DISTRIBUTION AND TRANSFORMATION OF PHYTOLITHS UNDER CONTINUOUS TEAK ROTATION

By

GAYATRI A S

(2016-20-030)

THESIS

Submitted in partial fulfilment of the requirement for the degree

of

B.Sc. - M.Sc. (Integrated) Climate Change Adaptation

Faculty of Agriculture

Kerala Agricultural University, Thrissur

COLLEGE OF CLIMATE CHANGE AND ENVIRONMENTAL SCIENCE

VELLANIKKARA, THRISSUR – 680656

KERALA, INDIA

2021

DECLARATION

I hereby declare that the thesis entitled **"DISTRIBUTION AND TRANSFORMATION OF PHYTOLITH UNDER CONTINUOUS TEAK ROTATION"** is a bonafede record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me any degree, diploma, fellowship or other similar title, of any other University or Society.

Vellanikkara, **GAYATRI A S**

(2016-20-030)

Date:

CERTIFICATE

Certified that this thesis entitled **"DISTRIBUTION AND TRANSFORMATION OF PHYTOLITH UNDER CONTINUOUS TEAK ROTATION"** is a record of research work done independently by Ms. Gayatri A. S under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

Vellanikkara

Date:

Dr. S Sandeep

(Major Advisor, Advisory Committee)

Senior Scientist, Department of Soil Science,

Sustainable Forest Management Division,

Kerala Forest Research Institute.

CERTIFICATE

We, the undersigned members of the advisory committee of Ms. Gayatri A. S, a candidate for the degree of B.Sc. – M.Sc. (Integrated) Climate Change Adaptation agree that the thesis entitled **"Distribution and transformation of phytoliths under continuous teak rotation**" may be submitted by Ms. Gayatri A. S in partial fulfilment of the requirement for the degree.

Dr. A.V. Santhoshkumar

(Chairman, Advisory Committee)
Senior Scientist
Department of Soil Science
Sustainable Forest Management
Division
KSCSTE – Kerala Forest Research Institute
Peechi, Thrissur
Kerala, India

(Member, Advisory Committee)
Professor and Head
Department of Forest Biology
College of Forestry
Kerala Agricultural University
Vellanikkara, Thrissur
Kerala, India.

Dr. P.O. Nameer

(Member, Advisory Committee)
Dean
College of Climate Change and
Environmental Science
Kerala Agriculture University
Vellanikkara, Thrissur
Kerala, India

Dr Vijayan. V

(Member, Advisory Committee)
Department of Soil Science and
Agricultural Chemistry
College of Agriculture
Kerala Agricultural University
Vellanikkara, Thrissur
Kerala, India

CERTIFICATE

We, the undersigned members of the advisory committee of Ms. Gayatri A. S, a candidate for the degree of B.Sc. – M.Sc. (Integrated) Climate Change Adaptation agree that the thesis entitled **"Distribution and transformation of phytoliths under continuous teak rotation**" may be submitted by Ms. Gayatri A. S in partial fulfilment of the requirement for the degree.

Dr. S. Sandeep

(Chairman of advisory committee) – Senior scientist, Department of Soil Science, Sustainable Forest Management Division, KSCSTE – Kerala Forest Research Institute, Peechi, Thrissur - Kerala, India

Dr. P.O. Nameer

(Member of advisory committee) – Dean, College of Climate Change and Environmental Science, Kerala Agricultural University, Vellanikkara – Thrissur, Kerala - India

Dr. A.V. Santhoshkumar

(Member of advisory committee) – Professor and Head – Department of Forest Biology, College of Forestry, Kerala Agricultural University, Vellanikkara, Thrissur – Kerala-India

Dr Divya Vijayan. V

(Member of advisory committee) – Department of Soil Science and Agricultural Chemistry, College of Agriculture, Kerala Agricultural University, Vellanikkara – Thrissur, Kerala - India

Dr U. Surendran

(External Examiner) – Senior scientist & Head (i/c), Land and Water Management Research Group, CWRDM, Kozhikode, Kerala - India

ACKNOWLEDGEMENT

When all good things come to an end, memories are left behind. In this regard I feel highly obliged to all those who have helped me to see this day.

