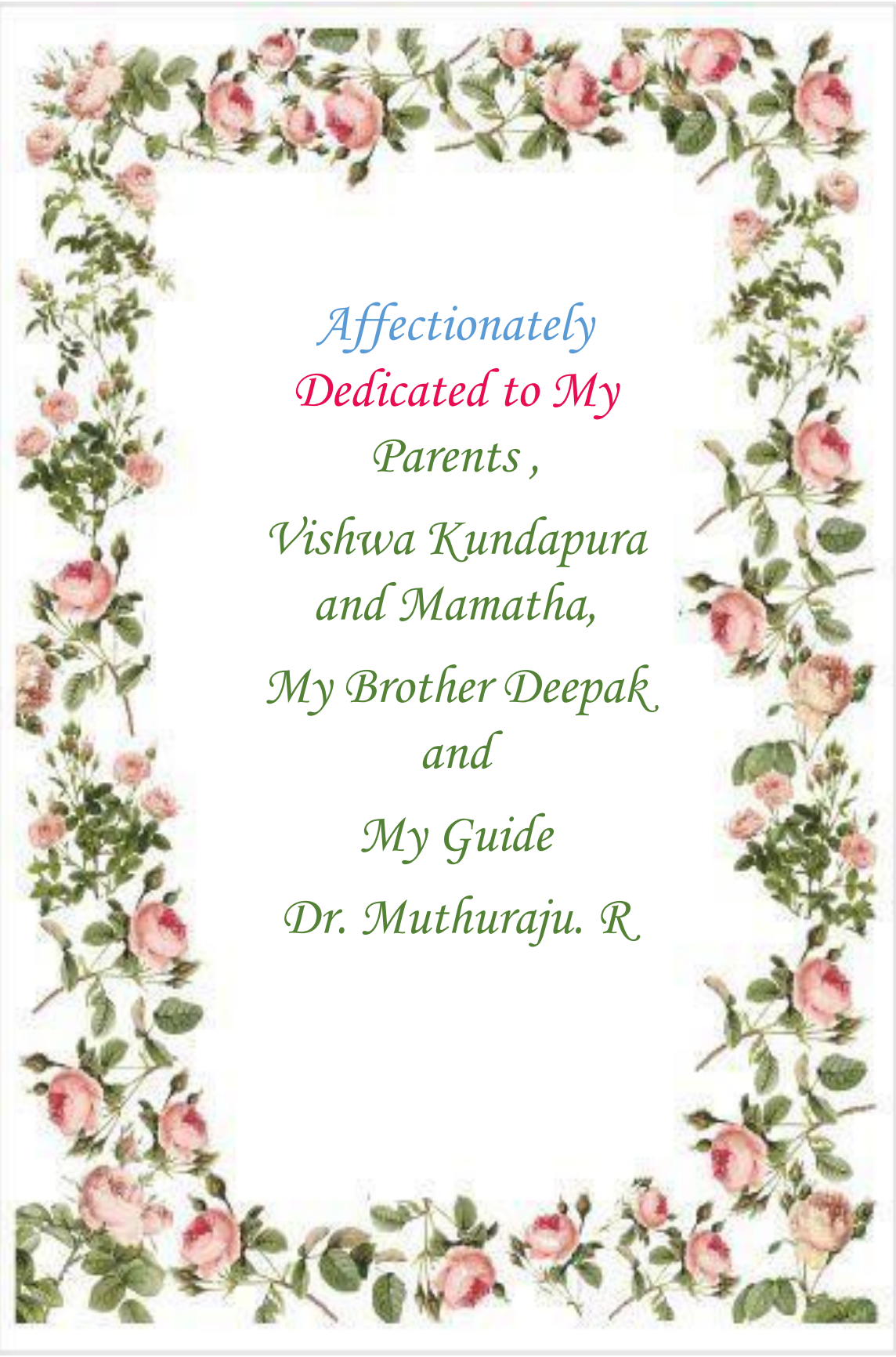
MASTER OF SCIENCE (Agriculture)

in

AGRICULTURAL MICROBIOLOGY

BENGALURU

AUGUST, 2018



Affectionately
Dedicated to My
Parents ,
Vishwa Kundapura
and Mamatha,
My Brother Deepak
and
My Guide
Dr. Muthuraju. R

DEPARTMENT OF AGRICULTURAL MICROBIOLOGY
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CERTIFICATE

This is to certify that the thesis entitled "MICROBIAL BIOMASS CARBON STOCKS AT HOME GARDEN AGROFORESTRY SYSTEM IN PARTS OF WESTERN GHATS" submitted by Ms. DEEPTHI KUNDAPURA, ID. No. PALB 6164 in partial fulfillment of the requirements for the award of for the award of the degree of MASTER OF SCIENCE (Agriculture) in AGRICULTURAL MICROBIOLOGY to the University of Agricultural Sciences, Bengaluru, is a record of bonafide research work carried out by her during the period of her study in this University, under my guidance and supervision and the thesis has not previously been formed the basis for the award of any degree, diploma, associate-ship, fellowship or other similar titles.

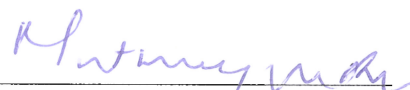
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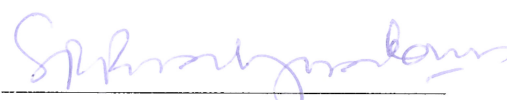
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ACKNOWLEDGEMENT

Gratitude is one of the most powerful human emotions. Saying thank you acknowledges our dependence on others. No man is an island. We should appreciate the act of a good deed and the time it took to perform that deed. It is important to recognize the time it took, especially because we are a time-deprived society.

Dear God, I want to take a moment, not to ask for anything from you, but simply to thank you for everything.

*I express my gratitude to, **Dr. Muthuraju, R.**, Asst. Professor, Department of Agricultural Microbiology, University of Agricultural Sciences, GKVK, Bengaluru, Chairperson of my Advisory Committee for his patient guidance, encouragement and advice he has provided throughout my time as his student. I have been extremely fortunate to have a guide like him who is a tough task-master and who always tried to bring out the best in me.*

*I extend thanks to the members of my advisory committee **Dr. G. P. Brahmaprakash**, Professor and former Head, Department of Agricultural Microbiology, University of Agricultural Sciences, GKVK, Bengaluru, **Dr. K. T. Prasanna**, Professor and Head, Department of Forestry and Environmental Sciences, University of Agricultural Sciences, GKVK, Bengaluru for their supervision. I extend thanks to **Dr. R. Krishna Murthy**, member of my advisory committee for his constant supervision, invaluable guidance and for taking time to address my constant queries.*

*I take this opportunity to express my deep sense of gratitude and respectful regards to **Dr. Hombegowda**, Scientist (Forestry), ICAR- Indian Institute of Soil and Water Conservation (IISWC), Orissa, for his valuable information and suggestions that have been very helpful for this study.*

*I thank **Dr. B. Narayanaswamy**, Professor, Department of Agricultural Microbiology, GKVK Bengaluru and **Dr. B. Shivanna**, Asst. Professor, Department of Agricultural Entomology, GKVK Bengaluru for their timely advices and moral support.*

*Completing this work would have been all the more difficult had it not been the support of seniors like **Dr. Vidhyashree, D. N., Mr. Praveen Ranadev**. Sincere thanks to my senior **Mr. Arun Kumar Pandit** for being Google for my queries and for bearing with me for my FAQs. I extend thanks to my friends **Pravin Maledavar, Nitin Bawankule, Jagadeesh** and **Sandhya** for their love and affection. I extend thanks to **Jyotsna, Divya, Radhika** and **Ramya** for their support.*

I am also thankful to the Teaching & Non-Teaching staff members of Dept. of Agricultural Microbiology, UAS, GKVK, Bangalore, for their kind suggestion and necessary facilities to conduct the experiments.

*Family is where life begins and love never ends. I would always remain indebted to the love and support of my family without whom I would have been nothing and couldn't have made it so far. Much thanks to my dearest father **Vishwa Kundapura**, mother **Mamata**, brother **Deepak**, aunt **Jyothi**, uncle **Jagadish** and my little brother **Sai Samarth** for their constant support, encouragement, love, blessings and what not.*

*Knowing that I have friends who encourage, appreciate and love me, is a great feeling! Heartfelt thanks to my dearest best friend **Mr. Manjunath(Manjy)** and loving junior **Ms. Badrunnisha** for always being there for me in my ups and downs. You guys are wonderful! I thank **Mrs. Tanuja** for being a great friend and a good senior and guiding me in my academic and non-academic life. I thank **Chaithra**, **Sowmya**, **Uooha** for their timely help. I thank **Rahul** and **Abhijeet** for their support.*

I acknowledge the several friends and well wishers, whom I might have missed to mention above and whose best wishes have always encouraged me.

**BENGALURU,
AUGUST, 2018**

(DEEPTHI KUNDAPURA)

MICROBIAL BIOMASS CARBON STOCKS AT HOME GARDEN AGROFORESTRY SYSTEM IN PARTS OF WESTERN GHATS

DEEPTHI KUNDAPURA

ABSTRACT

Soil microbial biomass is important in nutrient cycling and release, acting as source and sink for plant nutrients as it is the most reactive part of the soil organic matter. The present study focuses on the assessment of soil characters as influenced by land-use systems and soil depth and the importance of home garden agroforestry system in enhancing soil microbial biomass carbon stocks. The soil samples were collected from different land-use systems and analyzed for soil microbial and biochemical parameters. The soil microbial biomass carbon ($396.58 \mu\text{g g}^{-1}$), nitrogen ($51.23 \mu\text{g g}^{-1}$) and phosphorus ($5.12 \mu\text{g g}^{-1}$) were higher in forest soils and decreased with depth compared to other land use systems. Functional groups of microorganisms *i.e.*, nitrogen fixers ($107.07 \times 10^3 \text{ CFU g}^{-1}$), phosphate solubilizers ($35.71 \times 10^3 \text{ CFU g}^{-1}$), potassium solubilizers ($15.28 \times 10^3 \text{ CFU g}^{-1}$), cellulose degraders ($103.28 \times 10^3 \text{ CFU g}^{-1}$) and lignin degraders ($60.71 \times 10^3 \text{ CFU g}^{-1}$) were higher in forest soils followed by home garden and agriculture soils. Soil dehydrogenases ($151.3 \mu\text{g TPF g}^{-1}\text{h}^{-1}$), urease ($62.7 \mu\text{g NH}_4^+-\text{N g}^{-1}\text{h}^{-1}$), acid and alkaline phosphatases (43.57 and $19.13 \mu\text{g PNP g}^{-1}\text{h}^{-1}$) activities were also higher in forest soils. Soil organic-C (2.63 %), available-N (0.29 %), pH (5.6) and electrical conductivity (0.057 dSm^{-1}) were also higher in forest soils followed by home garden agroforestry system and the least were in intensive agriculture soils. This suggests that the establishment of home garden agroforestry system on agriculture land helps the soil microbial biomass stocks to rebound to near-forest levels.

AUGUST, 2018
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**ಪಶ್ಚಿಮ ಘಟ್ಟ ಪ್ರದೇಶದಅರಣ್ಯ-ಕೃಷಿ ಕೈತೋಟಪದ್ಧತಿಯ ಮಣ್ಣಿನಲ್ಲಿರುವ ಸೂಕ್ಷ್ಮಾಣು
ಜೀವರಾಶಿ ಇಂಗಾಲದ ಮಟ್ಟ**

ದೀಪ್ತಿ ಕುಂದಾಪುರ

ಪ್ರಬಂಧ ಸಾರಾಂಶ

ಮಣ್ಣಿನ ಸೂಕ್ಷ್ಮಾಣು ಜೀವರಾಶಿಯು ಪೋಷಕಾಂಶ ಚಕ್ರ ಹಾಗೂ ಬಿಡುಗಡೆಯಲ್ಲಿ ಮುಖ್ಯವಾದ ಪಾತ್ರವನ್ನು ವಹಿಸುತ್ತದೆ. ಇದು ಮಣ್ಣಿನ ಸಾವಯವ ವಸ್ತುಗಳಲ್ಲಿ ಅತ್ಯಂತಕ್ರಿಯಾತ್ಮಕ ಭಾಗವಾಗಿರುವಕಾರಣ ಸಸ್ಯಗಳ ಬೆಳವಣಿಗೆಗೆ ಅಗತ್ಯ ಪೋಷಕಾಂಶಗಳನ್ನು ಒದಗಿಸುತ್ತದೆ ಹಾಗೂ ಮಣ್ಣಿನ ಫಲವತ್ತತೆಯ ಸ್ಥಿತಿಯನ್ನು ಪ್ರತಿಬಿಂಬಿಸುತ್ತದೆ. ಆದ್ದರಿಂದಇದನ್ನು ವಿವಿಧ ಭೂ-ಬಳಕೆ ಪದ್ಧತಿಗಳ ಮಣ್ಣಿನಗುಣಮಟ್ಟವನ್ನು ನಿರ್ಣಯಿಸಲು ಸೂಚಕವಾಗಿ ಬಳಸಬಹುದು. ಈ ದಿಸೆಯಲ್ಲಿ ಬೆಂಗಳೂರು ಕೃಷಿ ವಿಶ್ವವಿದ್ಯಾಲಯ, ಸೂಕ್ಷ್ಮಾಣುಜೀವಿಶಾಸ್ತ್ರ ವಿಭಾಗದ ವತಿಯಿಂದ ನಡೆದ ಈ ಸಂಶೋಧನೆಯಲ್ಲಿ ವಿವಿಧ ಭೂ-ಬಳಕೆ ಪದ್ಧತಿಗಳಲ್ಲಿ (ಅರಣ್ಯ, ಕೈತೋಟಅರಣ್ಯ ಕೃಷಿ, ಕೃಷಿ) ಎರಡು ಆಳಗಳಿಂದ (0-೧೦, ೧೦-೨೦ ಸೆ.ಮಿ) ಮಣ್ಣಿನ ಮಾದರಿಗಳನ್ನು ಸಂಗ್ರಹಿಸಿ ವಿಶ್ಲೇಷಿಸಲಾಗಿದೆ. ಈ ಸಂಶೋಧನೆಯಲ್ಲಿ ಪರಿಗಣಿಸಲಾದ ಭೂ-ಬಳಕೆ ಪದ್ಧತಿಗಳಲ್ಲಿ ಅತ್ಯಂತಉತ್ತಮ ಮಣ್ಣಿನ ಸೂಕ್ಷ್ಮಾಣು ಜೀವರಾಶಿ ಇಂಗಾಲ (396.58 ಮೈಕ್ರೋಗ್ರಾಂ/ಗ್ರಾಂ), ಸಾರಜನಕ (51.23 ಮೈಕ್ರೋಗ್ರಾಂ/ಗ್ರಾಂ), ರಂಜಕ (5.12 ಮೈಕ್ರೋಗ್ರಾಂ/ಗ್ರಾಂ) ಅರಣ್ಯ ಮಣ್ಣಿನಲ್ಲಿಕಂಡುಬಂದಿದೆ, ನಂತರಕೈತೋಟ ಹಾಗೂ ಕೃಷಿ ಮಣ್ಣಿನಲ್ಲಿ ಕನಿಷ್ಠ ಪ್ರಮಾಣದಲ್ಲಿಕಂಡುಬಂದಿದೆ. ಅಲ್ಲದೆ, ಸಾರಜನಕ ಸ್ಥಿರೀಕರಿಸುವ ಸೂಕ್ಷ್ಮಾಣುಜೀವಿಗಳ (107.07×10^3 ಸಿ.ಎಫ್.ಯು/ಗ್ರಾಂ), ರಂಜಕಕರಗಿಸುವ ಸೂಕ್ಷ್ಮಾಣುಜೀವಿಗಳ (35.71×10^3 ಸಿ.ಎಫ್.ಯು/ಗ್ರಾಂ), ಪೊಟ್ಟಾಶ್ಕರಗಿಸುವ ಸೂಕ್ಷ್ಮಾಣುಜೀವಿಗಳ (15.28×10^3 ಸಿ.ಎಫ್.ಯು/ಗ್ರಾಂ), ಸೆಲ್ಯುಲೋಸ್‌ಜೀರ್ಣಿಸುವ ಸೂಕ್ಷ್ಮಾಣುಜೀವಿಗಳ (103.28×10^3 ಸಿ.ಎಫ್.ಯು/ಗ್ರಾಂ) ಮತ್ತು ಲಿಗ್ನಿನ್‌ಜೀರ್ಣಿಸುವ ಸೂಕ್ಷ್ಮಾಣುಜೀವಿಗಳ (60.71×10^3 ಸಿ.ಎಫ್.ಯು/ಗ್ರಾಂ) ಸಂಖ್ಯೆಯೂಅರಣ್ಯ ಪದ್ಧತಿಯ ಮಣ್ಣಿನಲ್ಲಿ ಹೆಚ್ಚಾಗಿ ಕಂಡುಬಂದಿವೆ. ಅಂತೆಯೇ, ಮಣ್ಣಿನ ಕಿಣ್ವಗಳಾದ ಡೀಹೈಡ್ರೋಜಿನೇಸ್ (151.3 ಮೈಕ್ರೋಗ್ರಾಂ ಟಿ.ಪಿ.ಎಫ್/ಗ್ರಾಂ/ಗಂ), ಯೂರಿಯೇಸ್ (62.7 ಮೈಕ್ರೋಗ್ರಾಂಅಮೋನಿಯಂ-ಸಾರಜನಕ/ಗ್ರಾಂ/ಗಂ) ಕ್ಷಾರಿಯ ಮತ್ತುಆಮ್ಲ ಫಾಸ್ಫೇಟೇಸ್‌ಚಟುವಟಿಕೆಯೂ (43.57 ಹಾಗೂ 19.13 ಮೈಕ್ರೋಗ್ರಾಂ ಪಿ.ಎನ್.ಪಿ/ಗ್ರಾಂ/ಗಂ) ಅರಣ್ಯ ಮಣ್ಣಿನಲ್ಲಿ ಹೆಚ್ಚು ಕಂಡುಬಂದಿದ್ದು, ನಂತರಕೈತೋಟ ಪದ್ಧತಿಯ ಮಣ್ಣಿನಲ್ಲಿ ಹಾಗೂ ಕೃಷಿ ಮಣ್ಣಿನಲ್ಲಿ ಕನಿಷ್ಠ ಪ್ರಮಾಣದಲ್ಲಿಕಂಡುಬಂದಿದೆ. ಕೃಷಿ ಭೂಮಿಯಲ್ಲಿ ಮರಗಳ ಆಧಾರಿತಕೈತೋಟಅರಣ್ಯ-ಕೃಷಿ ಪದ್ಧತಿಯನ್ನು ಅಳವಡಿಸಿಕೊಂಡಲ್ಲಿ ಮಣ್ಣಿನಲ್ಲಿರುವ ಸೂಕ್ಷ್ಮಾಣು ಜೀವರಾಶಿ ಇಂಗಾಲದ ಮಟ್ಟ ಮತ್ತುಉಪಯುಕ್ತ ಸೂಕ್ಷ್ಮಾಣುಜೀವಿಗಳ ಚಟುವಟಿಕೆಗಳು ಅರಣ್ಯ ಮಣ್ಣಿನ ಹಾಗೆ ಫಲವತ್ತತೆಯನ್ನು ಹೆಚ್ಚಿಸುವುದೆಂದು ಈ ಅಧ್ಯಯನದಿಂದ ತಿಳಿದು ಬರುತ್ತದೆ.

ಆಗಸ್ಟ್, ೨೦೧೮

ಕೃಷಿ ಸೂಕ್ಷ್ಮಜೀವಿಶಾಸ್ತ್ರ ವಿಭಾಗ

ಕೃ.ವಿ.ವಿ., ಜಿ.ಕೆ.ವಿ.ಕೆ., ಬೆಂಗಳೂರು-೬೫

(ಮುತ್ತುರಾಜು. ಆರ್)

ಪ್ರಧಾನ ಸಲಹೆಗಾರರು

Microbial Biomass Carbon Stocks at Home Garden Agroforestry System in Parts of Western Ghats



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Introduction

Carbon emissions are a major contributor to climate change. Forests act as a significant carbon store. 650 billion tons of carbon which is nearly one third of the total in terrestrial ecosystems, are captured in forests. Forest soils also store a quantity of carbon equaling that of the global forest biomass, about 45 % each.

The soil microbial biomass plays an important role in ecosystem function primarily through the regulation of nutrient cycles. In their search for energy to grow, the soil microbial biomass relies on nutrients in the plant litter and soil. Because of its competitive ability, the soil microbial biomass is often considered the source and sink of essential plant nutrients. Carbon stocks in home gardens compared to intensively cultivated agriculture lands, shows the potential of incorporating tree species in crop production systems which slows down depletion of carbon after conversion and also their carbon sequestration potential.

Although the potential of carbon storage in traditional agroforestry systems like home gardens is lower compared to natural forests, it is still high compared to intensively cultivated lands.

Objective

Estimation of microbial biomass carbon stock and nitrogen

Material and Methods

Samples were collected from various parts of Western Ghats viz., Kottayam, Thrissur, Mallapuram, Kannur and Kasargoad of Kerala; Bantawala and Karkala regions of Karnataka.

The microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN) were estimated following chloroform fumigation and extraction method (Carter, 1991). Ninhydrin-reactive nitrogen released during fumigation of the soil was determined using ninhydrin reagent and was used as a measure of the microbial biomass C and N.

- 10 g each of the soil sample was fumigated with ethanol- free chloroform for five days in screw-capped tubes.
- Then the caps were removed and the chloroform was let to evaporate in oven at 40 °C.
- The contents were then extracted with 2M KCl by placing the tubes on a reciprocal shaker for 30 minutes.
- It was then filtered using Whatmann No. 1 filter paper.
- To 2 ml of the extract, 4 ml of freshly prepared ninhydrin reagent was added and the mixture was boiled in a water bath for 20 minutes.
- It was allowed to cool and the volume was made up to 10 ml using a 1:1 mixture of methoxy ethanol and distilled water.
- Purple colour was developed, whose intensity was measured at 570 nm using spectrophotometer.
- Similar procedure was followed for another set without the addition of chloroform.
- A standard curve was developed using five different concentrations of L- Leucine N (3.5- 16.8 µg N ml⁻¹) dissolved in 2M KCl. Absorbance values were compared with the standard curve and the MBC and MBN were calculated using the following formulae:

$$\square \text{MBC} = (a-b)/W \times 24$$

$$\square \text{MBN} = (a-b)/W \times 2.8,$$

where a=Ninhydrin-reactive N in fumigated sample,

b= Ninhydrin-reactive N in unfumigated sample, W=Weight of the soil sample.

Results: The soil microbial biomass carbon and nitrogen in the forest soils were found to be significantly higher than the other land-use systems. The least was found to be in the intensive agriculture system.

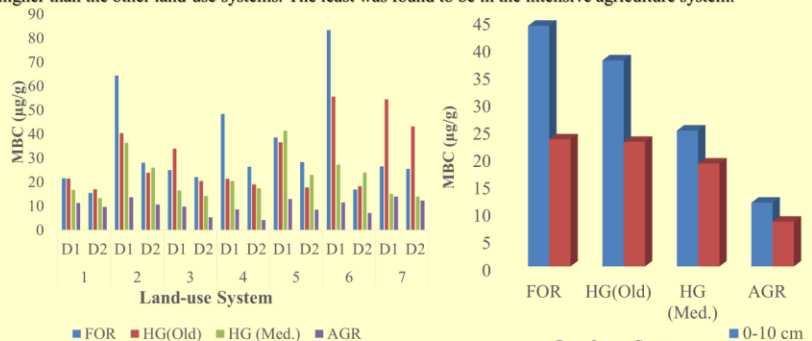


Figure 1. Microbial biomass carbon (µg/g) dynamics under different land-use systems at various depths

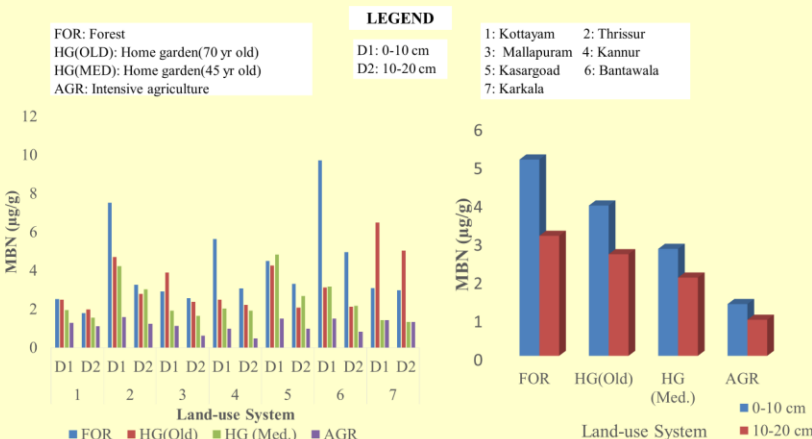


Figure 2. Microbial biomass nitrogen (µg/g) dynamics under different land-use systems at various depths

Discussion

In the current study, the highest soil microbial biomass carbon content was in the forest system (43.94µg/g in depth 1; 22.74µg/g in depth 2) followed by soils of home gardens (37.63µg/g in depth 1; 22.74 µg/g in depth 2 in 70 year old and 24.81 µg/g in depth 1; 18.78µg/g in depth 2 in 45 year old home gardens). The least was recorded in soils of intensive agriculture system (11.64µg/g in depth 1; 8.17 µg/g in depth 2). Low amounts of microbial biomass carbon content in the agricultural soils strongly implies decreased labile C concentrations and thus causing starvation of microorganisms in the soils.

The microbial biomass nitrogen showed a similar trend as the microbial carbon stocks indicating higher microbial biomass nitrogen in the forest soils followed by home garden agroforestry system. And the least was recorded in the agriculture soils.

This study shows that the soil microbial carbon and nitrogen stocks are the highest in the forest soils and that they decrease with soil depth, which is in consistency with the results of studies carried out by Yang *et al.* (2016). Lower decomposition rates of labile carbon in home garden soils suggest that home gardens can decelerate the carbon cycle and improve carbon sequestration in soil compared to intensive agriculture.

Summary

- Intensive agriculture results in significant reduction in soil C stock by the combined effects of rapid decomposition of soil organic matter by intensive ploughing and reduction of C input by roots and aboveground biomass.
- The ever depleting organic carbon stocks and the microbial biomass C and N stocks in soils of intensive agriculture system can be restored to at least near C stocks level as that of the forest soils by implementing semi-natural agroforestry system like home gardens.

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I INTRODUCTION

The soil microbial biomass is the living component of soil organic matter excluding plant roots and macrofauna (Jenkinson and Ladd, 1981). The soil microbial biomass has an important role in the ecosystem function as it regulates the nutrient cycles in soils. In their search for energy to grow, the soil microbial biomass relies on nutrients in the plant litter and in soil. Due to its competitive ability, the soil microbial biomass is considered as a source and sink of various plant nutrients (Horwarth, 2003).

Soils in equilibrium with a natural forest ecosystem have high carbon density. Land use change, particularly conversion to agricultural ecosystems, depletes the soil carbon stock. Thus, degraded agricultural soils have lower soil organic carbon (SOC) stock than their potential capacity. Consequently, afforestation of agricultural soils and management of forest plantations can enhance SOC stock through carbon sequestration. The rate of SOC sequestration and the magnitude and quality of soil carbon stock depend on the complex interaction between climate, soils, tree species and management and chemical composition of the litter as determined by the dominant tree species (Lal, 2004).

Intensive cultivation results in significant reduction in the soil carbon stocks by enhancing rapid decomposition of soil organic matter and by causing erosion. The soil carbon stock is shown to decrease after a land use change from natural and semi natural systems like forests and home gardens respectively to agriculture system. Soil organic matter losses were reported in 5 years in tropical regions and in around 25 years in temperate regions with land use from natural to agriculture system accounting to nearly 50 per cent loss of the native carbon stock due to the combined effect of rapid decomposition of the soil organic matter by intensive ploughing and significant decrease of carbon inputs by roots and above ground biomass (Guo and Gifford, 2002).

Crop production modifies various soil parameters, carbon sources and nutrient availability to the soil microbiota will be affected leading to decrease in the soil microbial biomass. The macro aggregates present in undisturbed soils of natural ecosystems serve as an important protection mechanism against the soil organic matter decomposition that

would otherwise be mineralized under intensive ploughing because of the macroaggregate destruction. The relative inaccessibility and protection of the soil organic matter from microbial and enzymatic attacks are the prime reason for higher carbon stocks in natural and semi natural ecosystems (Sainepo *et al.*, 2018).

Higher amounts of soil organic carbon and microbial biomass carbon stocks in home gardens as compared to intensive cultivated agriculture lands shows the potential of incorporating tree species in crop production systems. It not only helps to slowdown the depletion of carbon after conversion to carbon dioxide but also their carbon sequestration potential will be improved. Although the potential of carbon storage in the traditional agroforestry systems like home gardens is lower in comparison to natural forests, but higher compared to intensively cultivated lands (Murthy *et al.*, 2013).

Labile carbon pool (carbohydrates and microbial biomass) is of utmost importance as it fuels the soil food web and affects nutrient cycling and enhances soil quality and the ecosystem productivity (Hu *et al.*, 1997). The labile carbon pools of soil organic matter are often subjected to oxidation and drives the carbon dioxide flux from soils to the atmosphere, making way for global warming. Lower decomposition rates of labile carbon pool in home garden soils suggests that home gardens can decelerate the carbon cycle and improve carbon sequestration in soil compared to intensive agriculture practices.

The current study was undertaken to know the variations in soil microbial biomass carbon stocks with different land-use systems and at different soil depths. The research was conducted at the Department of Agricultural Microbiology, GKVK, Bengaluru with the following objectives:

1. Estimation of soil microbial biomass C, N and P in home garden agroforestry system.
2. Enumeration of functional groups of microorganisms in the soils of home garden agroforestry system.
3. To study the soil enzyme activities of the home garden agroforestry system.

II REVIEW OF LITERATURE

The key components of soil quality are the microbial biota, in particular the microbial component that plays a very significant role in sustainable systems (Herrick, 2000). Thus, conservation and sustainable management of the soil microbial biomass becomes very important for sustaining ecological balance. The information available on the microbial biomass carbon stocks in home garden agroforestry system in parts of Western Ghats is reviewed under the following headings:

2. 1. Effect of land-use change on the soil carbon stocks

Land-use changes may lead to increased soil organic carbon (SOC) stocks. Paul *et al.* (2002) observed increase in soil organic carbon when cropland was converted into grassland or afforested. However, the estimates of soil organic carbon losses and gains are subject to large errors and methodological bias (Goidts *et al.*, 2009) and the susceptibility of SOC to land-use change in tropical soils is insufficiently quantified. The estimated errors of the IPCC default values (Good Practice Guidelines) for SOC stock changes after land-use change are three to four times higher for tropical than for temperate regions (Penman *et al.*, 2003).

Tropical soils are estimated to emit 0.2 Gt carbon every year due to land-use changes, accounting for 10–30 per cent of the total C emission from deforestation (Achard *et al.*, 2004).

The dominant type of land-use change is the conversion of forest to agricultural systems with continuously high rates of 13 million hectare being deforested per year. Governmental measures to reduce deforestation have been effective only in some countries such as Costa Rica and India during the last year. The destruction of primary forest causes a rapid biomass carbon loss that is accompanied by a carbon loss from soils. A shift from higher to lower average total ecosystem carbon stocks increases in atmospheric CO₂. Soils are major carbon stores in tropical areas, with 36–60 per cent of ecosystem carbon in forests being stored in soil (FAO, 2006).

The reduction of land-use changes that lead to carbon losses from soils and biomass could be a substantial and economically sound contribution to reduce greenhouse gas emissions (Kindermann *et al.*, 2008). Avoiding deforestation activities could reduce anthropogenic carbon emission by 0.8–1.3 Gt C per year. The most cost-effective way to reduce carbon emissions can be achieved, if under a full carbon accounting scheme all major effects of human activities are included and reported. The land-use induced changes in biomass and SOC stocks are the major uncertainty in such accounting schemes and in life cycle assessments of tropical agricultural products.

Land-use changes in the tropics are responsible for 12–20 per cent of the human induced greenhouse gas emissions and are expected to remain the second largest source of greenhouse gas emission for the future (Werf *et al.*, 2009).

2.1.1. Significance of home gardens in maintaining soil carbon stocks

Home garden refers to the cultivation of a small portion of land which may be around the household or within working distance from the home. Home gardens can be described as a mixed cropping system that encompasses vegetables, fruits, plantation crops, spices, herbs, ornamental and medicinal plants grown in vicinity of the house, that can serve as a supplementary source of food and income to the family and are with low capital and simple technology.

Home gardens have a special role in carbon sequestration because of their ability for carbon storage in the standing biomass, soil and wood products and therefore reduces carbon dioxide concentration in the atmosphere. Removal of CO₂ from atmosphere through photosynthesis and its eventual storage in biomass and soil as organic matter is important.

At first sight, home gardens seem to lack structure as trees, shrubs and herbaceous plants grow in a complex mixture without any clear pattern (Brierley, 1976). However, a closer look at the vegetation shows that plants do seem to be organized in different patterns or layers. Thus, home gardens are also called as ‘multi-tier cropping’ as it

consists of different canopy strata. For instance, five canopy strata have been identified in the home gardens of Kerala.

It is a traditional land use practice around a homestead where several plant species are maintained by members of the household and their products are intended primarily for their consumption (Shrestha *et al.*, 2001). Home gardens occupies an area around 0.20 to 0.50 ha. In addition to efficient nutrient cycling, high biodiversity, low use of external inputs and soil conservation potential, they provide a diverse and stable supply of socioeconomic products and benefits to the families that maintain them.

Home garden agroforestry system has high carbon storage (sequestration) potential in their multiple plant species, especially in wood perennial species, and soil which help in conservation of carbon stock in existing forests by alleviating the pressure on natural forest (Schroth *et al.*, 2004).

Kumar *et al.* (2006) reported that home gardens are considered to have high carbon sequestration potential (CSP) due to their forest- like structure and composition and also due to specific management practices like addition of domestic wastes like kitchen wastes and so on, that tend to enhance nutrient cycling and increase soil organic matter, to some extent, help in carbon substitution by reducing fossil-fuel burning through promotion of wood fuel production. Most reports indicated that the addition of a large proportion of the relatively high quantity of plant materials produced in a system will increase carbon stock in soils (Lal, 2004). Therefore, it is reasonable to state that home gardens will help substantially in carbon sequestration (Kumar, 2006).

They are the most elaborate man made, tree-crop-animal associations, and as such the only agroforestry system which can claim a resemblance to natural forests. Hence their alternative name is “Agroforestry” (Torquebiau and Penot, 2006).

In spite of the prehistoric origin of the practice, accurate data on the extent of area under home gardens is not available. Estimating the area of home gardens is beset with several problems (Kumar, 2006).

The lack of boundaries between home gardens and adjoining agricultural fields makes it difficult to determine where home gardens end and other cultivated fields begin (Abebe *et al.*, 2006). Some efforts have been made in compiling statistics on the spread of home gardens. Such estimates include 5.13 million hectare of land under Pekarangans in Indonesia, 0.54 million ha under homesteads in the Bangladesh, 1.05 million ha in Sri Lanka and 1.44 million ha in Kerala, India (Kumar, 2006). For instance, in Kerala, homestead farming covers about 88 per cent of the total landholding and about 41 per cent of the total cultivable area of the Kerala (KLUB, 1989), while it covers about 14 per cent of the total area of the Sri Lanka (Senanayake *et al.*, 2009).

How much carbon could potentially be accumulated and stored in above and below ground compartments of an agroforestry system under different conditions of ecology and management is estimated to range from 0.29 to 15.21 Mg per hectare every year in the above ground biomass and 30– 300 Mg per hectare up to 1 meter depth in the soil (Nair *et al.*, 2010).

Agroforestry attracted special attention as a carbon sequestration strategy following its recognition of carbon sequestration activity under the afforestation and reforestation activities of the Kyoto protocol. This was in recognition of the perceived advantages of the large volume of above ground biomass and deep root systems of trees in accomplishing that task. The amount of carbon in the above ground and below ground biomass of an agroforestry system is generally much higher than in an equivalent land-use system without trees (Murthy *et al.* 2013).

In another estimate agroforestry contributes 19.30 per cent of total carbon stock under different land uses. The potential of agroforestry systems as carbon sink varies depending upon the growth and nature of the tree species, species composition, age of trees, geographic location, local climatic factors and management regimes. The growing body of literature indicates that agroforestry systems have the potential to sequester large amounts of above and below ground carbon in addition to soil organic carbon enhancement as compared to treeless farming systems. Most of these available reports on

carbon sequestration in agroforestry systems are estimates of carbon stocks (Ajit *et al.*, 2013).

To strengthen local food production in order to feed the growing populations, there is much attention towards home gardens as a strategy to enhance household food security and nutrition (Dilrukshi *et al.*, 2013). Home gardens also provide additional benefits such as income and livelihood for poor families.

Discussions related to importance of carbon sequestration of home gardens and indeed agroforestry systems in general are based more on hypothetical considerations than empirical results. The role of land use systems in capturing atmospheric carbon dioxide and storing the C in plant parts and soil became an important area of research during the past decade. Agroforestry systems have indirect effects on carbon sequestration because they reduce harvesting pressure on natural forests which are the largest sinks for terrestrial carbon (Kumar, 2015).

Home gardens agroforestry system is one of the most prevalent types of land use systems suitable to high rainfall areas in tropical conditions. It represents intimate, multi-storied combinations of various perennial and annual crops, sometimes in association with domestic animals, around the homestead. Traditional resource management adaptations such as home gardens in agroforestry systems may potentially provide options for improvement in livelihoods through simultaneous food production (either directly food grains, fruits, vegetables and root crops or indirectly improving soil conditions and there by promoting understory crop productivity especially on degraded sites), fodder and firewood, high biodiversity, low use of external inputs, soil conservation potential, nutritional security, ecological benefits, socio-cultural as well as mitigation of the impact of climate change. By providing supportive and complementary roles with a flexible approach, it offers specific social and environmental benefits across a range of landscapes and economies (Kumar, 2015).

Hombegowda *et al.* (2016) reported that the establishment of home garden agroforestry system on agriculture land caused soil organic carbon (SOC) stocks to

rebound to near-forest levels. The most important variable regulating SOC stocks and its changes was tree basal area, possibly indicative of organic matter inputs. Furthermore, climatic variables such as temperature and precipitation, and soil variables such as clay fraction and soil pH were likewise important regulators of SOC stock changes. Strong correlation was found between tree species diversity in home garden with the SOC stocks indicating possibilities to increase carbon stocks by proper tree species assemblies.

2. 2. Soil microbial biomass

The microbial activity is found to be influenced by the type of vegetation, substrate availability and abiotic factors in an ecosystem (Gupta and Singh, 1981). The most practicable and general measure of biological status of soil is the soil microbial biomass (Jenkinson, 1988). It plays a key role in soil nutrient transformations and largely controls the rate of C, N and other nutrient cycles.

Saranath and Singh (1995) reported that the microbial biomass carbon, nitrogen and phosphorous were maximum in forest and minimum in cropland soils. There was a decrease in the quantities of the microbial carbon, nitrogen and phosphorous along the forest- cropland gradient which can be attributed to the reduction in the total soil organic matter. Total soil organic C and total N showed significant positive relations with microbial C and N, denoting that the latter are limited by the magnitude of the soil organic matter.

Microbial biomass carbon, nitrogen and phosphorous are the most biologically active fraction of the soil organic carbon. They can therefore be used as suitable indices for assessing the soil health of various soil ecosystems (John and Adeniyi, 2005).

Barbhuiya *et al.* (2005) reported that the microbial biomass carbon, nitrogen and phosphorous was higher in undisturbed ecosystem (forest) than the disturbed ecosystem (crop land). Microbial biomass was negatively correlated with soil temperature and pH. Percentage contribution of microbial biomass carbon to organic carbon was higher in undisturbed ecosystem. The disturbed ecosystems had the lowest labile fractions of soil organic matter which may recover at lower rates. The soil microbial biomass was found

to be lesser during rainy season due to greater demand for nutrients by plants which limits the availability of nutrient to soil microbes, and therefore leading to lesser microbial biomass carbon, nitrogen and phosphorous.

2.3. Functional groups of microorganisms

The versatility and abundance of microorganisms are very high in the rhizosphere, which is the volume of soil influenced by plant roots where significant microbial activities occur (Hiltner, 1904).

The diversity of plant communities in forests and agroecosystem has received a great deal of scientific attention but the microbial diversity is often ignored. Dick (1992) described that soil is a fundamental component of agroecosystem. It acts as a biological entity with complex biochemical reaction. They are driving force of most terrestrial ecosystems, because of their capacity to regulation the rate of mineralization of organic substrates (Killham, 1994) and can perform important functions in the ecosystem. Little is known of the importance of the functional diversity of soil microbial communities for the sustained functioning of terrestrial ecosystems (Pankhurst *et al.*, 1996). Giller *et al.* (1997) reported the importance of microbial diversity in the functioning of soil.

The living population inhabiting soil includes macrofauna, mesofauna, microfauna and microflora. The relationship between microbial diversity and soil functionality is important because 80–90 per cent of the processes in soil are mediated by microbes (Nannipieri *et al.*, 2003). Bacteria and fungi are highly versatile. They can carry out almost all known biological reactions. The determination of the composition of microbial communities in soil is necessary for a better quantification of nutrient transformations. The soil microbial biomass varies with seasons.

Microbial communities are important for the functioning of the ecosystem (Patra *et al.*, 2005), both in relation to direct interactions with plants and with regard to nutrient and organic matter cycling. They are involved in the fundamental activities that ensure the stability and productivity of both agricultural systems and natural ecosystems.

The plant roots serve as ecological niche to many microorganisms in the rhizosphere. Carbon input by plants into soil through rhizodeposition is the primary source of the soil organic matter. These exudations by the plant roots induce fast carbon turnover in the root vicinity. The rhizosphere microorganisms utilize these substances as carbon and energy sources for their growth and reproduction. This increase in population results in increased soil microbial biomass which serves as a temporary reservoir of labile nutrients. This increase in microbial population accounts to increase in various other biological activities in the soil such as enzyme activities, mineralization capabilities, rate of nitrification, which in turn influence soil fertility. These biological parameters can also be used as effective indicators for assessing soil quality (Kaur *et al.*, 2005). Thus, the microflora of rhizosphere influence plant growth in many ways as all plant nutrients pass through it.

It is known that microorganisms can make nutrients available to plant by different mechanisms (Zhao *et al.*, 2016). In the soil, it is possible to find various types of microorganisms such as bacteria, fungi, actinomycetes, protozoa, and algae which bacteria are by far the most common (i.e., ~ 95%). There are an estimated sixty thousand different types of bacteria present in the soil, most of which have yet to be even named and each has its own particular roles and capabilities. The number and diversity of bacteria are influenced by the soil conditions such as organic carbon, temperature, moisture, electrical conductivity and other chemicals as well as by the number and types of plants found in those soils.

Soil microorganisms constitute a major portion of the biodiversity in soils and play a pivotal role in soil processes (Philippot *et al.*, 2013), which ultimately affect the functioning of terrestrial ecosystems.

Much of the nutrient cycling and carbon processing in natural environments occur through the activities of extracellular enzymes released by the microorganisms. These enzymes typically hydrolyze the polymers into smaller units that can be taken into the cells (Colin *et al.*, 2013). Microorganisms hence, by virtue of their enzymes are

responsible for various soil processes like nutrient mineralization and organic matter decomposition occurring in soils.

2.3.1. Nitrogen fixing microorganisms

Tropical forests are characterized by relatively high precipitation, low annual temperature fluctuation, high heterogeneity in plant diversity, large amounts of plant litter and unique soil chemistry. For these reasons, regulation of the nitrogen cycle in tropical forests may be very different from that of other ecosystems. This is of great importance because of growing concerns regarding the effect of land use change and elevated nitrogen deposition on nitrogen-cycling processes in tropical forests. In the context of global change, it is crucial to understand how environmental factors and land use changes in tropical ecosystems influence the composition, abundance and activity of key players in the nitrogen cycle.

In contrast to temperate forests, tropical forests have highly weathered soils which are primarily limited by P and N saturation leading to an open dynamic N cycle, with relatively high levels of nitrogen loss *via* denitrification and leaching (Brookshire *et al.*, 2012) balanced by high levels of nitrogen fixation.

Tropical soils are generally formed from older geologic substrates depleted of rock-derived elements such as phosphorus and other cations. Therefore, these soils are typically acidic and their fertility is often dependent on the cycling of a thin layer of organic matter associated with the large amount of plant litter material (Macrae *et al.*, 2013).

Nitrogen is an important component of proteins and nucleic acids and thus is an essential nutrient for all organisms. Furthermore, the nitrogen supply to organisms regulates primary productivity in any ecosystems. In nature it exists in multiple oxidation states and chemical forms. Transformations among these different forms are typically catalyzed by microorganisms (Hayatsu *et al.*, 2008).

The understanding of biological N cycling in soil ecosystems has been improving with the growing interest in integrating evolutionary and ecological theory into microbial ecology (Prosser *et al.*, 2007), the rapid development of molecular-based culture-independent methods (Caporaso *et al.*, 2011) and the use of N isotope tracer techniques (Kool *et al.*, 2010). These advances help us to understand microbial communities, their functional potential, physiological state and this has sparked a new interest in the functional link between soil microbial community structure and N cycling (Cusack *et al.*, 2011). It has led to understanding of the microbial community ecology involved in N processes in forest and agroforestry ecosystems, which provide a complete picture of the regulation of the N cycle and its response to environmental change.

In the tropics, active denitrification and intense leaching often decrease the effectiveness of nitrogen fertilizers to well below the level obtained in temperate climates.

This fact, with the high price of nitrogen fertilizers in many developing countries, challenge the wisdom of using the chemical approach in tropical forestry and agroforestry, which means that further efforts to improve biological nitrogen fixation are more than justified. Highly active nitrogen-fixing systems that can withstand the diverse and often harsh conditions of the tropics are not yet available, but by carefully selecting the genotypes of the symbiotic microorganisms and those of the host plant, the nitrogen-fixing potential of soils can be improved.

It is generally conceded that the contribution of the non-symbiotic nitrogen-fixing microflora to arable soils is small. However, in uncultivated soils where organic matter is not removed, non-symbiotic nitrogen additions may be significant. Moor (1974) summarized the reports of non-symbiotic nitrogen fixation in various soils and indicated total nitrogen gains from 10 to 50 kg/ha/year on temperate forest sites. Tropical rain forests were generally shown to have even higher accretion rates.

2.3.2. Phosphate solubilizing microorganisms

The plants acquire P from soil solution as phosphate anions. But they are extremely reactive and may be immobilized through precipitation with cations such as calcium, magnesium, iron and aluminium depending on particular properties of a soil. In these forms P is highly insoluble and a large portion of soluble inorganic phosphate applied to soil as chemical fertilizers is immobilized rapidly and becomes unavailable to plants (Goldstein, 1986). Therefore, the quantity available to plants is usually a small portion of its total application.

Kucey *et al.* (1989) reported a significant correlation between number of phosphate solubilizing bacteria and the levels of total p in soil suggesting that insoluble phosphates are solubilized by microorganisms.