At this moment of accomplishment, first and foremost I would like to express my sincere gratitude to my mentor ***Dr. Sandeep S****, Senior Scientist, Department of Soil Science, Sustainable Forest Management Division, KSCSTE- Kerala Forest Research Institute, Peechi, Thrissur. This work would not have been possible without his guidance, encouragement and support. The time which I spent in his council and company have made an inspiration on me which I will never forget.*

I feel great pleasure to express my cordial gratitude and indebtedness to ***Dr. P.O Nameer****, Professor and Head, Special Officer, Academy of Climate Change Education Research for his constant help and valuable suggestions without which this work would have not been completed.*

I express my sincere thanks to ***Dr A.V Santhoshkumar****, Professor and Head, Department of Forest Biology and Tree Improvement, College of Forestry, Kerala Agricultural University, Vellanikkara,* ***Dr Divya Vijayan V,*** *Department of Soil Science and Agricultural Chemistry College of Horticulture Kerala Agricultural University, Vellanikkara, who were the able members of my advisory committee for their timely cooperation and valuable support extended during the period of my MSc work.*

I owe a great deal of appreciation and gratitude to ***Tomjo C.P, Panchami Jaya, Vishnu V.J, Alan Rose, Faniya Tobi, Divyasree, Nisha, Sunitha and all the staffs*** *of Kerala Forest Research Institute who had helped several times during my work.*

I express my special thanks to my seniors ***Abhijith. V, Binsiya, Navya****, for the encouragement and undying support extended towards me and for*

*keeping my spirits up. I express my sincere gratitude to **Smrithy M G**, for her immense support during the whole period.*

*I greatly value my batch **CAMPEONES 2016**, the greatest treasure that I have ever possessed. Their support and care helped me overcome setbacks and stay focused on my graduate studies and hence the thesis. I deeply appreciate their beliefs in me.*

I thank God for having given me the opportunity to come across him in my life.

*Last but not the least, I am indebted to whole heartedly my **Amma, Achan, sister and my whole family** for lifting me up till this phase of life. Their sacrifice remains as a source of inspiration and which had kept me going ahead with full spirit during tough times.*

GAYATRI A. S

CONTENTS

CHAPTER NO:	TITLE	PAGE NO:
	LIST OF TABLES	VIII
	LIST OF FIGURES	IX- X
	ABBREVIATIONS	XI
1	INTRODUCTON	1-4
2	REVIEW OF LITERATURE	5-24
3	MATERIALS AND METHODS	25-37
4	RESULTS AND DISCUSSION	38-67
5	SUMMARY AND CONCLUSION	68-71
	REFERENCES	72-89
	ABSTRACT	90-93

LIST OF TABLES

SL NO:	TITLE	PAGE NO.
1	Different works done on phytolith	14-16
2	Studies done on phytolith outside India	16-19
3	Studies done on phytolith in India	20-21
4	Sampling site	26
5	List of treatments done in hydroponics	35
6a	Physical properties of soils of North Central laterite	39-40
6b	Chemical properties of soils of North Central laterite	41
6c	Chemical properties of soils of North Central laterite	42
6d	Soil organic carbon and PhytOC content of North Central laterite soil	43
7	Changes in PhytOC content of soil samples after HCl and oxalate treatments	51
8	Effect of Silicon treatments on PhytOC% intake	60

LIST OF FIGURES

TABLE NO.	TITLE	PAGE NO.
1	Development of phytolith	8
2a	Northern Central Laterite - Forest	27
2b	North Central Laterite - Plantation	27
2c	North Central Laterite – Open land	27
3a	Digestion unit and samples	31
3b	Sample for digestion	31
3c	Samples for digestion	31
3d	Filtered aspirator	31
3e	Samples after drying in the oven	31
3f	Drying of samples on hot plate	31
3g	Incubator shaker	31
4a	Hydroponics - Week 1 of treatment	36
4b	Hydroponics - Week 2 of treatment	36
4c	Hydroponics - Week 3 of treatment	37
5a	PhytOC content as a % of total soil organic carbon (toc) in plantations of NCL	44

5b	PhytOC content as a % of total soil organic carbon in natural forest of NCL	46
5c	Figure 15c. PhytOC content as a % of total soil organic carbon in open land of NCL	46
6a – 6l	Structural analysis of phytoliths	48-50
7a- 7z	Structural variations in Phytolith after Dissolution experiments	52-58
8a- 8u	Structural variations in phytoliths after dissolution experiments	61-65