The involvement of microorganisms in solubilization of insoluble phosphates was first shown by Stalstrom (1903). The phosphate solubilizing microorganisms represent 26-46 per cent of the total soil microflora (Chabot *et al.*, 1993). The population of inorganic phosphate solubilizing microorganisms are sometimes very low and sometimes even less than 10^2 CFU per gram of soil as observed in Northern Spain (Petix *et al.*, 2001).

2.3.3. Potassium solubilisers

After nitrogen and phosphorous, potassium (K) is the most important plant nutrient that has a key role in the growth, metabolism and development of plants. In addition to increasing plant resistance to diseases, pests and abiotic stresses, K is required to activate over 80 different enzymes responsible for plant and animal processes such as energy metabolism, starch synthesis, nitrate reduction, photosynthesis and sugar degradation (Almeida *et al.*, 2015)

It is proven that microbial soil community is able to influence soil fertility through soil processes viz. decomposition, mineralization, and storage and release of nutrients (Parmar and Sindhu, 2013). It was reported that some beneficial soil

microorganisms, a wide range of saprophytic bacteria, fungal strains and actinomycetes, could solubilize the insoluble K to soluble forms of K by various mechanisms including production of inorganic and organic acids, acidolysis, polysaccharides chelation and exchange reactions.

The K solubilizing bacteria (KSB) are effective in releasing K from inorganic and insoluble pools of total soil K through solubilization (Archana *et al.*, 2013). It has been reported that inoculation with KSB produced beneficial effect on growth of different plants (Ahmad *et al.*, 2016).

K solubilization is done by a wide range of saprophytic bacteria, fungal strains and actinomycetes (Bakhshandeh *et al.*, 2017). There are strong evidences that soil bacteria are capable of transforming soil K to the forms available to plant effectively (Meena *et al.*, 2015). There is considerable population of KSB in soil and in plant rhizosphere. These include both aerobic and anaerobic isolates but the most frequently found KSB in soil are aerobic. A considerably higher concentration of KSB is commonly found in the rhizosphere in comparison with non-rhizosphere soil (Padma and Sukumar, 2015). Solubilization of K by KSB from insoluble and fixed forms is an import aspect regarding K availability in soils. The ability to solubilize the silicate rocks is known in *B. mucilaginosus*, *B. circulanscan*, *B. edaphicus* etc. KSB are usually present in all soils and have been isolated from rhizosphere soil, non-rhizosphere soil, paddy soil (Bakhshandeh *et al.*, 2017) and saline soil (Bhattacharya *et al.*, 2016).

2.3.4. Cellulose degrading microorganisms

Cellulose is a polymer of glucose and is the most abundant organic material in nature. But it is relatively resistant to decomposition. A large number of bacteria, fungi and actinomycetes are involved in their degradation. The decomposition of cellulose is carried out by a set of enzymes called cellulases. The cellulose in the plant debris has to be degraded to glucose, cellobiose and low molecular weight oligosaccharides by cellulase enzymes which is produced by certain soil microorganisms. Most cellulolytic

bacteria do not excrete significant amounts of cellulases, but fungi are found to produce it appreciably.

Cellulases are a group of enzymes that catalyze the degradation or breakdown of cellulose, a polysaccharide build-up of β -1,4 linked glucose subunits. Cellulases in soils are derived mainly from plant debris incorporated into the soil and a limited amount may also originate from fungi and bacterial community in the soils (Richmond, 1991).

Hatami *et al.* (2008) studied the cellulolytic bacterial diversity in soil samples from forest and farming soils and found that the cellulose degrading bacterial population in forest soils were more than that in the farming soils.

2.3.5. Lignin degrading microorganisms

Lignin is often the most difficult portion of plant biomass to degrade, with fungi generally thought to dominate during late stage decomposition. Lignin in feedstock plant material represents a barrier to more efficient plant biomass conversion and can also hinder enzymatic access to cellulose.

The microbial degradation of lignin has been well studied in white-rot and brown-rot fungi. It is less studied in bacteria. A range of soil bacteria, often aromatic-degrading bacteria, are able to break down lignin. The extracellular peroxidase and laccase enzymes appear to be involved. Bacteria are involved in the degradation and modification of lignin in nature. Many strains are able to metabolize lignin-related compounds and some of them also mineralize and solubilize polymeric lignin. Cleavage of the different types of linkages in lignin, oxidations, demethylations and aromatic ring cleavages are catalyzed by bacterial enzymes.

Crawford and Crawford (1976) reported that lignin mineralization by the soil actinomycete, *Streptomyces viridosporus*, was optimal at a neutral to slightly acidic pH.

The vast majority of carbon stored in terrestrial ecosystems is stored as woody material in the earth's forests. Lignocellulosic components of plant tissues are the most

abundant organic compounds on earth; of this approximately 25 per cent is lignin. Lignin concentration is a major factor that controls organic matter decomposition rates. Soil temperature is a major abiotic factor influencing lignin degradation in forest ecosystems. The bulk of lignin degradation was found not to be at the peak of organic matter decomposition and microbial activity, but during the summer season. It was found that lower pH soils had decreased lignin degradation as compared to a neutral to slightly alkaline soil. In comparing two different ecosystems, he suggested that organic acids present in the more acidic ecosystem were suppressing microbial lignin degradation (Benner *et al.*, 1986).

Moisture and pH may be important factors in cellulose and lignin degradation and thus also in the release of CO₂ from the earth's carbon terrestrial sinks. Decomposition rates of leaf litter have been predicted from the leaves' lignin or nutrient (N or P) contents, the C:N ratio, and the lignin: N ratio (Taylor *et al.*, 1989).

The concentration of lignin in plant tissue is a major factor controlling organic matter degradation rates in forest ecosystems. Microbial biomass and lignin and cellulose decomposition are not significantly affected by soil acidity. Microbial biomass was greater at higher soil moisture contents. Lignin and cellulose decomposition significantly increased at higher soil temperatures and moisture contents. Soil moisture was more important in affecting microbial biomass than either soil temperature or soil pH (Donnelly *et al.*, 1990).

2. 4. Soil enzymes

Soil may be thought as a biological entity (a living tissue with complex biochemical reactions). Soil contains free enzymes, immobilized extracellular enzymes stabilized by three-dimension network of macromolecules and enzymes and enzymes with microbial cells (Skujins, 1978). It is well known that enzymes, which are proteins with catalytic properties owing to their specific activation energy, catalyse all biochemical reactions. Enzymes are catalysts which without undergoing permanent

alterations, cause chemical reactions to proceed at faster rates. In addition, they are specific to the type of chemical reactions in which they participate (Tabatabai, 1982).

Soil enzymes respond to soil management changes long before other soil quality indicators changes are detectable. These play important role in organic matter decomposition and nutrient cycling. With the exception of phosphatase activity, there is no strong evidence that directly relates enzyme activity to nutrient availability or crop productivity.

The enzymes produced by the proliferating microorganisms mediate many processes occurring in soils. These enzymes are substrate specific and act from either from outside or inside the living cells. Any threat to microbial activity is reflected in the biochemical transformation occurring in soils. Variations in the microbial populations might result in an alteration of the overall soil enzymatic activity. Enzymes have biological significance as they participate in the biological cycling of elements. They play a very important role in the initial phases of decomposition of organic residues and transformation of some of the mineral compounds (Harrison, 1979).

2.4.1. Soil urease activity

Urease enzyme is responsible for the hydrolysis of urea fertilizer applied to the soil into ammonia and carbon dioxide, with concomitant rise in the soil reaction leading to rapid loss of N to atmosphere through ammonia volatilization. Generally, urea is the main source of N in many crops. Despite the importance of this fertilizer, its efficiency has been reported to be low due to substantial amounts of N lost due to volatilization as ammonia in a process mediated by the urease enzyme (Tabatabai, 1982).

Urease activity in soil may originate from plant residues, animal waste or soil microbes. Plants are also a rich source, but there is no production of ureases by plant roots. Soil bacteria like *Nitrosomonas* and *Nitrospira* are known to produce ureases. The ability to hydrolyze urea is found to vary from 17-77 per cent by soil bacteria and from 78- 98 per cent by soil fungi. Soil ureases originate mainly from plants and microorganisms, found as both intra and extracellular enzymes (Burns, 1986).

With regard to its stability, it has been studied that extracellular urease associated with soil organo-mineral complexes is more stable than urease in the soil solution and the humus-urease complexes extracted from soil are highly resistant to denaturing agents like extreme temperatures and proteolytic enzyme attack. On the other hand, urease extracted from plants or microorganisms is rapidly degraded by proteolytic enzymes in soil (Zantua and Bremner, 1977). This suggests that a significant fraction of ureolytic activity in soil is carried out by extracellular urease which is stabilized by immobilization.

2.4.2. Soil dehydrogenase activity

Soil dehydrogenases are the major representatives of the oxidoreductase enzyme class. Among all enzymes in the soil environment, dehydrogenases are one of the most important and are used as an indicator of overall soil microbial activity (Salazar *et al.*, 2011). This is because they occur intracellularly in all living microbial cells and tightly linked with microbial oxidation processes and do not accumulate extracellularly in soils (Das and Varma, 2011).

Dehydrogenases are an integral part of microorganisms and are involved in organic matter oxidation; nevertheless, this activity is not consistently correlated with other properties of biological systems such as oxygen consumption, carbon dioxide production or microbial biomass (Dick *et al.*, 1996). However, it has been considered as a soil quality indicator, because it is involved in electron transport systems of oxygen metabolism and requires an intracellular environment to express its activity (Kandeler *et al.*, 2007).

Dehydrogenases play an important role in the biological oxidation of soil organic matter by transferring hydrogen from organic substrates to inorganic acceptors (Zhang *et al.*, 2010) like nicotinamide adenine dinucleotide (NAD) or its phosphate (NADP).

The overall dehydrogenases activity of a soil depends on the activities of various dehydrogenases, which are fundamental part of the enzyme of all living microorganisms like enzymes of the respiratory metabolism, the citrate cycle, and N metabolism (Subhani *et al.*, 2011). Thus, dehydrogenase activity serves as an indicator of the microbiological

redox systems and could be considered a good and adequate measure of microbial oxidative activities in soil. It also reflects metabolic activity of the soil and its activity is considered to be proportional to the biomass of the microorganisms in soils.

2.4.3. Soil phosphatase activity

Alkaline and acid phosphatases are phosphomonoesterases which act on a range of low molecular weight P compounds with monoester bonds, including mononucleotides, sugar phosphates and polyphosphates (Reid and Wilson, 1971). They are also involved in the degradation of phosphodiesteres like phospholipids and nucleic acids, which constitute the majority of the fresh organic P inputs to soil (Congrove, 1967). Initially the phosphodiesterases act on it and release phosphate monoester which then will be hydrolyzed by phosphomonoesterases to release free phosphate for biological uptake (Turner and Haygrath, 2005).

The activity of acid and alkaline phosphatase is found to be correlated with the soil organic matter content. Another factor that influences the rate of synthesis, release and stability of phosphatases is the soil pH. Their inducibility, release and exudation intensity by plant roots and soil microorganisms are determined by their need for orthophosphate which is in turn affected by soil reaction or pH (Aon and Colaneri, 2001).

Acid phosphatases generally prevail in acidic soils, whereas alkaline phosphatases in alkaline soils and hence their activities are negatively correlated. It is a well-established fact that phosphatase activities are correlated with the content of organic matter in soil. Agroforestry systems with higher organic matter content have greater phosphatase activities which help to mobilise and utilize the organic P in the soils to greater extents (Tabatabai and Dick, 1979).

Iqbal *et al.* (1998) reported that the activity of phosphatases was negatively correlated with soil pH and inversely correlated with electrical conductivity. The activity had a direct relationship between soil organic matter, nitrogen and bacterial population in the soils.

Margalet *et al.* (2017) reported that phosphatase activity in tropical and subtropical ecosystems strongly depend on the total soil nitrogen content. Its activity was higher in forest soils compared to grasslands and the least was in agriculture lands.

III MATERIAL AND METHODS

The present investigation, “Microbial biomass carbon stocks at home garden agroforestry system in parts of Western Ghats” was conducted in soils collected from seven locations of Kerala and Karnataka. The soil samples were air dried in shade, passed through two mm sieve and subjected to microbiological, biochemical and physicochemical analysis in the laboratory of the Department of Agricultural Microbiology, UAS, GKVK, Bengaluru.

3.1. Sampling details

The study was conducted across two states in southern India (Table 2) in an area that has a long-standing history of diverse agroforestry-based land-use practices. The region has a tropical monsoon climate. The mean annual precipitation ranged from 627 to 3422 mm and mean annual temperature ranged between 21.9 °C to 27.2 °C (Hijmans *et al.*, 2005).

In each plot soil samples were taken using a soil auger from 12 fixed locations around the plot at predefined soil depths (0-10 and 10-20 cm). The samples for each respective depth were pooled and thoroughly mixed to obtain a representative sample. The treatment details are presented in Table 01.

Table 1. Treatment details

Sl. No.	Treatments	Particulars
01.	Treatment 1	Forest ecosystem
02.	Treatment 2	Home gardens (75 year-old)
03.	Treatment 3	Home gardens (45 year-old)
04.	Treatment 4	Agriculture system

The forest plots of our study were most often community managed and considered “sacred groves”. For religious reasons people do not remove any wood from there. The remaining forests which we sampled were government owned; these too were relatively

undisturbed. Evergreen forests were found in humid climate, moist deciduous forest in moist sub-humid climate zone.

Table 02. Location details of the study area

Sl. No.	Location	Lattitude	Annual Rainfall (mm)	Mean Temp. (°C)
1	Kottayam, Kerala	9.5947°N 76.4855°E	2604	27.3
2	Thrissur, Kerala	10.52°N 76.21°E	3556	27.6
3	Mallapuram, Kerala	10°47'8.16"N 79°8'24.36"E	3057	27.6
4	Kannur, Kerala	11.8689°N 75.3555°E	2634	27.5
5	Kasargoad, Kerala	12.5°N 75.0°E	2986	27.7
6	Bantawala, Karnataka	12.8936°N 74.9947°E	4178	26.7
7	Karkala, Karnataka	13.2°N 74.983°E	4528	26.8

Agriculture in these regions is only practiced by small-holder farmers. Here, staple foods like tubers and vegetables for subsistence use were grown, with only organic matter inputs as nutrient supplement sources. During agriculture established forests were cleared using hand tools and most aboveground biomass was removed for domestic use. Sites were not burnt. Through informal interviews with the land owners we got information on current and past land uses and their management practices.

The home garden AFS has a multilayered canopy, consisting of a diverse tree admixture of different ages and sizes. The multipurpose trees grown here are found in association with shrubs and herbaceous species (Kumar *et al.*, 1994). The majority of households in the humid and moist sub-humid climate zones manage home garden AFS to satisfy their fruit, spice and vegetable needs (such as cassava, banana and ginger). For management, farmers loosen the soil once a year during vegetable cultivation. It consisted of a unique combination of trees and crops (*Artocarpus spp.*, *Mangifera indica*,

Myristica spp. and other mixed species) and originated from former agricultural land and some had replaced forests directly.

Meteorological data such as mean annual temperature and mean annual precipitation for the selected plots were retrieved from the World Clim database (Hijmans *et al.*, 2005). Each location cluster consisted of four land-use types: a natural forest reference and an agriculture reference and two home garden agroforestry plots at different ages: medium (45 years) and old (75 years).

3.2. Soil physicochemical properties

3.2.1. Soil reaction and Electrical conductivity

Soil pH was measured in 1:2.5 soil: water suspension, using pH meter (Jackson, 1967). The clear supernatant solution of the above soil - water suspension was taken out and the electrical conductivity was measured using conductivity bridge (Jackson, 1967).

3.2.2. Soil organic carbon

Soil organic carbon was estimated by Walkley and Black's wet oxidation method.

3.2.3. Available nitrogen

Twenty gram of soil was distilled with 100 mL of 0.32 N KMnO_4 and 100 mL of 2.5 per cent NaOH. The ammonia released during distillation was trapped in 4 per cent boric acid solution containing mixed indicator and titrated against standard H_2SO_4 (Subbiah and Asija, 1956).

3.3. Soil biochemical analyses

3.3.1. Microbial biomass C and N

Microbial biomass was estimated following chloroform fumigation and extraction method as proposed by Carter (1991). Ninhydrin- reactive nitrogen released



Plate 1. Overview of home garden agroforestry system

during the fumigation of the soil samples was determined using Ninhydrin reagent and the same was used as a measure of microbial biomass (C, N).

Each soil sample was divided into two sets; one set was fumigated with ethanol-free chloroform, while the other set was used unfumigated. 10 gram each of the soil sample was fumigated with ethanol-free chloroform for five days in screw-capped tubes. Then the caps were removed and the tubes were kept overnight in an oven at 40⁰ C to remove all the chloroform. The contents were then extracted with 2M KCl by placing the tubes on a reciprocal shaker for 30 minutes. The suspension was then filtered using Whatman No. 1 filter paper. In a similar manner, unfumigated set of the same soil samples were extracted. To a known volume of the filtrate, 4 mL of freshly prepared ninhydrin reagent was added and the mixture was boiled in a water bath for 20 minutes. The contents were then allowed to cool and the volume was made up to 10 mL using a 1:1 mixture of methoxy ethanol and distilled water. Purple colour was developed. The intensity of the purple colour developed was recorded using a Bosch and Lamb spectrophotometer at 570 nm wavelength. A standard curve was developed using five different concentrations of L- Leucine N (3.5- 16.8 microgram N mL⁻¹) dissolved in 2M KCl. Absorbance values were compared with the standard curve and the microbial biomass C and the microbial biomass N were calculated using the following formulae:

$$\text{Biomass C g}^{-1} \text{ soil} = \frac{\text{Ninhydrin reactive-N in unfumigated soil} - \text{Ninhydrin reactive-N in fumigated soil}}{\text{Weight of soil sample}} \times 24$$

$$\text{Biomass N g}^{-1} \text{ soil} = \frac{\text{Ninhydrin reactive-N in unfumigated soil} - \text{Ninhydrin reactive-N in fumigated soil}}{\text{Weight of soil sample}} \times 2.8$$

3.3.2. Microbial biomass P

The microbial biomass P in the samples was determined as per the procedure given by Brookes *et al.* (1982). Three sets of each sample containing 10 gram of oven dried soil was taken in screw cap tubes. The first set was fumigated with chloroform for five days and the other two sets were incubated aerobically for the same period. Following this, the first and the second sets were extracted with Bray's extracting solution (0.03 N NH_4F in 0.25 N HCl) and the third set was extracted with Bray's extracting solution spiked with inorganic P (as KH_2PO_4 equivalent to $25 \mu\text{g P g}^{-1}$ of oven dry soil). The tubes were then shaken for 30 minutes on a reciprocal shaker. The suspension was filtered using Whatman No. 1 filter paper. To a known aliquot of the filtrate,

5 mL of chloromolybdic acid was added and the contents were mixed thoroughly till the evolution CO_2 ceased. To this, 1 mL of working solution of stannous chloride was added and the volume was made up to 50 mL using distilled water and the contents were mixed well. The intensity of the colour developed was read at 660 nm using a Bosch and Lamb spectrophotometer. The value of P in the three sets were determined by comparing these values with a standard curve developed similarly using KH_2PO_4 .

The microbial biomass P content of the sample was calculated as

$$\text{Biomass P g}^{-1} \text{ soil} = \frac{25 (b-a)}{0.4 (c-a)}$$

Where a = P extracted from the unfumigated soil

b = P extracted from the fumigated soil

c = P extracted from the unfumigated soil spiked with inorganic P (as KH_2PO_4)

3.4. Enumeration of functional groups of microorganisms

Various functional groups of microorganisms viz., nitrogen fixers, phosphate solubilizers, potassium solubilizers, cellulose degraders and lignin degrading microorganisms were enumerated using suitable culture media by following the standard serial dilution and plate count technique.

3.4.1. Enumeration of nitrogen fixing microorganisms

The population of nitrogen fixers in the soil samples collected from each plot was enumerated by the standard dilution plating technique using Jensen's agar medium. The plates were incubated at 30 °C for 4-5 days and the number of colonies were counted and expressed as colony forming units (CFU) g⁻¹ dry soil.

3.4.2. Enumeration of phosphate solubilizing microorganisms

The population of phosphate solubilizing bacteria (PSB) in the soil samples collected from each plot was enumerated by the standard dilution plating technique using Pikovskaya's agar medium. The plates were incubated at 30 °C for 6-7 days and the number of colonies were counted and expressed as colony forming units (CFU) g⁻¹ dry soil.

3.4.3. Enumeration of potassium solubilizers

The population of potassium solubilizing bacteria (KSB) in the soil samples collected from each plot was enumerated by the standard dilution plating technique using Alexandrow's agar medium. The plates were incubated at 30 °C for 6-7 days and the number of colonies were counted and expressed as colony forming units (CFU) g⁻¹ dry soil.

3.4.4. Enumeration of cellulose degrading microorganisms

The population of cellulose degraders in the soil samples collected from each plot was enumerated by the standard dilution plating technique using cellulose agar medium. The plates were incubated at 30 °C for 6-7 days and the number of colonies were counted and expressed as colony forming units (CFU) g⁻¹ dry soil.

3.4.5. Enumeration of lignin degrading microorganisms

The population of lignin degrading microorganisms in the soil samples collected from each plot was enumerated by the standard dilution plating technique using lignin

sulphonic acid medium. The plates were incubated at 30 °C for 4-5 days and the number of colonies were counted and expressed as colony forming units (CFU) g⁻¹ dry soil.

3.5. Determination of soil enzyme activity

3.5.1. Dehydrogenase activity

The dehydrogenase activity in the soil samples were determined by the procedure described by Casida *et al.* (1964).

Two gram of soil was mixed thoroughly with 0.2 g of CaCO₃ and dispensed into test tubes. To each of the sample tube, 1 mL of 2% aqueous solution of 2,3,5- triphenyl tetrazolium chloride (TTC) and 2.5 mL of distilled water were added and thoroughly mixed. The tubes were then stoppered using corks and incubated at 37 °C for 24 hours after which corks were removed and 10 mL methanol was added to each tube and shaken well. The suspension was then filtered through a glass funnel fitted with Whatman No. 15 filter paper into a 50 mL volumetric flask. Each tube was rinsed with methanol. Additional methanol was added to the funnel until the red colour had disappeared. The volume of the filtrate was made up to 50 mL using methanol. The intensity of the red colour was measured using Bosch and Lamb spectrophotometer at a wavelength of 485 nm. The amount of 2,3,5- triphenyl tetrazolium formazan (TPF) was calculated by referring to standard curve obtained by using 500, 1000, 1500 and 2000µg of TPF per 100 mL. The dehydrogenase activities of the samples were then expressed as µg of TPF formed per gram of sample per hour.

3.5.2. Urease activity

The urease activity of the samples was determined by the method given by Eivazi and Tabatabai (1977).

One gram of the soil sample was taken in 50 mL Erlen Meyer flask. It was treated with 0.2 mL of toluene and 9 mL of THAM buffer and the flasks were swirled for few seconds to ensure proper mixing of the contents, followed by the addition of 1 mL of

0.2 mL urea, the flasks were swirled for few seconds and were placed in incubator at 37 °C. After 2 hours of incubation, the stoppers were removed and approximately 35 mL of $\text{KClAg}_2\text{SO}_4$ solution was added. The flasks were then swirled again and allowed to stand until the contents had cooled down to room temperature. The volume of the suspension was then made up to 50 mL using $\text{KClAg}_2\text{SO}_4$ solution. The contents were mixed and $\text{NH}_4\text{-N}$ was determined by steam distillation. Controls were performed in the same way, but 1 mL of 0.2 M urea was added after the addition of 35 mL of $\text{KCl-Ag}_2\text{SO}_4$ solution.

3.5.3. Acid and Alkaline Phosphatase activity

Acid and Alkaline Phosphatase activities were estimated as per the procedure described by Eivazi and Tabatabai (1977).

One gram each of the soil samples were taken in wide- mouthed test tubes. To this, 0.2 mL of toluene, 4 mL of modified universal buffer (pH 6.5 for acid phosphatase and pH 11 for alkaline phosphatase assay), 1 mL of P- nitrophenyl phosphate solution (made in the same buffer) were added. The tubes were swirled for a few seconds to mix the contents and stoppered with cork and placed in incubator at 37 °C. After 1 hour, the stoppers were removed and 1 mL of 0.5 M CaCl_2 , 4 mL of 0.5 M NaOH were added. The suspension was centrifuged at 3000 rpm, filtered and the intensity of yellow colour of the supernatant was measured using Bosch and Lamb spectrophotometer at 420 nm wavelength.

The p-nitrophenol (PNP) content of the supernatant was calculated by referring to standard curve obtained with standards containing 0, 10, 20, 30, 40 and 50 µg of P- nitro phenol. The control was performed in an equivalent manner, but after the addition of 0.5 M CaCl_2 and 0.5 M NaOH, p- nitro phenyl phosphate solution was added. The phosphatase activities of the samples were then expressed as micrograms of PNP per gram per hour of the sample with respect to the standard curve prepared using graded concentrations of PNP solution.

3.6. Statistical analysis

The data obtained under each parameter were analyzed as a multi-location experiment with completely randomized design (CRD) with the four land-use systems as four treatments with the two depths as two levels and the seven locations as seven replications.

IV RESULTS AND DISCUSSION

Investigations were conducted to study the dynamics of “Microbial biomass carbon stocks at home garden agroforestry system in parts of Western Ghats” in the Department of Agricultural Microbiology, UAS, GKVK, Bengaluru. Various microbial and biochemical parameters studied were, soil microbial biomass, the abundance of functional groups of soil microorganisms and the enzyme activities. The results obtained are presented and discussed in this chapter.

4.1. Variation in microbial biomass under different land-use systems at different depths

As the most active part in soil organic matter, soil microbial biomass is important in nutrient cycling and release, participating in the circulation of critical elements such as carbon and nitrogen. It can directly reflect soil fertility status and has been used as an indicator for assessing soil quality of different land-use systems as well as for evaluating the intensity of interference on soils. The microbial biomass carbon, nitrogen and phosphorous estimated in the study are discussed below.

4.1.1. Microbial biomass carbon

The microbial biomass carbon dynamics at different land-use systems at 0-10 cm and 10-20 cm depths is presented in Table 4.1.1. The microbial biomass carbon at 0-10 cm was the highest in the forest system ($396.58 \mu\text{g g}^{-1}$) compared to other land-use systems. It was on par with 75 year-old home garden agroforestry system ($376.32 \mu\text{g g}^{-1}$) and 45 year-old home garden agroforestry system ($248.08 \mu\text{g g}^{-1}$). The least biomass carbon was in agriculture system ($116.47 \mu\text{g g}^{-1}$).

The microbial biomass carbon decreased with depth. It showed similar trend with respect to land-use systems as that in the first depth. At 10-20 cm depth the highest microbial biomass carbon was in the forest system ($232.00 \mu\text{g g}^{-1}$) which was on par with 75 year-old home garden agroforestry system ($227.47 \mu\text{g g}^{-1}$) and 45 year-old home

Table 4.1.1. a) Microbial biomass carbon ($\mu\text{g g}^{-1}$) under different land-use systems at different locations

SL. NO.	Location details	Land-use systems							
		Forest		HG (75)		HG (45)		Agriculture	
		0-10cm	10-20cm	0-10cm	10-20cm	0-10cm	10-20cm	0-10cm	10-20cm
1	Kottayam	215.5	153.9	213.6	169.8	166.9	133.1	112	95.3
2	Thrissur	643.8	280.1	403.3	238.4	362.6	259.3	137.1	106.3
3	Mallapuram	249.3	220.5	338.7	203.6	164.9	141.1	97.3	52.6
4	Kannur	483.8	263.3	212.6	189.7	204.6	173.8	85.4	40.7
5	Kasargoad	385.4	283	365.6	177.8	414.3	229	129.2	84.4
6	Bantawala	633.5	167.9	556.3	181.8	272.2	239.4	115.2	70.5
7	Karkala	264.8	255.3	544.2	431.2	151.1	139	139.1	122.2

Note: HG (75)- 75 year-old Home garden; HG (45)- 45 year-old Home garden

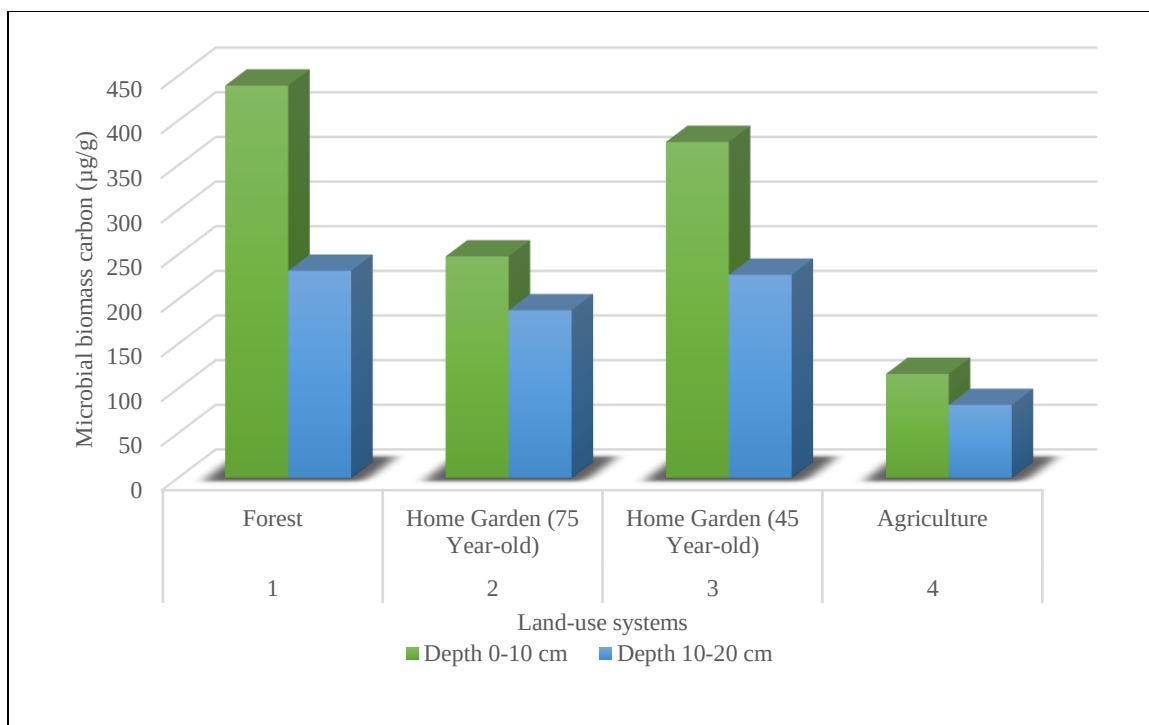


Fig.4.1.1. Microbial biomass carbon under different land-use systems at different depths

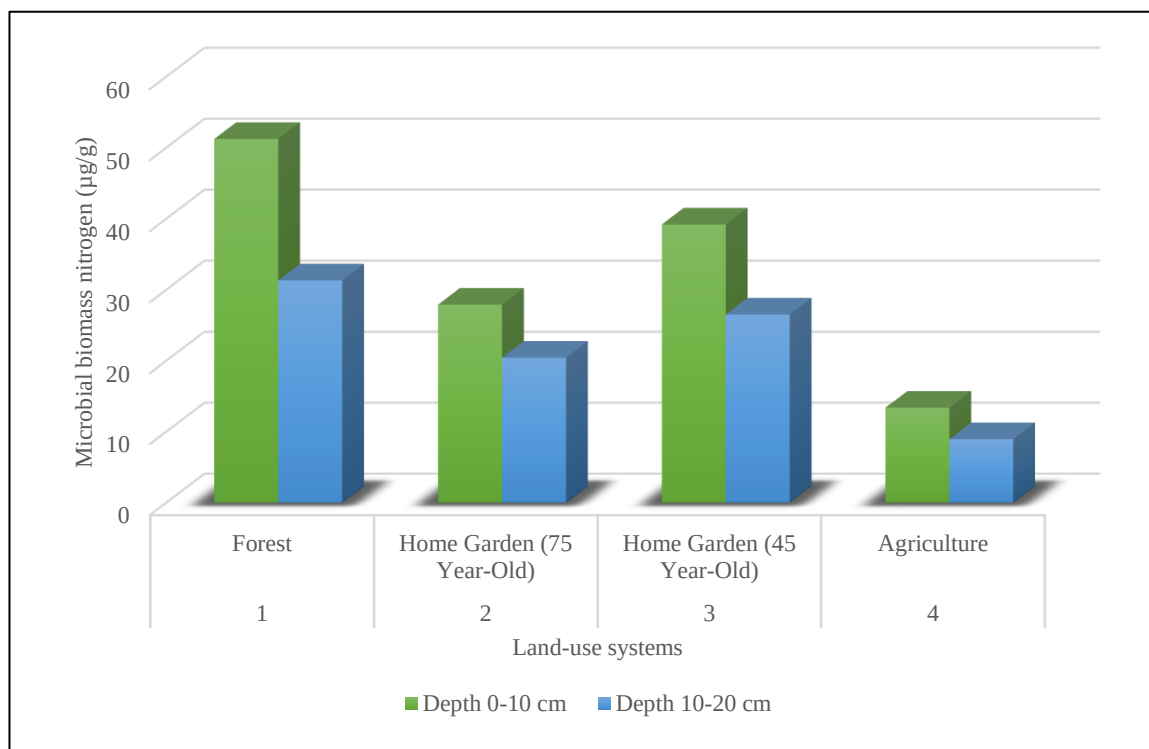


Fig.4.1.2. Microbial biomass nitrogen under different land-use systems at different depths

Table 4.1.1. b) Microbial biomass carbon ($\mu\text{g g}^{-1}$) under different land-use systems at different depths

Sl. No.	Treatments	Depth	
		0-10 cm	10-20 cm
1	Forest system	396.58 ^a	232.00 ^a
2	Home Garden (75 Year-old)	376.32 ^{ab}	227.47 ^a
3	Home Garden (45 Year-old)	248.08 ^{bc}	187.25 ^a
4	Agriculture	116.47 ^c	80.25 ^b

Note: The statistical analysis was carried out by Duncan's Multiple Range Test (DMRT). The mean values followed by the same superscripts are not significant with each other.

garden agroforestry system ($187.81 \mu\text{g g}^{-1}$). The least biomass carbon was recorded in agriculture system ($80.25 \mu\text{g g}^{-1}$).

The soil microbial biomass carbon was significantly higher in the forest system compared to other land-use systems and it decreased with soil depth, which could be accounted to the higher carbon sequestration potential of the forest systems compared to other land-use systems and also due to the least disturbance. The similarities in values of the biomass carbon in home gardens and forest system could be attributed to the similarity in their structures. When there is no disturbance to the soil system as in case of the forest system, as time progresses the soils keep accumulating carbon in the soil matrix and in the microbial biomass. The least microbial biomass carbon was in agriculture system, which may be attributed to the reduction in the total soil organic matter due to the constant disturbance of the soil caused due to various cultivation practices. These practices lead to gradual loss of the organic carbon in the soil due to rapid decomposition of the organic substrates present in the soil. This in turn causes starvation of the soil microbiota leading to low microbial biomass carbon content (Jenkinson and Ladd, 1981).

When the agricultural lands are transformed to traditional agroforestry systems like home gardens, the soil organic carbon increases to near forest-levels (Hombegowda *et al.*, 2016) which directly influences the soil microbial biomass carbon stocks. Although the microbial biomass carbon storage in traditional agroforestry systems like home gardens is lower compared to natural forests, it is still high compared to intensively cultivated lands. This shows the potential of incorporating tree species in crop production systems which slows down depletion of carbon after conversion and also their carbon sequestration potential (Kumar, 2006).

The higher values of microbial biomass carbon in the home garden agroforestry system can be accounted to the higher activities of microorganisms due to more availability of litter as organic carbon input. Soil organic carbon showed significant positive relations with microbial carbon denoting that the latter are limited by the magnitude of the soil organic matter.

Similar results were reported by various authors regarding the dynamics of soil microbial biomass carbon under different land-use systems and different depths down the soil profile, but no work has been carried out considering home garden agroforestry system.

The soil microbial biomass carbon dynamics in our study is in agreement with the summary by Smith *et al.* (1990) who reported that generally soil microbial biomass C values in soil increase in the order: agriculture < forest < grassland.

Our study is in agreement with the study carried out by Anita and Yang (2014). They considered three systems and found the highest microbial biomass carbon (MBC) in spruce soils which was least disturbed, followed by hemlock soils, and the least was in grassland soils. They found that the MBC was highest in the surface soil and that it declined with soil depth.

4.1.2. Microbial biomass nitrogen

The microbial biomass nitrogen dynamics at different land-use systems at 0-10cm and 10-20 cm depths is presented in Table 4.1.2. The microbial biomass nitrogen at the top soil layer i.e., 0-10 cm was found to be higher in the forest system (51.23 $\mu\text{g g}^{-1}$) which was on par with 75 year-old home garden agroforestry system (39.20 $\mu\text{g g}^{-1}$) and 45 year-old home garden system (27.90 $\mu\text{g g}^{-1}$). The least biomass nitrogen was in agriculture system (13.38 $\mu\text{g g}^{-1}$).

The microbial biomass nitrogen decreased with depth. At 10-20 cm depth the highest microbial biomass nitrogen was in the forest system (31.31 $\mu\text{g g}^{-1}$) which was on par with 75 year-old home garden agroforestry system (26.51 $\mu\text{g g}^{-1}$). It was followed by 45 year-old home garden agroforestry system (20.42 $\mu\text{g g}^{-1}$) and the least biomass nitrogen was recorded in agriculture system (8.94 $\mu\text{g g}^{-1}$).

The soil microbial biomass nitrogen was significantly higher in the forest system compared to other land-use systems and it decreased with increase in soil depth, which could be accounted to the higher organic matter input compared to other land-use systems and also due to the least disturbance. The similarities in values of the biomass nitrogen in home gardens and forest system could be attributed to the similarity in their structures. The least microbial biomass nitrogen was in agriculture system, which may be attributed to the reduction in the soil organic matter due to the constant disturbance of the soil caused by various cultivation practices.

Similar finding was obtained in studies carried out by Wang *et al.* (2004). The distribution of microbial biomass nitrogen in the soil profiles of five different vegetation systems including bare area (Br), Bamboo (Bmb), Chinese Fir (CF), Citrus Orchard (Ctr) and Rice field (Rf) were investigated. The microbial biomass P levels in the Bmb system was found to be significantly higher than other systems, and it decreased with increasing soil depth in all vegetation systems.

The decrease in microbial biomass N with increase in depth was also found by Yang *et al.* (2016) who reported that the soil microbial biomass nitrogen content

Table 4.1.2. a) Microbial biomass nitrogen ($\mu\text{g g}^{-1}$) under different land-use systems at different locations

Sl. No.	Location details	Land-use systems							
		Forest		HG (75)		HG (45)		Agriculture	
		0-10cm	10-20cm	0-10cm	10-20cm	0-10cm	10-20cm	0-10cm	10-20cm
1	Kottayam	25.1	17.9	24.9	19.8	19.4	15.5	12.9	11.1
2	Thrissur	75.1	32.6	47	27.8	42.3	30.2	15.9	12.4
3	Mallapuram	29.1	25.7	39	23.7	19.2	16.4	11.3	6.14
4	Kannur	56.4	30.7	24.8	22.1	20.2	19.2	9.9	4.7
5	Kasargoad	44.9	33.1	42.6	20.7	48.3	26.7	15.1	9.8
6	Bantawala	97.2	49.5	31.2	21.2	31.7	21.7	15.1	8.2
7	Karkala	30.8	29.7	64.9	50.3	14.2	13.3	13.5	10.3

Note: HG (75)- 75 year-old Home garden; HG (45)- 45 year-old Home garden

decreased with soil depth but increased with revegetation. In our study, transformation of agricultural system to home garden agroforestry system could be related to revegetation.

4.1.3. Microbial biomass phosphorous

The microbial biomass phosphorous dynamics at different land-use systems at 0-10 cm and 10-20 cm depths is presented in Table 4.1.3. The microbial biomass phosphorous at the top soil layer i.e., 0-10 cm was highest in the forest system ($5.12 \mu\text{g g}^{-1}$) which was on par with 75 year-old home garden agroforestry system ($3.92 \mu\text{g g}^{-1}$) and 45 year-old home garden ($2.79 \mu\text{g g}^{-1}$). The least biomass nitrogen was in agriculture system ($1.33 \mu\text{g g}^{-1}$).

The microbial biomass phosphorous decreased with depth. At 10-20 cm depth biomass phosphorous was highest in the forest system ($3.13 \mu\text{g g}^{-1}$). It was on par with 75 year-old home garden agroforestry system ($2.65 \mu\text{g g}^{-1}$) and 45 year-old home garden agroforestry system ($2.04 \mu\text{g g}^{-1}$). The least microbial biomass phosphorous was recorded in agriculture system ($0.89 \mu\text{g g}^{-1}$).

Table 4.1.2. b) Microbial biomass nitrogen ($\mu\text{g g}^{-1}$) under different land-use systems at different depths

Sl. No.	Treatments	Depth	
		0-10 cm	10-20 cm
1	Forest	51.23 ^a	31.31 ^a
2	Home Garden (75 Year-Old)	39.2 ^{ab}	26.51 ^{ab}
3	Home Garden (45 Year-Old)	27.9 ^{bc}	20.42 ^b
4	Agriculture	13.38 ^c	8.94 ^c

Note: The statistical analysis was carried out by Duncan's Multiple Range Test (DMRT). The mean values followed by the same superscripts are not significant with each other.

Table 4.1.3. a) Microbial biomass phosphorus ($\mu\text{g g}^{-1}$) variation at different land-use systems at different locations

Sl. No.	Location details	Land-use systems							
		Forest		HG (75)		HG (45)		Agriculture	
		0-10cm	10-20cm	0-10cm	10-20cm	0-10cm	10-20cm	0-10cm	10-20cm
1	Kottayam	2.51	1.79	2.49	1.98	1.94	1.55	1.29	1.11
2	Thrissur	7.51	3.26	4.7	2.78	4.23	3.02	1.59	1.24
3	Mallapuram	2.91	2.57	3.9	2.37	1.92	1.64	1.13	0.614
4	Kannur	5.64	3.07	2.48	2.21	2.02	1.92	0.99	0.47
5	Kasargoad	4.49	3.31	4.26	2.07	4.83	2.67	1.51	0.98
6	Bantawala	9.72	4.95	3.12	2.12	3.17	2.17	1.51	0.82
7	Karkala	3.08	2.97	6.49	5.03	1.42	1.33	1.35	1.03

Note: HG (75)- 75 year-old Home garden; HG (45)- 45 year-old Home garden

Table 4.2.1. a) Population of nitrogen fixers ($\times 10^3$ CFU/g) under different land-use systems at different locations

Sl. No.	Location details	Land-use systems							
		Forest		HG (75)		HG (45)		Agriculture	
		0-10cm	10-20cm	0-10cm	10-20cm	0-10cm	10-20cm	0-10cm	10-20cm
1	Kottayam	38.5	12	113	34	54	41	43.5	37
2	Thrissur	234	77	67	6	51	18	76	39
3	Mallapuram	107	17	56	3	52	0	34.75	17
4	Kannur	36.5	21.4	104	86	98	46.5	78	54.5
5	Kasargoad	117	23	127	105	132.5	59	76	33
6	Bantawala	75.5	25	163	34	71	3	65.5	19
7	Karkala	141	23.7	57	43	57	43.5	93	89

Note: HG (75)- 75 year-old Home garden; HG (45)- 45 year-old Home garden

Table 4.1.3. b) Microbial biomass phosphorus ($\mu\text{g g}^{-1}$) variation at different land-use systems at different depths

Sl. No.	Treatments	Depth	
		0-10 cm	10-20 cm
1	Forest	5.12 ^a	3.13 ^a
2	Home Garden (75 Year-old)	3.92 ^{ab}	2.65 ^{ab}
3	Home Garden (45 Year-old)	2.79 ^{bc}	2.04 ^b
4	Agriculture	1.33 ^c	0.89 ^c

Note: The statistical analysis was carried out by Duncan's Multiple Range Test (DMRT). The mean values followed by the same superscripts are not significant with each other.

The soil microbial biomass phosphorous was significantly higher in the forest system compared to other land-use systems and it decreased with increase in soil depth which could be accounted to higher organic matter input compared to other land-use systems and also due to the least disturbance.

Similar study was conducted by Brookes *et al.* (1984) where a decline in biomass P from 24 to 3% was observed when an old grassland soil was put into an arable rotation for about 20 year accounted for about 50% of the decline in total soil organic P during this period. When an old arable soil reverted to woodland, soil organic P doubled in 100 year; biomass P increased 11-fold during the same period.

Our study is in agreement with the study carried out by Anita and Yang (2014). They considered three systems and found the highest microbial biomass phosphorous in spruce soils, followed by hemlock soils, and were lowest in grassland soils They found that the MBP was highest in the surface soil and it declined with soil depth.