SYMBOLS AND ABBREVIATION

CO_2	Carbon dioxide
AR5	Fifth Assessment Report
SOM	Soil organic matter
PhytOC	Phytolith occluded carbon
IPCC	Inter governmental Panel on Climate Change
Ppmv	Parts per million volumes
GT	Giga tonne
Pg	Peta gramme
Tg	Tera gramme
NCL	North Central Laterite
CEC	Cation Exchange Capacity
cmols	centimoles
kg/ha	Kilogramme per hectare
mg/kg	Milligram per kilogramme
cmol/kg	centimoles per kilogramme
TOC	Total organic carbon
C	Carbon
cm	centimetre

INTRODUCTION

CHAPTER 1

INTRODUCTION

Today's world is facing the horrors of climate change in the form of different threats and impacts. Rise in global temperature, warming of ocean, shrinking of ice sheets, glacial retreat, decreased snow cover, sea level rise, extreme events, acidification of ocean, disruption of ecosystem, breakdown of the biogeo chemical cycles etc are a few of such horrors. Global warming, one of the main drivers of climate change is caused by the increase in various greenhouse gases like carbon dioxide, methane, nitrous oxide, chlorofluro carbons, sulphur hexa fluoride.

Global Warming Potential (GWP) measure how much energy the emissions of 1 ton of a gas will absorb over a given period of time, relative to the emissions of 1 ton of carbon dioxide (CO_2) and helps us to compare the global warming effects of different gases. As per AR5, GWP value for CO_2 is 1, which is much lower than that of CH_4 (28) and N_2O (265), still CO_2 have an upper hand in causing global warming because it is released in large amounts to atmosphere through fossil fuel burning, land use. As per Working group I of Fifth Assessment Report (AR5), CO_2 have a high residence time, as it is not destroyed over period and just moves among different parts of ocean-land-atmosphere system.

According to (AR5), since 2011, the atmospheric concentration of CO_2 has reached annual averages of 410 ppm. CO_2 emitted through human activities over the past six decades amounts to about 56% per year and is taken up by the land and ocean. According to Sixth Assessment Report (AR6) Global surface temperature (referring to both global mean surface temperature and global surface air

temperature) was found to be 1.09 (0.95 TO 1.02) ºC higher in 2011 – 2020 than 1850 – 1900 with larger increase over land with 1.59 (1.34 – 1.83) º C than over ocean with 0.88 (0.68 – 1.01) º C. Atmospheric CO_2 concentrations in 2019 were higher than what was seen in at least 2 million years (high confidence). Data from NOAA's Mauna Loa observatory shows the rate of CO_2 growth over the past decade is 100 to 200 times greater than what Earth experienced during the transition from the last Ice Age.

The constant rise in global average temperature has hastened the release of enormous amounts of carbon from soil, resulting in enhanced soil respiration (Chan *et al*.,2002, Jansson *et al*.,2010, Watson *et al*.,2000, Schulp *et al*.,2008) At the moment, there are two efficient approaches to manage CO_2 levels in the atmosphere: reducing emissions and increasing carbon sinks. Soil is the greatest carbon reservoir in terrestrial ecosystems, according to studies (Falkowski *et al.,*2000). Soil's total organic carbon concentration is three times that of plant carbon pools (Watson 2000, Falkowski 2000, Eswaran *et al*.,1993). Despite the soil's immense potential to store carbon, land use change, complex carbon storage systems, and continually changing environmental circumstances mean that most organic carbon in soil cannot survive for long periods of time (Lal 2003, Freibauer 2004). As a result, finding a safe and effective long-term carbon sequestration method is essential

Thus, it is very important to remove this CO_2. Sequestration is the process by which atmospheric CO_2 is captured and stored. This is majorly of two types – biologic (in vegetation, ocean, soil etc.) and geologic (in underground geologic formations). Biologic sequestration or bio sequestration involves continued or enhanced biological processes by which carbon is captured and stored. Soil organic carbon can be classified to recalcitrant and labile soil carbon based on availability to soil microorganisms and decomposability, where soil microbial biomass carbon, dissolved organic matter, and easily oxidative organic matter comprises of labile carbon whereas Soil organic matter (SOM) which is resistant to microbial decomposition or that is protected by soil mineral particles. (Fang et al. 2005; von Lützow *et al*. 2007). Phytoliths are one example for recalcitrant carbon.

Phytoliths are silicified structures in plants which can store organic carbon called PhytOC (Phytolith occluded carbon). After the decomposition of the vegetation, it is passed on to the soil. This carbon stored in phytoliths are resistant to disintegration and remain in soil for long time ((Parr & Sullivan,2005). Phytoliths are found in abundant quantities in monocots like rice, wheat, bamboo and in some dicots (Parr & Sullivan ,2005). Among the terrestrial systems, plant biomass is a major sink for atmospheric carbon.