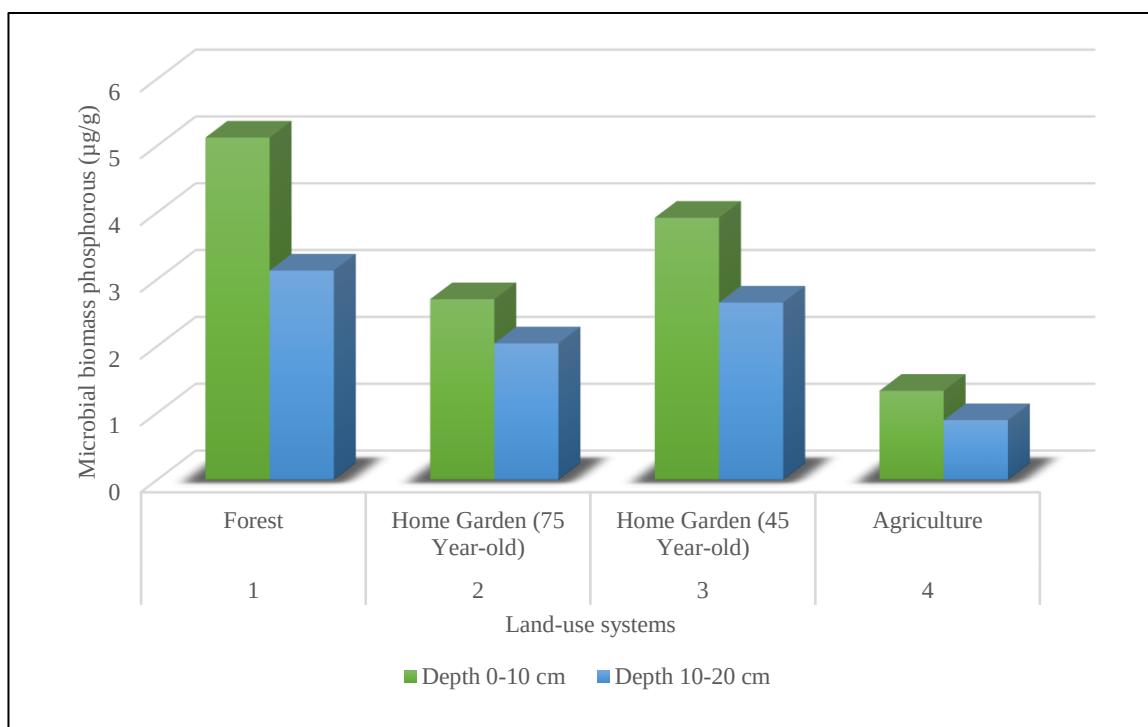


Fig.4.1.3. Microbial biomass phosphorus at different land-use systems at different depths

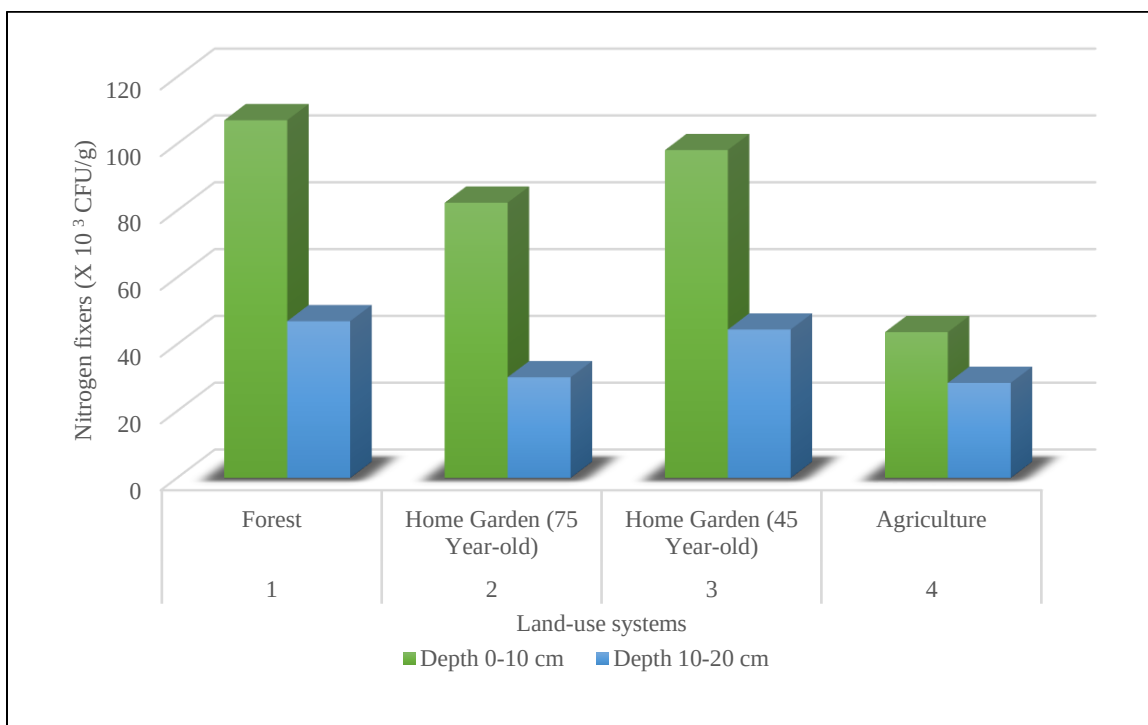


Fig.4.2.1. Population of nitrogen fixers under different land-use systems at different depths

4.2. Variation in population of functional groups of microorganisms under different land-use systems at different depths

Soil is a habitat for a wide variety of microorganisms. These microbes obtain carbon and energy from the root exudates and other compounds in the soil and regulate the soil nutrients cycle. Some of the important functional groups of soil microorganisms were enumerated and are discussed below.

4.2.1. Nitrogen fixing microorganisms

The population of nitrogen fixers at different land-use systems at 0-10cm and 10-20 cm depths is presented in Table 4.2.1. The population of nitrogen fixers at 0-10 cm was found to be the highest in the forest system (107.07×10^3 CFU g⁻¹). It was followed by 75 year-old home garden agroforestry system (98.14×10^3 CFU g⁻¹) and the 45 year-old home garden agroforestry system (82.39×10^3 CFU g⁻¹). The least population was in agriculture system (73.64×10^3 CFU g⁻¹).

Table 4.2.1. b) Population of nitrogen fixers ($\times 10^3$ CFU/g) under different land-use systems at different depths

Sl. No.	Treatments	Depth	
		0-10 cm	10-20 cm
1	Forest	107.07	46.92
2	Home Garden (75 Year-old)	98.14	44.42
3	Home Garden (45 Year-old)	82.39	30.14
4	Agriculture	43.64	28.44

Note: The statistical analysis was carried out by Duncan's Multiple Range Test (DMRT). No significant difference was found among the mean values.

The nitrogen fixers population decreased with depth. At 10-20 cm depth the population of nitrogen fixers was the highest in forest system (46.92×10^3 CFU g⁻¹), it was followed by 75 year-old home garden agroforestry system (44.42×10^3 CFU g⁻¹) and

45 year-old home garden agroforestry system (30.14×10^3 CFU g⁻¹) and the least population was recorded in agriculture system (28.44×10^3 CFU g⁻¹).

Seventy-eight per cent of the atmosphere is covered with molecular nitrogen which cannot be used by plants. This molecular nitrogen must first combine with oxygen or hydrogen to produce compounds such as ammonia or nitrate. This is called nitrogen fixation, a part of which occurs by lightning and some and majority is done by a group of soil dwelling microorganisms called nitrogen fixers.

The population of nitrogen fixers was significantly higher in the forest system compared to other land-use systems and it decreased with increase in soil depth, which could be accounted to the higher organic matter input compared to other land-use systems and also due to the least disturbance. The least population was in agriculture system, which may be attributed to the reduction in the total soil organic matter inputs and frequent supplementation of nitrogen as chemical fertilizers.

Similar findings were inferred from a study by Meliani *et al.* (2012). The microbial diversity including nitrogen fixers in forest and agricultural soils at different depths (5-10, 10-15 and 15-20 cm) were estimated. They found that the population of nitrogen fixers was significantly higher in the forest soils when compared to agriculture soils. They also found that their population decreased with increase in depth.

The decrease in the population of nitrogen fixers with increase in depth was also noticed by Bardgett *et al.* (1997) in their study of microbial diversity in grassland sites. They noticed that their population was the highest in the top 5 cm of soil and that it decreased down the soil profile till a depth of 15 cm.

The decrease in their populations with depth is also supported by work of Doran (1980) who found that the population of various microorganisms in the surface of an undisturbed land was around 7.31 times higher than that in the surface of a ploughed soil.

4.2.2. Phosphate solubilizing bacteria

The population of phosphate solubilizing bacteria under different land-use systems at 0-10 cm and 10-20 cm depths is presented in Table 4.2.2. The population of phosphate solubilizing bacteria at 0-10 cm was the highest in the forest system (35.71×10^3 CFU g⁻¹). It was on par with 75 year-old home garden agroforestry system (35.07×10^3 CFU g⁻¹) followed by the 45 year-old home garden agroforestry system (25.78×10^3 CFU g⁻¹). The least population was in agriculture system (13.64×10^3 CFU g⁻¹).

The population of phosphate solubilizing bacteria decreased with depth. At 10-20 cm depth the highest activity was in the forest system (3×10^3 CFU g⁻¹). It was on par with 75 year-old home garden agroforestry system (2.85×10^3 CFU g⁻¹) followed by 45 year-old home garden agroforestry system (0.5×10^3 CFU g⁻¹). The PSB population was not there in agriculture system.

The population of phosphate solubilizers was significantly higher in the forest system compared to other land-use systems and that they decreased with increase in soil depth, which could be accounted to the higher organic matter input compared to other land-use systems and also due to the least disturbance. The similarity in their populations in home gardens and forest system could be attributed to similar soil structures. At the soil surface there is availability of litter which serves as organic input for the organisms which decreases with increase in depth which in turn leads to decrease in their population. Similar findings were inferred from a study by Meliani *et al.* (2012). The microbial diversity including phosphate solubilizers in forest and agricultural soils at different depths (5-10, 10-15 and 15-20 cm) were estimated. They found that the population of phosphate solubilizers was significantly higher in the forest soils when compared to agriculture soils. They also found that their population decreased with increase in depth.

The decrease in the population of phosphate solubilizing bacteria with increase in depth was also noticed by Bardgett *et al.* (1997) in their study of microbial diversity in

Table 4.2.2. a) Population dynamics of phosphate solubilizing bacteria ($\times 10^3$ CFU/g) under different land-use systems at different locations

Sl. No.	Location details	Land-use systems							
		Forest		HG (75)		HG (45)		Agriculture	
		0-10cm	10-20cm	0-10cm	10-20cm	0-10cm	10-20cm	0-10cm	10-20cm
1	Kottayam	10	0	8	0	34	8	7	0
2	Thrissur	14.5	0	80.5	0	13	0	39.5	0
3	Mallapuram	46.5	0	7	0	83.5	13	13	0
4	Kannur	4	0	0	0	8.5	0	5	0
5	Kasargoad	14	6	36	20	11	0	11	0
6	Bantawala	3.5	0	97	0	73	0	13	0
7	Karkala	88	0	17	0	7	0	7	0

Note: HG (75)- 75 year-old Home garden; HG (45)- 45 year-old Home garden

Table 4.2.2. b) Population dynamics of phosphate solubilizing bacteria ($\times 10^3$ CFU/g) under different land-use systems at different depths

Sl. No.	Treatments	Depths	
		0-10 cm	10-20 cm
1	Forest	35.71	3.0
2	Home Garden (75 Year-old)	35.07	2.85
3	Home Garden (45 Year-old)	25.78	0.85
4	Agriculture	13.64	0

Note: The statistical analysis was carried out by Duncan's Multiple Range Test (DMRT). No significant difference was found among the mean values.

grassland sites. They noticed that their population was the highest in the top 5 cm of soil and that it decreased down the soil profile till a depth of 15 cm.

The decrease in their populations with depth is also supported by works of Doran (1980) who found that the population of various microorganisms in the surface of an undisturbed land was around 7.31 times higher than that in the surface of a ploughed soil.

4.2.3. Potassium solubilizing bacteria

The population of phosphate solubilizing bacteria under different land-use systems at 0-10 cm and 10-20 cm depths is presented in Table 4.2.3. The population of potassium solubilizing bacteria at 0-10 cm was more in forest system (15.28×10^3 CFU g^{-1}). It was on par with 75 year-old home garden agroforestry system (15×10^3 CFU g^{-1}) followed by the 45 year-old home garden agroforestry system (14×10^3 CFU g^{-1}). The least population was in agriculture system (7.7×10^3 CFU g^{-1}).

The population of potassium solubilizing bacteria decreased with depth. At 10-20 cm depth their population was significantly higher in forest system (7.28×10^3 CFU g^{-1}).

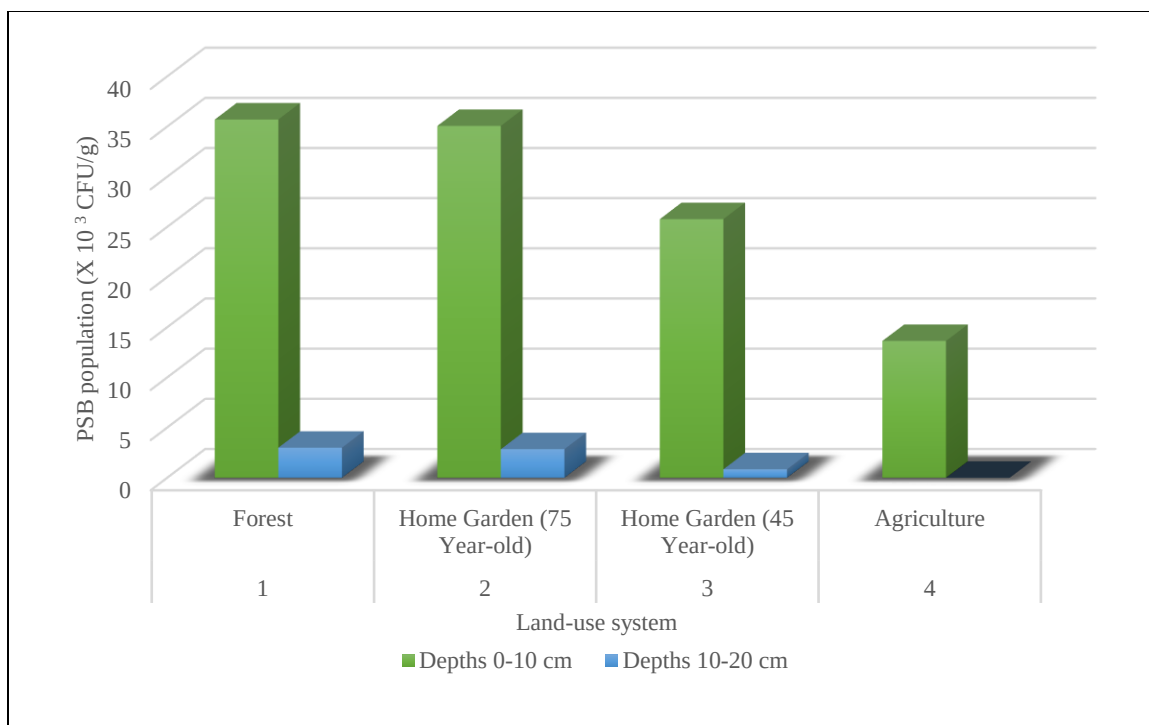


Fig.4.2.2. Population dynamics of phosphate solubilizing bacteria under different land-use systems at different depths

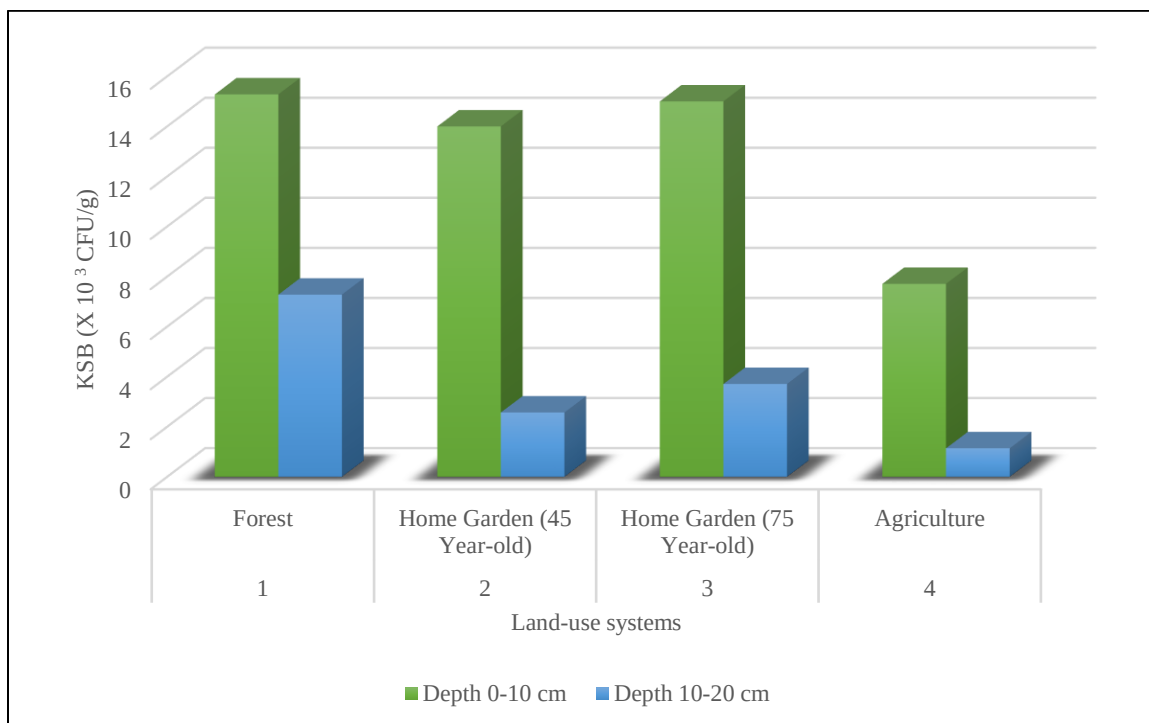


Fig.4.2.3. Population dynamics of potassium solubilizing bacteria under different land-use systems at different depths

Table 4.2.3. a) Population dynamics of potassium solubilizing bacteria ($\times 10^3$ CFU/g) under different land-use systems at different locations

Sl. No.	Location details	Land-use systems							
		Forest		HG (75)		HG (45)		Agriculture	
		0-10cm	10-20cm	0-10cm	10-20cm	0-10cm	10-20cm	0-10cm	10-20cm
1	Kottayam	30	12	31	22	3	0	8	3
2	Thrissur	17	3	7	1	3	0	57	5
3	Mallapuram	13	3	2	0	5	0	17	5
4	Kannur	16	1	3	0	17	6	5	0
5	Kasargoad	19	7	11	3	8	3	9	0
6	Bantawala	11	0	17	10	5	0	4	0
7	Karkala	1	0	27	15	13	9	5	2

Note: HG (75)- 75 year-old Home garden; HG (45)- 45 year-old Home garden

Table 4.2.3. b) Population dynamics of potassium solubilizing bacteria ($\times 10^3$ CFU/g) under different land-use systems at different depths

Sl. No.	Treatments	Depths	
		0-10 cm	10-20 cm
1	Forest	15.28	7.28
2	Home Garden (75 Year-old)	15.00	3.71
3	Home Garden (75 Year-old)	14.00	2.57
4	Agriculture	7.71	1.14

Note: The statistical analysis was carried out by Duncan's Multiple Range Test (DMRT). There was no significant difference among the mean values.

It was followed by 75 year-old home garden agroforestry system (3.71×10^3 CFU g^{-1}) and 45 year-old home garden agroforestry system (2.57×10^3 CFU g^{-1}). The least population was recorded in agriculture system (1.14×10^3 CFU g^{-1}).

The population of potassium solubilizing bacteria was significantly higher in the forest system compared to other land-use systems and that they decreased with increase in soil depth, which could be accounted to the higher organic matter input compared to other land-use systems and also due to the least disturbance. The similarity in their populations in home gardens and forest system could be attributed to similar soil structures. The least population was in agriculture system, which may be attributed to the reduction in the total soil organic matter due to the constant disturbance of the soil caused by various cultivation practices.

Similar findings were inferred from a study by Meliani *et al.* (2012). The microbial diversity including potassium solubilizers in forest and agricultural soils at different depths (5-10, 10-15 and 15-20 cm) were estimated. They found that the population of potassium solubilizers was significantly higher in the forest soils when compared to agriculture soils. They also found that their population decreased with increase in depth.

The decrease in the population of potassium solubilizing bacteria with increase in depth was also noticed by Bardgett *et al.* (1997) in their study of microbial diversity in grassland sites. They noticed that their population was the highest in the top 5 cm of soil and that it decreased down the soil profile till a depth of 15 cm.

The decrease in their populations with depth is also supported by works of Doran (1980) who found that the population of various microorganisms in the surface of an undisturbed land was around 7.31 times higher than that in the surface of a ploughed soil.

4.2.4. Cellulose degrading bacteria

The population of cellulose degrading bacteria under different land-use systems at 0-10cm and 10-20 cm depths is presented in Table 4.2.4. The population of cellulose degraders at 0-10 cm was found to be higher in forest system ($103.28 \times 10^3 \text{ CFU g}^{-1}$). It was on par with 75 year-old home garden agroforestry system ($102.07 \times 10^3 \text{ CFU g}^{-1}$) was followed by the 45 year-old home garden agroforestry system ($66.71 \times 10^3 \text{ CFU g}^{-1}$). The least population was in agriculture system ($44.00 \times 10^3 \text{ CFU g}^{-1}$).

The cellulose degraders population decreased with depth. At 10-20 cm depth their population was significantly higher in forest system ($62.78 \times 10^3 \text{ CFU g}^{-1}$). It was followed by 45 year-old home garden agroforestry system ($46.57 \times 10^3 \text{ CFU g}^{-1}$) and 75 year-old home garden agroforestry system ($39.71 \times 10^3 \text{ CFU g}^{-1}$). The least population was recorded in agriculture system ($25.07 \times 10^3 \text{ CFU g}^{-1}$).

Microorganisms that can produce cellulase enzymes (cellulolytic microorganisms) can degrade cellulose. Bacteria isolated from soil secrete several enzymes which degrade lignocellulosic biomass. These enzymes are commonly produced by some bacterial genera such as *Cellulomonas*, *Pseudomonas*, *Bacillus*, and *Micrococcus*. In our study we found that the population of cellulose degraders was significantly higher in the forest system compared to other land-use systems which could be attributed to the abundance of cellulosic material which could be accounted to the higher organic matter input compared to other land-use systems and also due to the least disturbance. The similarity in their populations in home gardens and forest system could

be attributed to similar soil structures. The least population was in agriculture system, which may be attributed to the reduction in the total soil organic matter due to the constant disturbance of the soil caused due to various cultivation practices. At the soil surface, litter and root exudates serve as organic input for the organisms which decreases with increase in depth which in turn leads to decrease in their population. Down the soil profile there is no litter available as carbon source in the form of cellulose which supports the decrease in population of cellulose degraders with increased depth.

Similar findings were inferred from a study by Meliani *et al.* (2012). The microbial diversity including cellulose degraders in forest and agricultural soils at different depths (5-10, 10-15 and 15-20 cm) were estimated. They found that the population of cellulose degraders was significantly higher in the forest soils when compared to agriculture soils. They also found that their population decreased with increase in depth.

The decrease in the population of cellulose degrading bacteria with increase in depth was also noticed by Bardgett *et al.* (1997) in their study of microbial diversity in grassland sites. They noticed that their population was the highest in the top 5 cm of soil and that it decreased down the soil profile till a depth of 15 cm.

Decrease in microbial population and diversity down the forest soil profiles using phospholipid fatty acid (PLFA) analyses was showed by Fritze *et al.* (2000) and Ekelund *et al.* (2001) showed a decrease in culturable cellulose degraders abundance with depth.

Table 4.2.4. a) Population dynamics of cellulose degraders ($\times 10^3$ CFU/g) under different land-use systems at different locations

Sl. No.	Location details	Land-use systems							
		Forest		HG (75)		HG (45)		Agriculture	
		0-10cm	10-20cm	0-10cm	10-20cm	0-10cm	10-20cm	0-10cm	10-20cm
1	Kottayam	107	70	164	75.5	43	22	105	47
2	Thrissur	129	70	90	52	72	5	177	70
3	Mallapuram	109	90	63	6	106	77	48	2
4	Kannur	54	10	36	11	86	70	98	53.5
5	Kasargoad	117	101	94	7	149	89	53	7
6	Bantawala	140	43.5	39	9	137	12	112.5	79
7	Karkala	67	55	121	15	65	3	121	67.5

Note: HG (75)- 75 year-old Home garden; HG (45)- 45 year-old Home garden

Table 4.2.4. b) Population dynamics of cellulose degraders ($\times 10^3$ CFU/g) under different land-use systems at different depths

Sl. No.	Treatments	Depths	
		0-10 cm	10-20 cm
1	Forest	103.28	62.78
2	Home Garden (45 Year-old)	94.00	39.71
3	Home Garden (75 Year-old)	102.07	46.57
4	Agriculture	66.71	25.07

Note: The statistical analysis was carried out by Duncan's Multiple Range Test (DMRT). No significant difference was found among the mean values.

4.2.5. Lignin degrading microorganisms

The population of lignin degrading bacteria under different land-use systems at 0-10 cm and 10-20 cm depths is presented in Table 4.2.5. The population of lignin degraders at 0-10 cm was found to be significantly higher in forest system (60.71×10^3 CFU g^{-1}). It was followed by 75 year-old home garden agroforestry system (29.14×10^3 CFU g^{-1}) which was on par with 45 year-old home garden agroforestry system (25.85×10^3 CFU g^{-1}) and The least population was in agriculture system (23.28×10^3 CFU g^{-1}).

The lignin degraders population decreased with depth. At 10-20 cm depth their population was significantly higher in forest system (18×10^3 CFU g^{-1}). It was followed by 45 year-old home garden agroforestry system (8.42×10^3 CFU g^{-1}) and 75 year-old home garden agroforestry system (8.28×10^3 CFU g^{-1}). The least population was in agriculture system (3.42×10^3 CFU g^{-1}).

In our study we found that the population of lignin degraders was significantly higher in the forest system compared to other land-use systems and that they decreased

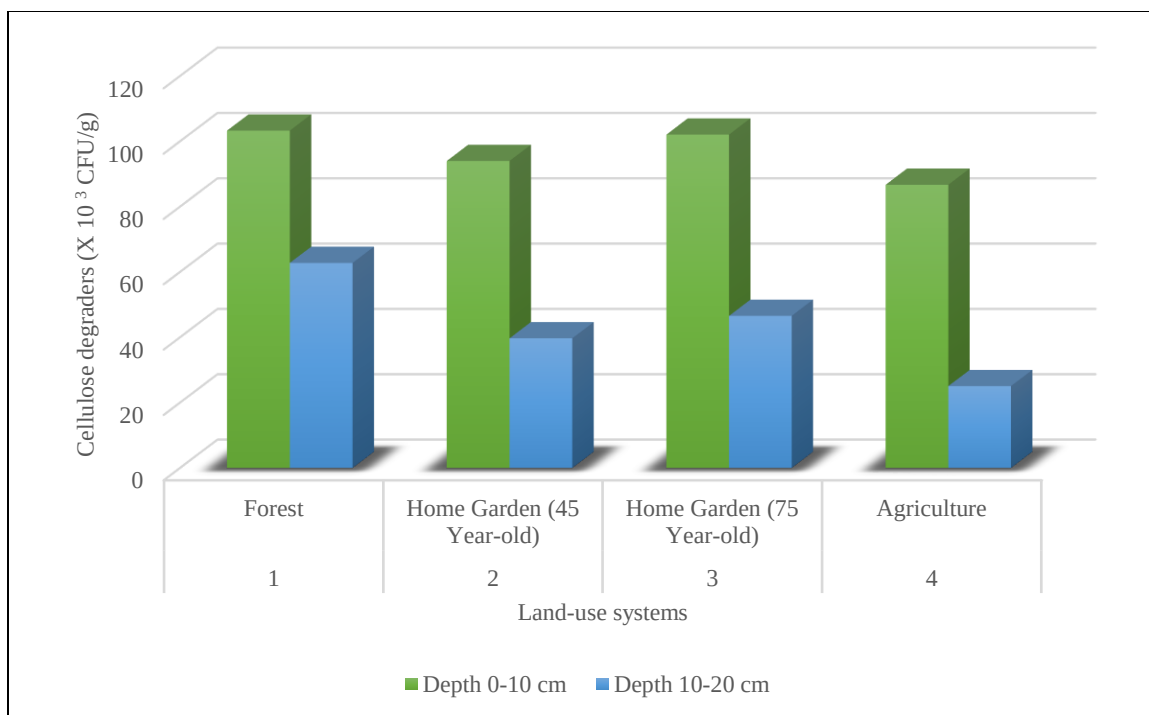


Fig.4.2.4. Population dynamics of cellulose degraders under different land-use systems at different depths

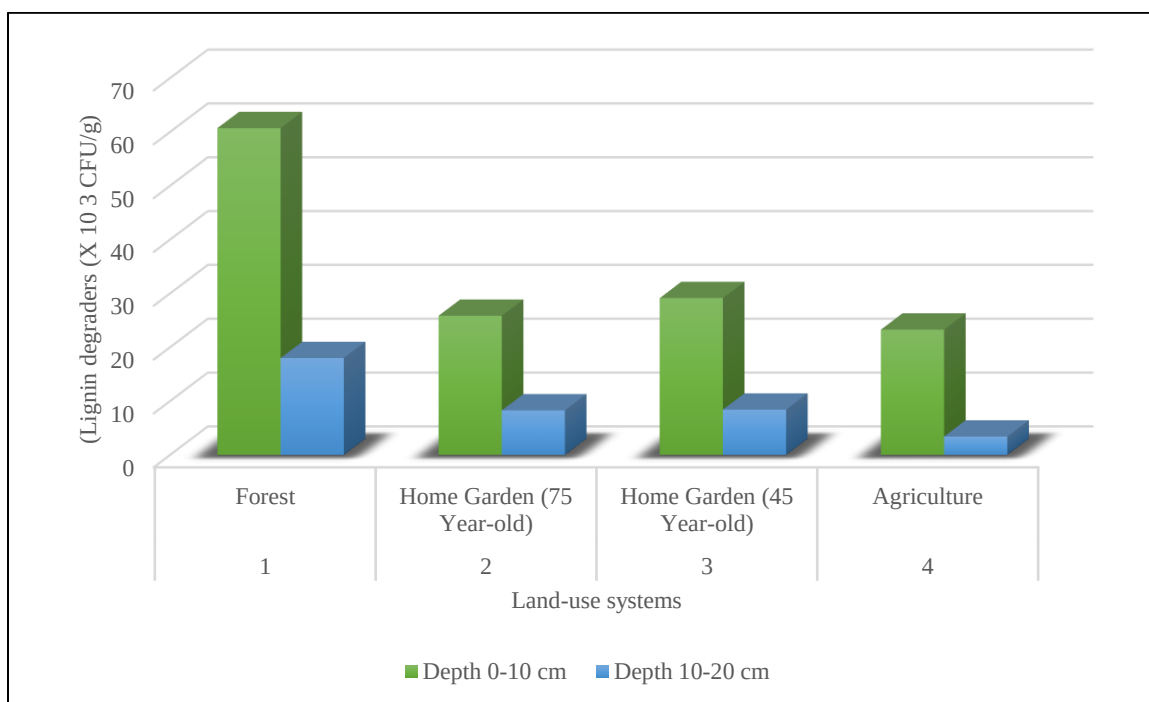


Fig.4.2.5. Population dynamics of lignin degraders under different land-use systems at different depths

Table 4.2.5. a) Population dynamics of lignin degraders ($\times 10^3$ CFU/g) under different land-use systems at different locations

Sl. No.	Location details	Land-use systems							
		Forest		HG (75)		HG (45)		Agriculture	
		0-10cm	10-20cm	0-10cm	10-20cm	0-10cm	10-20cm	0-10cm	10-20cm
1	Kottayam	15	3	44	33	11	1	13	25
2	Thrissur	21	11	67	6	52	13	57	22
3	Mallapuram	13	0	17	3	6	0	21	2
4	Kannur	86	3	27	30	23	6	34	2
5	Kasargoad	105	5	37	20	7	2	28	3
6	Bantawala	58	19	63	34	9	2	12	5
7	Karkala	33	17	43	0	55	0	16	0

Note: HG (75)- 75 year-old Home garden; HG (45)- 45 year-old Home garden

with increase in soil depth, which could be accounted to the higher organic matter input compared to other land-use systems and also due to the least disturbance. The similarity in their populations in home gardens and forest system could be attributed to the similarity in their structures. The least population was in agriculture system, which may be attributed to the reduced litterfall as a source of lignocellulosic material. At the soil surface, litter and root exudates serve as organic input for the organisms which decreases with increase in depth which in turn leads to decrease in their population.

At the soil surface there is availability of litter which serves as carbon source which is rich in lignin content. Down the soil profile there is no litter available as carbon source in the form of lignin which supports the decrease in population of cellulose degraders with increased depth.

Table 4.2.5. b) Population dynamics of lignin degraders ($\times 10^3$ CFU/g) under different land-use systems at different depths

Sl. No.	Treatments	Depth	
		0-10 cm	10-20 cm
1	Forest	60.71 ^a	18.00
2	Home Garden (75 Year-old)	25.85 ^b	8.28
3	Home Garden (45 Year-old)	29.14 ^b	8.42
4	Agriculture	23.28 ^b	3.42

Note: The statistical analysis was carried out by Duncan's Multiple Range Test (DMRT). The mean values followed by the same superscripts are not significant with each other. No significant difference was found among the mean values at 10-20 cm depth.

Similar findings were inferred from a study by Meliani *et al.* (2012). The microbial diversity including lignin degraders in forest and agricultural soils at different depths (5-10, 10-15 and 15-20cm) were estimated. They found that the population of lignin degraders was significantly higher in the forest soils when compared to agriculture soils. They also found that their population decreased with increase in depth.

The decrease in the population of lignin degrading bacteria with increase in depth was also noticed by Bardgett *et al.* (1997) in their study of microbial diversity in grassland sites. They noticed that their population was the highest in the top 5 cm of soil and that it decreased down the soil profile till a depth of 15 cm.

Decrease in microbial population and diversity down the forest soil profiles using phospholipid fatty acid (PLFA) analyses was showed by Fritze *et al.* (2000) and Ekelund *et al.* (2001) showed a decrease in culturable lignin degraders abundance with depth.

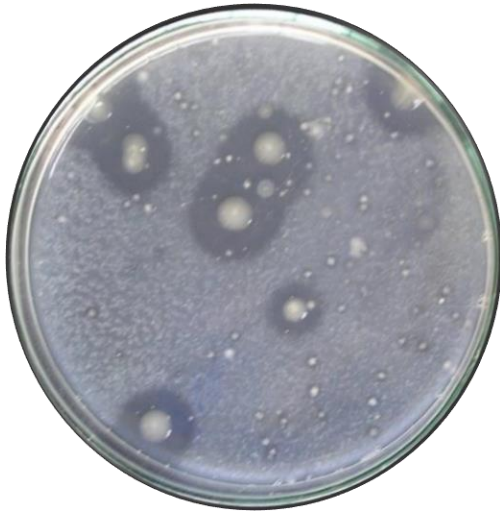
The decline in the microbial population with depth is because the decline in resource availability through the soil profile is predominately a function of both decreasing carbon concentrations and a reduction in carbon quality with soil depth (Trumbore, 2000).

4.3. Soil enzyme activity

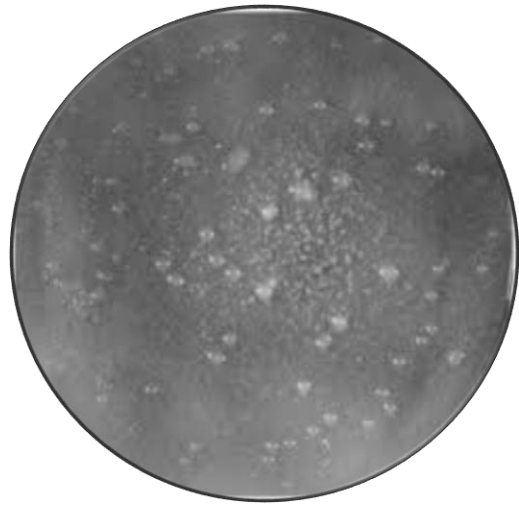
Enzymes are the vital activators in life processes, likewise in the soil they are known to play a substantial role in maintaining soil health and its environment. The enzymatic activity in the soil is mainly of microbial origin, being derived from intracellular, cell-associated or free enzymes. The activity of dehydrogenase, urease, alkaline and acid phosphatases are discussed.

4.3.1. Urease activity

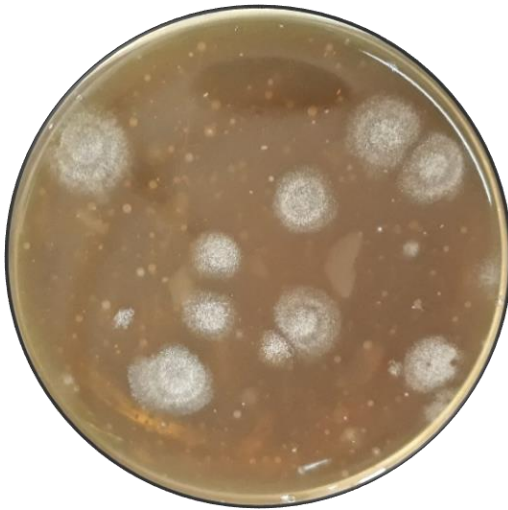
The urease activity under different land-use systems at 0-10 cm and 10-20 cm depths is presented in Table 4.3.1. The urease activity at 0-10 cm was found the highest in the agriculture system ($62.7 \mu\text{g NH}_4^+\text{-N g}^{-1} \text{ h}^{-1}$). It was on par with forest system ($60.9 \mu\text{g NH}_4^+ - \text{N g}^{-1} \text{ h}^{-1}$) followed by 75 year-old home garden agroforestry system ($57.5 \mu\text{g NH}_4^+\text{-N g}^{-1} \text{ h}^{-1}$). The least activity was in 45 year-old home garden agroforestry system ($57.1 \mu\text{g NH}_4^+\text{-N g}^{-1} \text{ h}^{-1}$).



PSB on Pikovskaya's agar



Nitrogen fixers on Jensen's agar



Lignin degraders on Lignin sulfonic
acid agar



Cellulose degraders on cellulose agar

Plate 2: Functional groups of microorganisms

The urease activity decreased with depth. At 10-20 cm depth the urease activity was significantly higher in agriculture system ($46.4 \mu\text{g NH}_4^+\text{-N g}^{-1} \text{ h}^{-1}$). It was on par with urease activity in forest system ($43.53 \mu\text{g NH}_4^+\text{-N g}^{-1} \text{ h}^{-1}$) followed by 75 year-old home garden agroforestry system ($44.6 \mu\text{g NH}_4^+\text{-N g}^{-1} \text{ h}^{-1}$). The least activity was in 45 year-old home garden agroforestry system ($38.1 \mu\text{g NH}_4^+\text{-N g}^{-1} \text{ h}^{-1}$).

Urea is added to the crop plants as a source of nitrogen in the cultivated lands, it requires to be broken down into plant available form as ammonium ions. Urease is the enzyme that aids in the process. The soil urease activity was significantly higher in the agriculture system compared to other land-use systems and it decreased with increase in soil depth. The soil microorganisms produce urease and secrete it into soil as and when there is urea in the soil, which supports the higher urease activity of the soils under agriculture system. In forest and home garden agroforestry systems, there is no supply of additional nitrogen as chemical fertilizers as urea thus leading to minimal production of the urease enzyme in the soil. The similarity in urease activity in home gardens and forest system could be attributed to the similarity in their structures.

The study by Smith and Powlson (2003) showed that the presence of added nitrogen source which acts as readily available N pool stimulates the urease activity, which supports the higher soil urease activity under agriculture system in our study. The decrease in activity of soil urease with depth was also showed by Taylor *et al.* (2002).

Table 4.3.1. a) Urease activity ($\mu\text{g NH}_4^+ \text{-N g}^{-1} \text{ h}^{-1}$) under different land-use systems at different locations

Sl. No.	Location details	Land-use systems							
		Forest		HG (75)		HG (45)		Agriculture	
		0-10cm	10-20cm	0-10cm	10-20cm	0-10cm	10-20cm	0-10cm	10-20cm
1	Kottayam	84.70	38.50	63.00	46.30	53.30	46.80	42.90	42.30
2	Thrissur	51.60	39.60	68.60	55.90	56.40	17.00	56.40	44.90
3	Mallapuram	56.70	48.10	55.00	52.00	55.60	44.80	64.10	26.70
4	Kannur	64.70	55.40	52.50	35.60	50.40	45.50	77.20	54.10
5	Kasargoad	56.50	55.30	46.70	46.30	86.10	57.60	78.50	52.00
6	Bantawala	55.80	40.10	61.60	41.80	42.10	30.70	60.10	49.00
7	Karkala	56.70	35.70	55.20	39.80	55.60	40.20	59.80	55.90

Note: HG (75)- 75 year-old Home garden; HG (45)- 45 year-old Home garden

Table 4.3.1. b) Urease activity ($\mu\text{g NH}_4^+ \text{-N g}^{-1} \text{ h}^{-1}$) under different land-use systems at different depths

Sl. No.	Treatments	Depths	
		0-10 cm	10-20 cm
1	Forest	60.9	45.3
2	Home Garden (75 Year-old)	57.5	44.6
3	Home Garden (45 Year-old)	57.0	38.1
4	Agriculture	62.7	46.4

Note: The statistical analysis was carried out by Duncan's Multiple Range Test (DMRT). The mean values followed by the same superscripts are not significant with each other. There was no significant difference among the mean values.

4.3.2. Dehydrogenase activity

The dehydrogenase activity under different land-use systems at 0-10 cm and 10-20 cm depths is presented in Table 4.3.2. The dehydrogenase activity at the top soil layer *i.e.*, 0-10 cm was higher in forest system ($151.31 \mu\text{g TPF g}^{-1} \text{ h}^{-1}$). It was on par with 75 year-old home garden agroforestry system ($132.98 \mu\text{g TPF g}^{-1} \text{ h}^{-1}$) and 45 year-old home garden ($118.38 \mu\text{g TPF g}^{-1} \text{ h}^{-1}$). The least dehydrogenase activity was in agriculture system ($117.02 \mu\text{g TPF g}^{-1} \text{ h}^{-1}$).

The dehydrogenase activity at 10-20 cm followed the same trend as that at 0-10 cm. The dehydrogenase activity was higher in forest system ($103.76 \mu\text{g TPF g}^{-1} \text{ h}^{-1}$). It was on par with 75 year-old home garden ($103.71 \mu\text{g TPF g}^{-1} \text{ h}^{-1}$) and 45 year-old home garden agroforestry system ($93.75 \mu\text{g TPF g}^{-1} \text{ h}^{-1}$). The least activity was in agriculture system ($86.94 \mu\text{g TPF g}^{-1} \text{ h}^{-1}$).

Dehydrogenase enzyme is often used as a measure of any disruption caused by pesticides, trace elements or management practices to the soil as well as a direct measure of soil microbial activity. The soil dehydrogenase activity was significantly higher in the

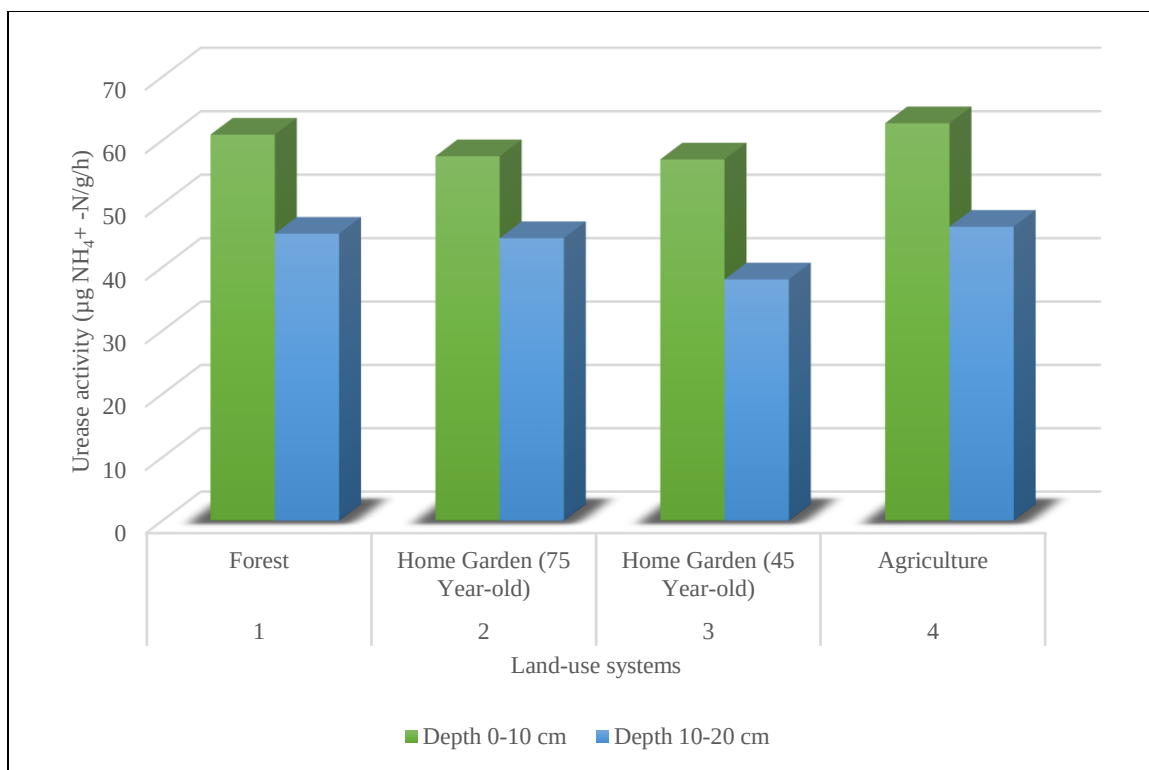


Fig.4.3.1. Urease activity under different land-use systems at different depths

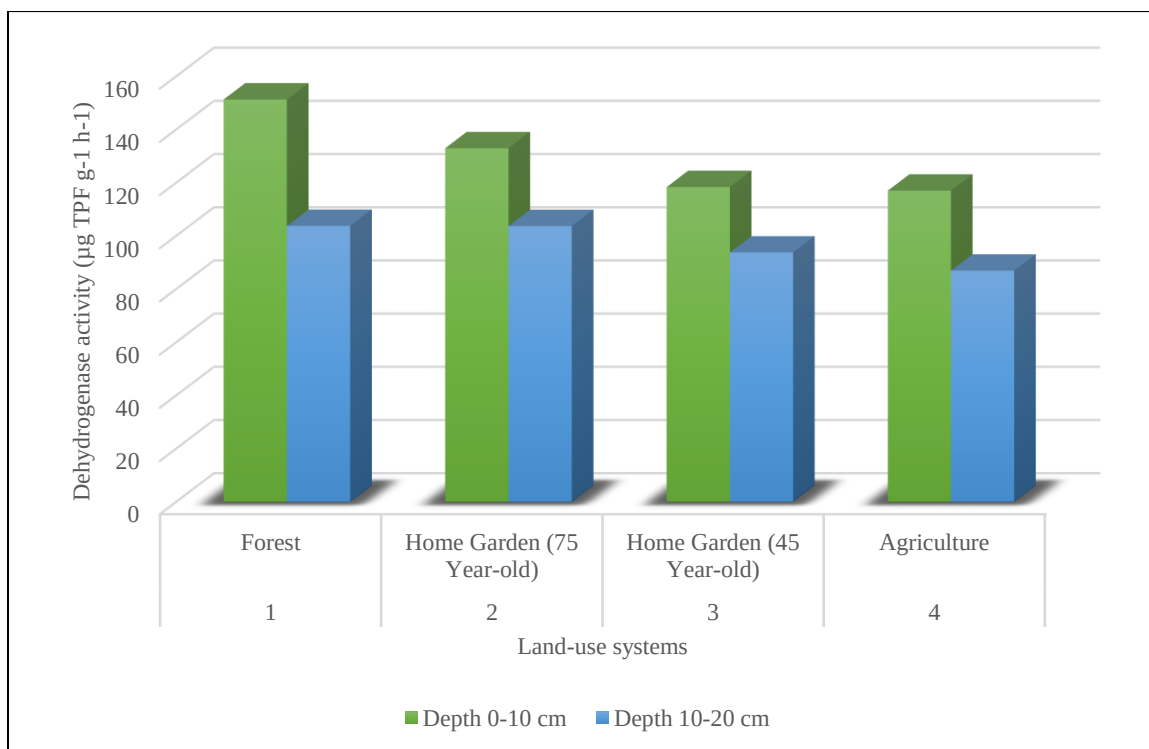


Fig.4.3.2. Dehydrogenase activity under different land-use systems at different depths

Table 4.3.2. a) Dehydrogenase activity ($\mu\text{g TPF g}^{-1} \text{ h}^{-1}$) under different land-use systems at different locations

Sl. No.	Location details	Land-use systems							
		Forest		HG (75)		HG (45)		Agriculture	
		0-10cm	10-20cm	0-10cm	10-20cm	0-10cm	10-20cm	0-10cm	10-20cm
1	Kottayam	121.37	95.79	157.88	100.44	100.44	97.65	133	104.16
2	Thrissur	94.86	86.49	131.14	101.37	124.49	100.09	129.28	86.44
3	Mallapuram	177.65	121.84	128.35	90.21	162.77	135.79	159.04	87.42
4	Kannur	127.42	95.79	106.95	101.37	141.37	92.07	99.77	73
5	Kasargoad	92.07	91.14	274.39	95.79	105.09	85.56	107.42	98.58
6	Bantawala	95.79	88.35	127.42	112.53	150.67	123.7	93.93	93.43
7	Karkala	119.56	76.86	133.01	124.63	146.02	91.14	96.72	65.56

Note: HG (75)- 75 year-old Home garden; HG (45)- 45 year-old Home garden

Table 4.3.2. b) Dehydrogenase activity ($\mu\text{g TPF g}^{-1} \text{ h}^{-1}$) under different land-use systems at different depths

Sl. No.	Treatments	Depths	
		0-10 cm	10-20 cm
1	Forest	151.30	103.76 ^a
2	Home Garden (75 Year-old)	132.97	103.71 ^a
3	Home Garden (45 Year-old)	118.38	93.75 ^b
4	Agriculture	117.02	86.94 ^b

Note: The statistical analysis was carried out by Duncan's Multiple Range Test (DMRT). The mean values followed by the same superscripts are not significant with each other. No significant difference was found among the means at 0-10 cm depth.

forest system compared to other land-use systems and it decreased with increase in soil depth, which could be accounted to the higher organic matter input compared to other land- use systems and also due to the least disturbance. The similarity in its activity in home gardens and forest system could be attributed to the similarity in their structures. When there is no disturbance to the soil system as in case of the forest system, as time progresses the soils keep accumulating organic matter which leads to increased microbial population which directly accounts for increased dehydrogenase activity. The least dehydrogenase activity was in agriculture system, which may be attributed to the reduction in the microbial population in the cultivated lands due to starvation by means of loss of soil organic matter due to the constant disturbance of the soil caused due to various cultivation practices.

The higher dehydrogenase activity in forest soils could be attributed to higher microbial population in this system, since dehydrogenases occur intracellularly in all living microbial cells and tightly linked with microbial oxidation-reduction processes and do not accumulate extracellularly in soils (Das and Varma, 2011), which also supports its least activity under agriculture system. Similar findings were obtained by Doran *et al.* (1980). He reported that the soil enzyme dehydrogenase showed higher activities in the soils of undisturbed sites than in conventional tillage or agriculture lands.

Our results coincide with studies by Bram *et al.* (2010) who reported a strong negative impact of intensive chemical fertilizer and pesticide use on soil enzyme activities. Dehydrogenase activity was correlated with soil organic matter content and pH. Soil microbial biomass carbon and dehydrogenase activity were found to be higher under forest.

The trend found in the dehydrogenase activities as affected by land use in our current study agrees with previous studies showing lower activities in cultivated soils when compared to the corresponding undisturbed or less-disturbed soils (Martnez *et al.* 2003).

In the soils subjected to intense agriculture use, the values of the soil enzyme activities were always lower than the forest lands; in the agricultural soils the enzyme activity was on average 42% of that in the forest soils. In the reforested and grassland soils the values of the enzyme activities were lower, equal or higher than the forest soils (Trasar *et al.*, 2008). This upholds the higher enzyme activity of soils under forest system in our study.

4.3.3. Alkaline and acid phosphatase activity

The alkaline phosphatase activity under different land-use systems at 0-10 cm and 10-20 cm depths is presented in Table 4.3.3. The alkaline phosphatase activity 0-10 cm was found to be significantly higher in forest system ($19.13 \mu\text{g PNP g}^{-1} \text{h}^{-1}$). It was on par with 45 year-old home garden agroforestry system ($14.87 \mu\text{g PNP g}^{-1} \text{h}^{-1}$). It was followed by the 45 year-old home garden ($11.25 \mu\text{g PNP g}^{-1} \text{h}^{-1}$). The least activity was in agriculture system ($10.14 \mu\text{g PNP g}^{-1} \text{h}^{-1}$).

The alkaline phosphatase activity decreased with depth. At 10-20 cm depth the activity of alkaline phosphatase was higher in forest system ($9.62 \mu\text{g PNP g}^{-1} \text{h}^{-1}$). It was on par with 45 year-old home garden agroforestry system ($9.07 \mu\text{g PNP g}^{-1} \text{h}^{-1}$) followed by 75 year-old home garden agroforestry system ($8.62 \mu\text{g PNP g}^{-1} \text{h}^{-1}$). The least alkaline phosphatase activity was in agriculture system ($7.16 \mu\text{g PNP g}^{-1} \text{h}^{-1}$).

The acid phosphatase activity under different land-use systems at 0-10 cm and 10-20 cm depths is presented in Table 4.3.4. The activity of acid phosphatase at 0-10 cm was found to be significantly higher in forest system (43.57 $\mu\text{g PNP g}^{-1} \text{ h}^{-1}$). It was followed by 45 year-old home garden agroforestry system (31.4 $\mu\text{g PNP g}^{-1} \text{ h}^{-1}$) and 75 year-old home garden (26.78 $\mu\text{g PNP g}^{-1} \text{ h}^{-1}$). The least acid phosphatase activity was in agriculture system (26.0 $\mu\text{g PNP g}^{-1} \text{ h}^{-1}$).

The acid phosphatase activity at the second depth *i.e.*, 10-20 cm followed the same trend. The highest activity was in the forest system (24.19 $\mu\text{g PNP g}^{-1} \text{ h}^{-1}$) followed by 45 year-old home garden (22.05 $\mu\text{g PNP g}^{-1} \text{ h}^{-1}$) which was followed by 75 year-old home garden agroforestry system (18.81 $\mu\text{g PNP g}^{-1} \text{ h}^{-1}$) and the least activity was in agriculture system (15.6 $\mu\text{g PNP g}^{-1} \text{ h}^{-1}$). The activity was found to decrease with depth.

In soil ecosystems, phosphatases (alkaline and acid phosphatases) are believed to play critical roles in P cycles as evidence shows that they are correlated to P stress and plant growth. Apart from being good indicators of soil fertility, phosphatase enzyme plays a key role in the soil system (Eivazi and Tabatabai, 1977). When there is a signal indicating P deficiency in the soil, phosphatase secretion from plant roots is increased to enhance the solubilization and remobilization of phosphate, thus influencing the ability of the plant to cope with P-stressed conditions (Karthikeyan *et al.*, 2002).

The phosphatases are important, because they provide P for plant uptake by releasing available form of P from immobile organic phosphates. The alkaline and acid phosphatase activities were significantly higher in the forest system compared to other land-use systems and they decreased with increase in soil depth, which could be accounted to the higher organic matter input compared to other land-use systems and also due to the least disturbance. The least activity was in agriculture system, which may be attributed to the reduction in the total soil organic matter due to the constant disturbance of the soil caused due to various cultivation practices.

Table 4.3.3. a) Alkaline phosphatase activity ($\mu\text{g PNP g}^{-1} \text{ h}^{-1}$) under different land-use systems at different locations

Sl. No.	Location details	Land-use systems							
		Forest		HG (75)		HG (45)		Agriculture	
		0-10cm	10-20cm	0-10cm	10-20cm	0-10cm	10-20cm	0-10cm	10-20cm
1	Kottayam	9.22	9.16	9.2	8.4	25.3	10.8	8.4	7.8
2	Thrissur	19.43	10.27	8.9	7.7	5.9	5.8	9.1	6.8
3	Mallapuram	22.59	8.86	9.1	8.4	19.8	9.6	7.1	3.9
4	Kannur	14.63	8.46	11.4	8.4	8.8	8.1	12.1	8.9
5	Kasargoad	15.64	8.65	15.1	7.3	9.5	9.1	12.3	8.3
6	Bantawala	16.27	8.38	8.4	8.1	21.6	14.4	14.8	7.3
7	Karkala	36.18	9.77	16.7	12.1	13.2	9.6	7.18	7.15

Note: HG (75)- 75 year-old Home garden; HG (45)- 45 year-old Home garden

Table 4.3.3. b) Alkaline phosphatase activity ($\mu\text{g PNP g}^{-1} \text{ h}^{-1}$) under different land-use systems at different depths:

Sl. No.	TREATMENTS	Depths	
		0-10 cm	10-20 cm
1	Forest	19.13 ^a	9.62
2	Home Garden (75 Year-old)	14.87 ^{ab}	9.07
3	Home Garden (45 Year-old)	11.25 ^b	8.62
4	Agriculture	10.14 ^b	7.16

Note: The statistical analysis was carried out by Duncan's Multiple Range Test (DMRT). The mean values followed by the same superscripts are not significant with each other. No significant difference was found among the means at 10-20 cm depth.

The alkaline phosphatase activity was much lower than the acid phosphatase activity in all the samples, which could be attributed to the acidic reaction of these soils.

Similar findings were obtained by Doran *et al.* (1980). He reported that the soil phosphomonoesterases (alkaline and acid phosphatases) showed higher activities in the soils of undisturbed sites than in conventional tillage or agriculture lands.

The trend found in the enzyme activities as affected by land use in our current study is in agreement with previous studies showing lower activities in cultivated soils when compared to the corresponding undisturbed or less-disturbed soils (Martnez *et al.*, 2003). They showed that higher organic matter input maintained high levels of phosphatase activity in soil, which supports the higher phosphatase activity in the forest sites in our study. The phosphatase activity is a combined effect of a higher degree of enzyme stabilization to humic substances and an increase in the soil microbial biomass with increased soil carbon content.

The decrease in activities of soil phosphomonoesterases (alkaline and acid phosphatases) with depth was also showed by Taylor *et al.* (2002).

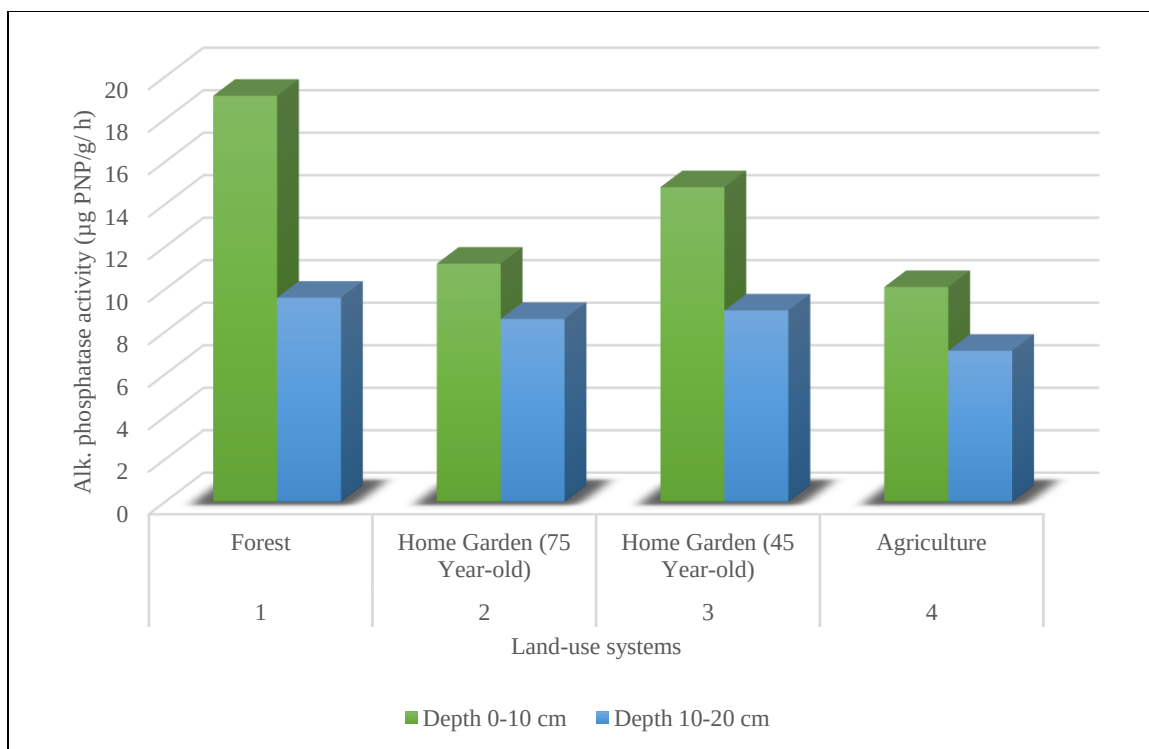


Fig.4.3.3. Alkaline phosphatase activity under different land-use systems at different depths

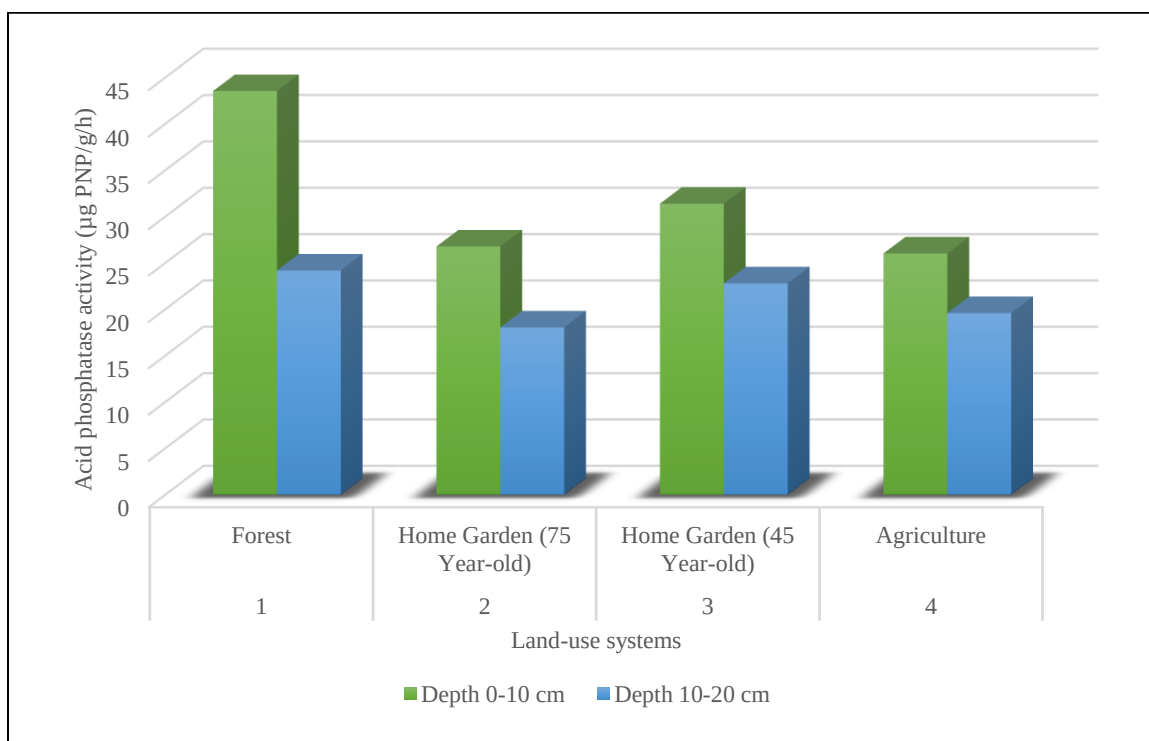


Fig. 4.3.4. Acid phosphatase activity under different land-use systems at different depths

Table 4.3.4. a) Acid phosphatase activity ($\mu\text{g PNP g}^{-1} \text{ h}^{-1}$) under different land-use systems at different locations

Sl. No.	Location details	Land-use systems							
		Forest		HG (75)		HG (45)		Agriculture	
		0-10cm	10-20cm	0-10cm	10-20cm	0-10cm	10-20cm	0-10cm	10-20cm
1	Kottayam	44.99	41.9	33.05	23	19.55	14.62	31.79	20.37
2	Thrissur	52.41	39.74	20.37	16.89	20	16.97	18.7	16.61
3	Mallapuram	30.93	10.14	21.99	16.64	35.34	26.79	22.25	14.6
4	Kannur	47.1	23.12	32.09	15.92	27.44	24.53	28.38	24.29
5	Kasargoad	41.94	36.47	17.41	15.97	24.82	21.38	27.01	26.16
6	Bantawala	56.13	25.46	14.41	12.32	56.62	39.46	29.26	23.14
7	Karkala	31.4	15.1	48.2	36.5	36.08	15.97	24.85	22.19

Note: HG (75)- 75 year-old Home garden; HG (45)- 45 year-old Home garden

Table 4.3.4. Acid phosphatase activity ($\mu\text{g PNP g}^{-1} \text{ h}^{-1}$) under different land-use systems at different depths:

Sl. No.	Treatments	Depths	
		0-10 cm	10-20 cm
1	Forest system	43.57 ^a	24.19
2	Home Garden (75 Year-old)	31.40 ^a	22.05
3	Home Garden (45 Year-old)	26.78 ^b	18.81
4	Agriculture	26.03 ^b	15.60

Note: The statistical analysis was carried out by Duncan's Multiple Range Test (DMRT). The mean values followed by the same superscripts are not significant with each other. There was no significant difference among the mean values at 10-20 cm depth.

4.4. Soil chemical properties

A soil's properties are largely determined by its parent material and weathering during its formation. Plant growth is influenced by the physical, chemical and biological properties of the soil. Soil chemical properties like soil reaction, soil electrical conductivity, organic matter content and available nitrogen content were estimated and discussed. Understanding soil properties is essential for nutrient planning and land-use decisions.

4.4.1. Soil organic carbon content

The organic carbon status at different land-use systems at 0-10 cm and 10-20 cm depths is presented in Table 4.4.1. The organic carbon content at the top soil layer i.e., 0-10 cm was found to be significantly higher in the forest system (2.63%). It was on par with 75 year-old home garden agroforestry system (2.35%) and 45 year-old home garden system (2.06%). The least organic carbon content was in agriculture system (0.67%).

The organic carbon status decreased with depth. At 10-20 cm depth the organic carbon content was significantly higher in the forest system (1.98%). It was on par with

75 year-old home garden agroforestry system (1.58%) and 45 year-old home garden agroforestry system (1.48%). The least organic carbon content was recorded in agriculture system (0.35%).

Soil organic carbon is an important global carbon pool, about 3 times larger than the amount of carbon stored in vegetation and twice the amount stored in the atmosphere. It provides energy for soil microorganisms, nutrient storage and supply (especially nitrogen, phosphorus and sulphur). It also improves soil structure as well as the soil's ability to hold water and resist acidification. But soil cultivation results in loss of organic carbon through release as carbon dioxide (CO₂) into the atmosphere.

The organic carbon status obtained in our study is in agreement with the studies by Boyer and Groffman (1996) who found that agricultural soils generally have lower amounts of total and microbial C than forest soils. When forest ecosystems are converted to agriculture, there is generally a marked decline in the amounts of total and labile soil organic carbon.

Higher soil organic carbon stocks in home garden agroforestry system in our study is supported by the study of Hombegowda *et al.* (2016) which showed that the establishment of home garden agroforestry system on agriculture land caused soil organic carbon stocks to rebound to near forest levels. The most important variable regulating SOC stocks and its changes was tree basal area, possibly indicative of organic matter inputs. Furthermore, climatic variables such as temperature and precipitation, and soil variables such as clay fraction and soil pH were likewise important regulators of SOC stock changes. Strong correlation was found between tree species diversity in home garden with the SOC stocks indicating possibilities to increase carbon stocks by proper tree species assemblies.

Table 4.4.1. a) Soil organic carbon (%) under different land-use systems at different locations

Sl. No.	Location details	Land-use systems							
		Forest		HG (75)		HG (45)		Agriculture	
		0-10cm	10-20cm	0-10cm	10-20cm	0-10cm	10-20cm	0-10cm	10-20cm
1	Kottayam	2.44	1.92	2.78	1.63	2.19	1.68	1.35	0.91
2	Thrissur	3.42	2.26	1.98	0.88	1.46	1.32	0.83	0.034
3	Mallapuram	2.19	1.62	2.86	1.43	2.86	1.43	0.68	0.71
4	Kannur	3.72	2.55	3.002	1.38	1.97	1.53	1.98	0.704
5	Kasargoad	2.72	1.88	2.25	2.39	1.47	1.87	1.85	0.45
6	Bantawala	2.76	1.55	2.41	0.72	2.56	1.65	1.36	0.92
7	Karkala	3.19	2.11	3.13	2.004	1.88	1.62	0.86	0.69

Note: HG (75)- 75 year-old Home garden; HG (45)- 45 year-old Home garden

Table 4.4.1. b) Soil organic carbon (%) under different land-use systems at different depths

Sl. No.	Treatments	Depths	
		0-10 cm	10-20 cm
1	Forest	2.63 ^a	1.98 ^a
2	Home garden (75 year-old)	2.35 ^a	1.58 ^a
3	Home garden (45 year-old)	2.06 ^a	1.48 ^a
4	Agriculture	0.67 ^b	0.36 ^b

Note: The statistical analysis was carried out by Duncan's Multiple Range Test (DMRT). The mean values followed by the same superscripts are not significant with each other.

4.4.2. Available nitrogen

The available nitrogen content at different land-use systems at 0-10 cm and 10-20 cm depths is presented in Table 4.4.2. The available nitrogen content at 0-10 cm soil depth was found to be highest in the forest system (0.29%). It was followed by 75 year-old home garden agroforestry system (0.17%) which was on par with 45 year-old home garden system (0.16%). The least available nitrogen content was in agriculture system (0.11%). The available nitrogen content decreased with depth. At 10-20 cm depth the organic carbon content was highest in the forest system (0.15%). It was followed by 75 year-old home garden agroforestry system (0.13%) and 45 year-old home garden agroforestry system (0.12%). The least available nitrogen content was recorded in agriculture system (0.09%).

Nitrogen is one of the major elements required for life. Some N absorbed by trees is returned to the soil in fallen litter. Maintenance of forest soil fertility is partly dependent on the return of N and mineral nutrients by decay of litter. Leaves and twigs that are shed annually add up to several thousand kilograms of organic material possessing approximately 1% N-containing compounds which explains the higher available N content in forest and home garden agroforestry system soils compared to agriculture lands.

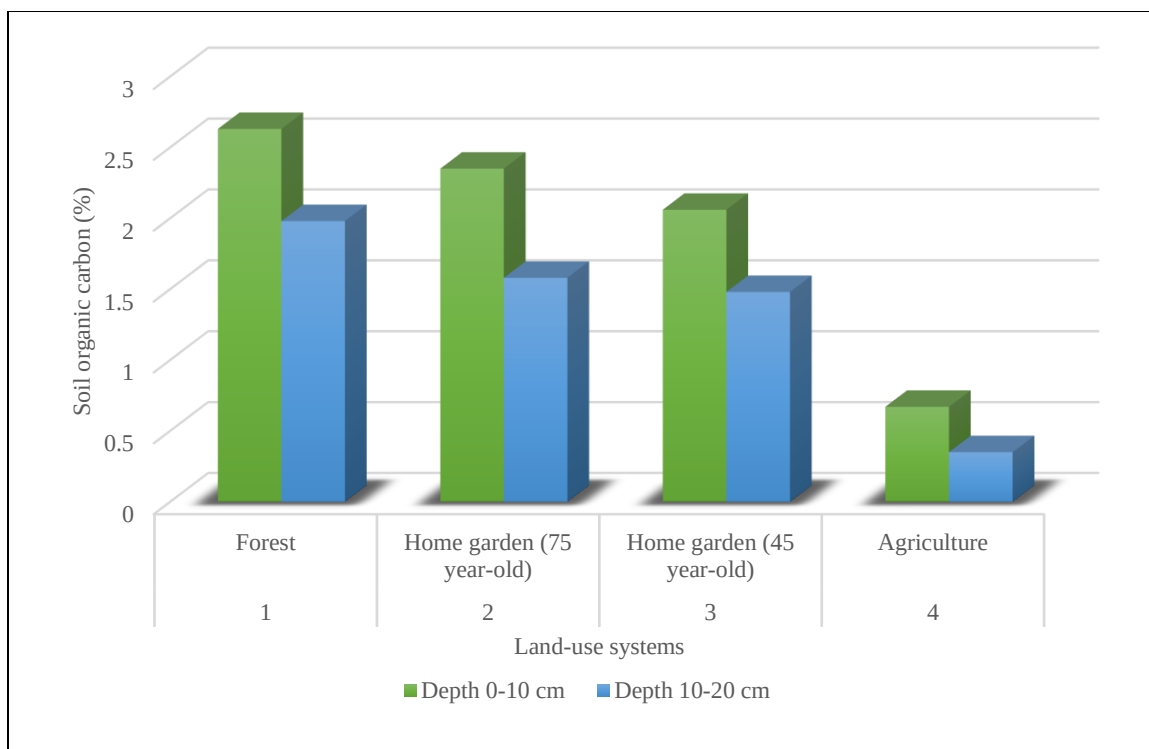


Fig.4.4.1. Soil organic carbon content under different land-use systems at different depths

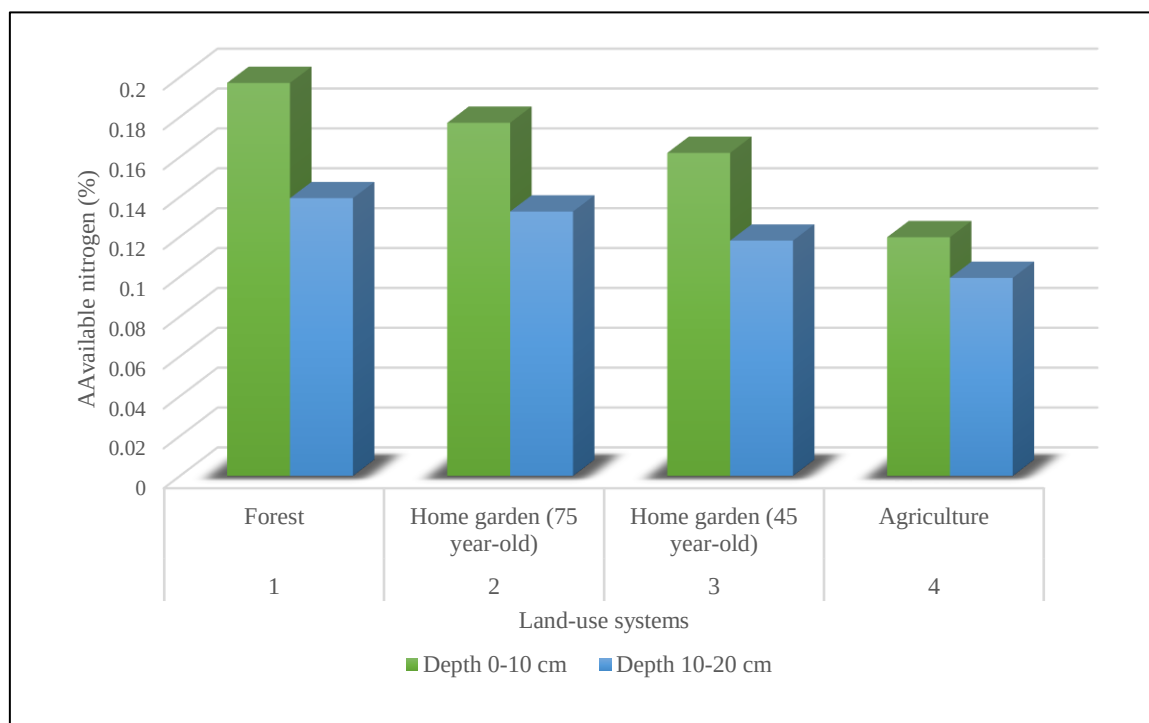


Fig.4.4.2. Percentage available nitrogen under different land-use systems at different depths

4.4.2. a) Available nitrogen (%) under different land-use systems at different locations

Sl. No.	Location details	Land-use systems							
		Forest		HG (75)		HG (45)		Agriculture	
		0-10cm	10-20cm	0-10cm	10-20cm	0-10cm	10-20cm	0-10cm	10-20cm
1	Kottayam	0.198	0.133	0.192	0.14	0.223	0.177	0.121	0.08
2	Thrissur	0.09	0.086	0.131	0.116	0.294	0.2	0.088	0.105
3	Mallapuram	0.103	0.107	0.221	0.127	0.128	0.117	0.066	0.071
4	Kannur	0.131	0.088	0.16	0.13	0.097	0.056	0.174	0.142
5	Kasargoad	0.176	0.189	0.125	0.131	0.228	0.159	0.175	0.134
6	Bantawala	0.215	0.068	0.259	0.151	0.198	0.12	0.122	0.089
7	Karkala	0.221	0.155	0.152	0.133	0.212	0.146	0.092	0.074

Note: HG (75)- 75 year-old Home garden; HG (45)- 45 year-old Home garden

Table.4.4.2. b) Available nitrogen (%) under different land-use systems at different depths

Sl. No.	TREATMENTS	Depths	
		0-10 cm	10-20 cm
1	Forest	0.19	0.13
2	Home garden (75 year-old)	0.17	0.13
3	Home garden (45 year-old)	0.16	0.11
4	Agriculture	0.11	0.09

Note: The statistical analysis was carried out by Duncan's Multiple Range Test (DMRT). There was no significant difference among the mean values.

4.4.3. Soil reaction

The soil reaction or pH under different land-use systems at 0-10 cm and 10-20 cm depths is presented in Table 4.4.3. The pH at the top soil layer *i.e.*, 0-10 cm was found to be higher or near-neutral in the forest system (5.80). It was on par with 75 year-old home garden agroforestry system (5.68) and 45 year-old home garden system (5.46). The least pH content was in agriculture system (5.14) which was near-acidic.

The pH decreased with depth. At 10-20 cm depth the pH was higher in the forest system (5.6). It was on par with 75 year-old home garden agroforestry system (5.55) and 45 year-old home garden agroforestry system (5.35). The least p^H was recorded in agriculture system (5.1).

Soil pH value is actually a measure of hydrogen ion concentration. Soil pH affects the amount of nutrients and chemicals that are soluble in soil water, and therefore the amount of nutrients available to plants. Some nutrients are more available under acid conditions while others are more available under alkaline conditions. However, most mineral nutrients are readily available to plants when soil pH is near neutral. The correct

Table.4.4.3. a) Soil reaction under different land-use systems at different locations

Sl. No.	Location details	Land-use systems							
		Forest		HG (75)		HG (45)		Agriculture	
		0-10cm	10-20cm	0-10cm	10-20cm	0-10cm	10-20cm	0-10cm	10-20cm
1	Kottayam	5.52	5.38	5.34	5.64	5.42	5.23	4.98	5.32
2	Thrissur	5.264	4.849	5.92	5.91	5.562	5.569	4.949	4.917
3	Mallapuram	5.719	5.642	5.916	4.703	5.769	5.315	5.738	5.543
4	Kannur	5.673	5.431	5.716	5.422	5.927	5.618	4.685	5.189
5	Kasargoad	5.363	5.367	5.555	5.533	5.941	6.016	5.129	5.402
6	Bantawala	5.719	5.096	5.989	6.015	5.747	5.532	5.386	5.788
7	Karkala	5.247	4.972	5.614	5.839	6.118	6.121	5.591	5.626

Note: HG (75)- 75 year-old Home garden; HG (45)- 45 year-old Home garden

Table.4.4.3. b) Soil reaction under different land-use systems at different depths

Sl. No.	Treatments	Depths	
		0-10 cm	10-20 cm
1	Forest	5.74	5.60
2	Home garden (75 year-old)	5.68	5.55
3	Home garden (45 year-old)	5.45	5.35
4	Agriculture	5.14	5.18

Note: The statistical analysis was carried out by Duncan's Multiple Range Test (DMRT). There was no significant difference among the means.

balance is where the soil pH is between 5.5 and 7.5 which is usually true in case of forest soils.

The lower pH under agriculture system could be attributed to frequent fertilization with chemical fertilizers which leads to acidification of these soils.

4.4.4. Soil electrical conductivity

The soil electrical conductivity under different land-use systems at 0-10 cm and 10-20 cm depths is presented in Table 4.4.4. The electrical conductivity at the top layer i.e., 0-10 cm was found to be higher in the forest system (0.66 dS m^{-1}). It was on par with 75 year-old home garden agroforestry system (0.55 dS m^{-1}) and 45 year-old home garden system (0.53 dS m^{-1}). The least electrical conductivity was in agriculture system (0.21 dS m^{-1}).

Table.4.4.4. a) Soil electrical conductivity (dS m⁻¹) under different land-use systems at different locations

Sl. No.	Location details	Land-use systems							
		Forest		HG (75)		HG (45)		Agriculture	
		0-10cm	10-20cm	0-10cm	10-20cm	0-10cm	10-20cm	0-10cm	10-20cm
1	Kottayam	0.124	0.08	0.15	0.044	0.098	0.058	0.086	0.037
2	Thrissur	0.126	0.058	0.163	0.075	0.089	0.06	0.074	0.059
3	Mallapuram	0.061	0.049	0.077	0.04	0.123	0.042	0.062	0.046
4	Kannur	0.072	0.045	0.055	0.078	0.108	0.104	0.049	0.029
5	Kasargoad	0.066	0.05	0.086	0.056	0.091	0.044	0.121	0.063
6	Bantawala	0.147	0.054	0.124	0.072	0.091	0.038	0.101	0.041
7	Karkala	0.091	0.056	0.06	0.036	0.03	0.023	0.062	0.031

Note: HG (75)- 75 year-old Home garden; HG (45)- 45 year-old Home garden

Table.4.4.4. b) Soil electrical conductivity (dS m⁻¹) under different land-use systems at different depths

Sl. No.	TREATMENTS	Depths	
		0-10 cm	10-20 cm
1	Forest	0.65	0.057
2	Home garden (75 year-old)	0.55	0.056
3	Home garden (45 year-old)	0.53	0.052
4	Agriculture	0.21	0.043

Note: The statistical analysis was carried out by Duncan's Multiple Range Test (DMRT). There was no significant difference among the mean values.

The electrical conductivity decreased with depth. At 10-20 cm depth the electrical conductivity was higher in the forest system (0.057 dS m⁻¹). It was on par with 75 year-old home garden agroforestry system (0.056 dS m⁻¹) and 45 year-old home garden agroforestry system (0.053 dS m⁻¹). The least electrical conductivity was recorded in agriculture system (0.043 dS m⁻¹).

EC is a valuable agricultural tool that provides spatial information for soil quality assessment and precision agriculture applications including the recommendation of site-specific management remedies (Corwin and Lesch, 2005).

Soil electrical conductivity is a measurement that correlates with soil properties that affect crop productivity, including soil texture, cation exchange capacity (CEC), drainage conditions, organic matter level, salinity, and subsoil characteristics (Robert *et al.*, 2006).

It indicates the cation exchange capacity of the soils which is an indirect measure of the soil fertility which supports our results of higher EC in the forest soils compared to other land-use systems. It also indirectly measures the organic matter- related soil properties like organic carbon.

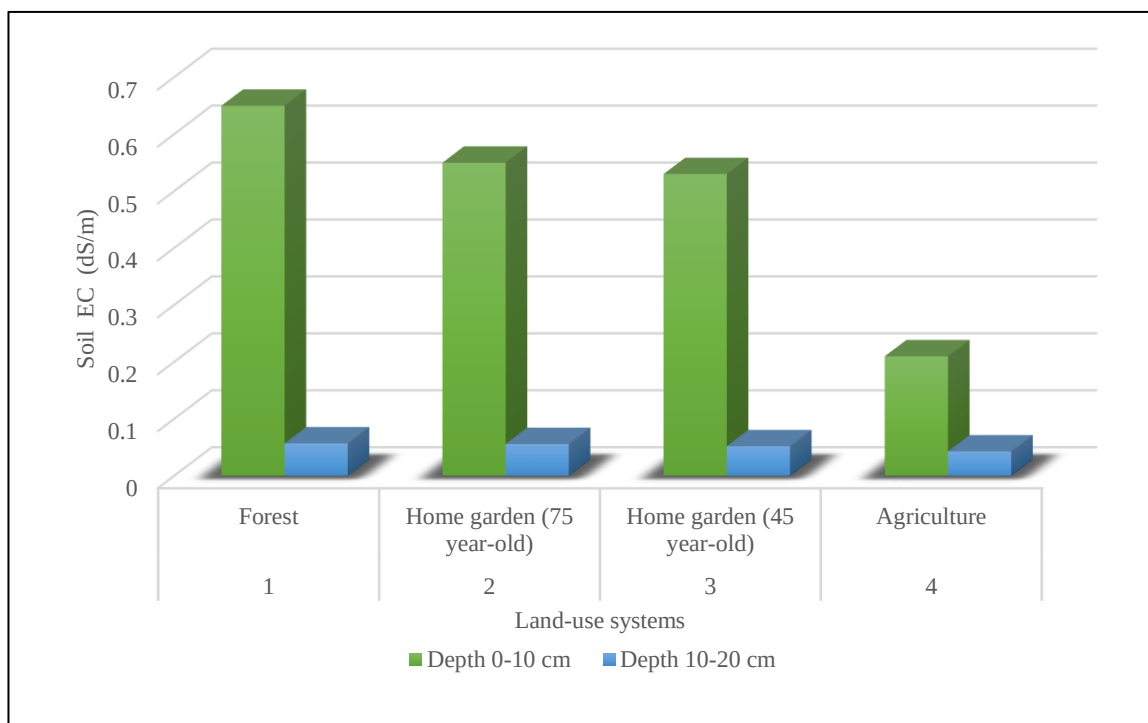


Fig.4.4.3. Soil electrical conductivity under different land-use systems at different depths

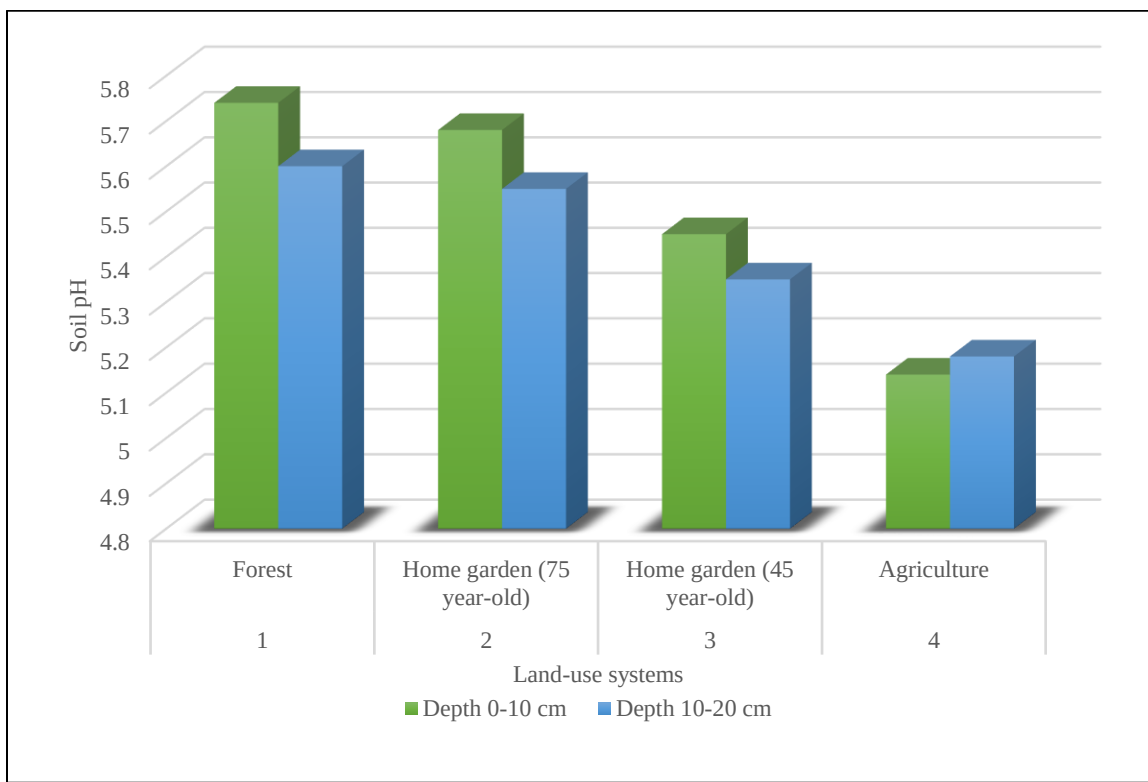


Fig.4.4.4. Soil reaction under different land-use systems at different depths

As EC indirectly indicates the organic matter status of the soil, it supports the lower EC of soils under agriculture system which has low organic carbon content.

4.5. Correlation study

The correlation study suggested that all the microbial parameters like the soil microbial biomass C, N and P, the population of functional groups of microorganisms and the soil enzymes had strong positive correlation with the soil physicochemical properties like soil pH, EC, soil organic carbon and available nitrogen.

V SUMMARY

As the most active part in soil organic matter, soil microbial biomass is important in nutrient cycling and release, acting as source and sink for plant nutrients. It can directly reflect soil fertility status and can be used as an indicator for assessing soil quality of different land-use systems. The present study focuses on the assessment of soil microbial and biochemical characters as influenced by the land-use systems and soil depth and the importance of home garden agroforestry system in maintaining soil carbon stocks. The soil samples were collected and analyzed in the laboratory for different parameters at the Department of Agricultural Microbiology, University of Agricultural Sciences, GKVK, Bengaluru. The results thus obtained from this study are summarized below.

The investigation was studied in a chronosequence approach to study how soil microbial carbon stocks changed when the original forests are converted to agriculture, and then subsequently to home garden agroforestry system. Investigations were carried out in soil samples collected from seven locations including parts of Kerala and Karnataka from 0-10 and 10-20 cm depths under four land-use systems viz., forest system, 45 year-old home garden agroforestry system, 75 year-old home garden agroforestry system and intensive agriculture system. The objectives of this study were i) to estimate the microbial biomass carbon, nitrogen and phosphorous ii) to enumerate the functional groups of microorganisms iii) determination of soil enzyme activities.

The soil microbial biomass carbon, nitrogen and phosphorus were found to be significantly higher in the forest soils compared to all other treatments. The abundance of different functional groups of microorganisms such as nitrogen fixers, phosphate solubilizers, potassium solubilizers, cellulose degraders and lignin degraders were also found to be significantly higher in the soils under forest system compared to all other treatments. Soil enzyme activities viz., dehydrogenases, acid and alkaline phosphatases activities were also found to be significantly higher in the soils under forest system with urease as exception which was found to be higher in soils under intensive agriculture system.

The soil chemical parameters such as organic-C, available-N, available-N, soil reaction and electrical conductivity were also found to be significantly higher in the forest soils.

These results suggest that the establishment of home garden agroforestry system on agriculture land helps the soil microbial biomass carbon stocks to rebound to near-forest levels.

The most important variable regulating SMBC stocks and its changes was litter fall, possibly indicative of organic matter inputs. It also shows that the indigenous beneficial microbial activity can be stimulated and their abundance, biochemical parameters such as dehydrogenases, acid and alkaline phosphatases and urease activities and microbial parameters like soil microbial biomass C, N and P could be conserved by taking up agroforestry systems like home gardens instead of intensive agriculture.

The higher soil microbial biomass carbon stocks in home gardens compared to intensively cultivated agriculture lands, shows the potential of incorporating tree species in crop production systems which slows down depletion of carbon after conversion and also their carbon sequestration potential. Although the potential of carbon storage in traditional agroforestry systems like home gardens is lower compared to natural forests, it is still high compared to intensively cultivated lands.

Intensive agriculture is a threat to environment and to mankind. Intensive agriculture results in significant reduction in soil carbon stock by the combined effects of rapid decomposition of soil organic matter by intensive ploughing and reduction of carbon input by roots and aboveground biomass. The ever-depleting organic carbon stocks and the microbial biomass carbon stocks in soils of intensive agriculture system can be restored to at least near C stocks level as that of the forest soils by implementing semi-natural agroforestry system like home gardens.

The role of land use systems in capturing atmospheric carbon dioxide and storing the C in plant parts and soil has become an important area of research since the past decade. Agroforestry systems have indirect effects on carbon sequestration because they

reduce harvesting pressure on natural forests which are the largest sinks for terrestrial carbon. The growing body of literature indicates that agroforestry systems has the potential to sequester large amounts of above and below ground carbon in addition to soil organic carbon enhancement, as compared to treeless farming systems.

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APPENDIX

Bray's extractant No.1 (0.03 N NH_4F in 0.025 N HCl)

1.11g of NH_4F was dissolved in about 250 ml distilled water and 2 ml of conc. HCl was added to this and the volume made to one litre.

Chloromolybdic acid

15 g of ammonium-molybdate was dissolved in 300 ml of hot distilled water (50 – 60°C) and 350 ml of 10N HCl was added slowly with rapid stirring. The solution was cooled and the volume was made to one litre and stored in amber coloured bottle.

Stannous chloride stock solution

10 g of SnCl_2 was dissolved in 25 ml of conc. HCl and a piece of pure metallic tin was added and stored in an amber coloured glass stoppered bottle. The working solution was prepared by diluting 0.5 ml of stock solution to 66 ml with distilled water just before use. Working solution was prepared fresh.

Modified universal buffer (MUB)

12.1 g of tris (hydroxymethyl) amino methane (THAM), 11.6 g of Maleic acid, 14.0 g of citric acid, and 6.3 g of boric acid (H_3BO_3) were dissolved in 488 ml of 1 N NaOH and the solution was diluted to one litre and stored in a refrigerator.

Modified universal buffer (MUB) 6.5 and 11 pH

200 ml of MUB stock solution was placed in a 500 ml beaker containing a magnetic stirring bar and the beaker was placed on a magnetic stirrer. The solution was titrated to pH 6.5 with 0.1 N HCl and the volume was adjusted to one litre with water. Another 200 ml of the MUB stock solution was titrated to pH 11 by using 0.1 N NaOH and the volume was adjusted to one litre with distilled water.

Chloromolybdic acid

Chloromolybdic acid reagent was prepared by dissolving 7.5 g of ammonium molybdate in 150 ml distilled water to which 162 ml of conc. HCl was added. The volume was made up to one litre with distilled H₂O.

Jensen's agar:

Ingredients	gram / litre
Sucrose	20.000
Dipotassium phosphate	1.000
Magnesium sulphate	0.500
Sodium chloride	0.500
Ferrous sulphate	0.100
Sodium molybdate	0.005
Calcium carbonate	2.000
Agar	15.000

Pikovskayas agar:

Ingredients	gram / litre
Yeast extract	0.500
Dextrose	10.000
Calcium phosphate	5.000
Ammonium sulphate	0.500
Potassium chloride	0.200
Magnesium sulphate	0.100

Manganese sulphate	0.0001
Ferrous sulphate	0.0001
Agar	15.000

Akexandrow agar:

Ingredients	gram / litre
Magnesium sulphate	0.500
Calcium carbonate	0.100
Potassium alumino silicate	2.000
Glucose	5.000
Ferric chloride	0.005
Calcium phosphate	2.000
Agar	20.000

Dubose cellulose agar:

Ingredients	gram / litre
NaNO ₃	0.5
K ₂ HPO ₄	1.0
Cellulose	1.0
MgSO ₄	0.5
KCl	0.5
Fe ₂ SO ₄	Trace
Agar	15.00