Many phytolith studies have been carried out in monocots like rice, bamboo, maize etc but phytolith studies on dicots are less, especially in teak, a major plantation in the Southern Western Ghats. This project aims to assess the phytolith contents in soils under continuous teak cultivations and effects of different soil parameters on their structure and content.

The objective of the study is to evaluate the changes in the vertical distribution of phytoliths in soil phytolith transformations under continuous teak rotation affecting the efficiency of teak plants in bio sequestering carbon in phytolith.

REVIEW OF LITERATURE

CHAPTER 2

REVIEW OF LITERATURE

Atmospheric CO_2 is very much important for photosynthesis and sustenance of life but its increasing concentration can affect Earth's climate (Beedlow, 2004). Since the pre-industrial era, anthropogenic greenhouse gas (GHG) emissions have resulted in significant increases in atmospheric carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (NOx) concentrations (N_2O) (AR5 2014). Due to greenhouse gases' (GHG) radiative forcing there has been a 0.6 ºC rise in global temperature during the 20th century and by 2100 it is projected to show a rise from 1.4 to 5.6 ºC relative to 1990 (IPCC 2001). About half of the 6 petagrams (10^{15}) of carbon emitted per year as a reason of human activities are absorbed by our biosphere i.e., land and ocean (Schimel *et al*. 2001). IPCC (2001) also stated that CO_2 concentration has elevated from 280 ppmv in 1750 to 367 ppmv in 1999 and the current rate of increase is 1.5 ppmv/year or 3.3 Pg C/year.

2.1 Bio Sequestration

Carbon sequestration is the process of transferring and securely storing atmospheric CO2 into other long-lived carbon reservoirs that would otherwise be vented or remain in the atmosphere (Lal, 2008). Biological carbon sequestration can be defined as the storage of carbon dioxide in vegetation such as grasslands or forests, soils and oceans. The photosynthetic uptake of atmospheric carbon dioxide is crucial to global carbon (C) cycling (CO_2).

Total C stock (organic and inorganic C) in terrestrial systems is estimated to be roughly 3170 GT—2500 GT in the soil, 560 GT in plant biomass, and 110 GT in microbial biomass, respectively. The total amount of carbon in the oceans is 38,000 GT (Jansson et al.,2010). According to Batjes (1996), the largest reservoirs of carbon of terrestrial carbon cycle and soils have more thrice amount of carbon than vegetation while having twice as much that is present in atmosphere. Lal (2004), stated that cumulative potential of soil carbon sequestration over 25-50 years is 30-60 Pg. For the first half of the twenty-first century, until alternatives to fossil fuels become available, SOC sequestration is the most cost-effective and viable solution (Battelle, 2000). Sequestration of soil organic carbon (SOC) will buy us time to find replacements for fossil fuels and also improve soil's quality (Lal, 2003). According to Parr and Sullivan (2005), phytoliths are bio-sequestered inert form of organic carbon within plants and on decomposition of the vegetation phytolith-occluded carbon (PhytOC) will be passed on to and accumulate in soil.

2.2 Phytoliths - Formation

Phytoliths (also known as "plant opal" or "plant stone") are silica bodies formed by plants as a result of bio-mineralization and deposited in the intracellular and extracellular structures of their leaf, stem, and root systems. Monosilicic acid is the form in which plant roots will take up silica from the soil solution (Siever and Scott, 1963). Carbon occlusion occurs during this type of biomineralization process within phytoliths (Jones and Milne, 1963). Within plant tissue, silica deposits can be found in three places: (1) cell wall deposits, (2) cell lumen infillings, and (3) intercellular gaps of the cortex. The shape of living cells is commonly replicated by cell wall deposits of silica, but not by those growing in the lumen (Piperno,1988). According to Wilding *et al.* (1967), the occluded carbon in any

phytolith was most probably the original cytoplasmic organic components within the plant cell around which in vivo silicification had taken place. All grasses' silicified epidermal cells in the leaf and stem are incredibly efficient in occluding carbon (Parr and Sullivan, 2005). Silica is deposited in both the cytoplasm and vacuoles of the plant cells intracellularly whereas phytoliths are deposited in almost all plant parts i.e., roots, stems, leaves, fruits, inflorescence as intercellularly (He *et al*.,2014).

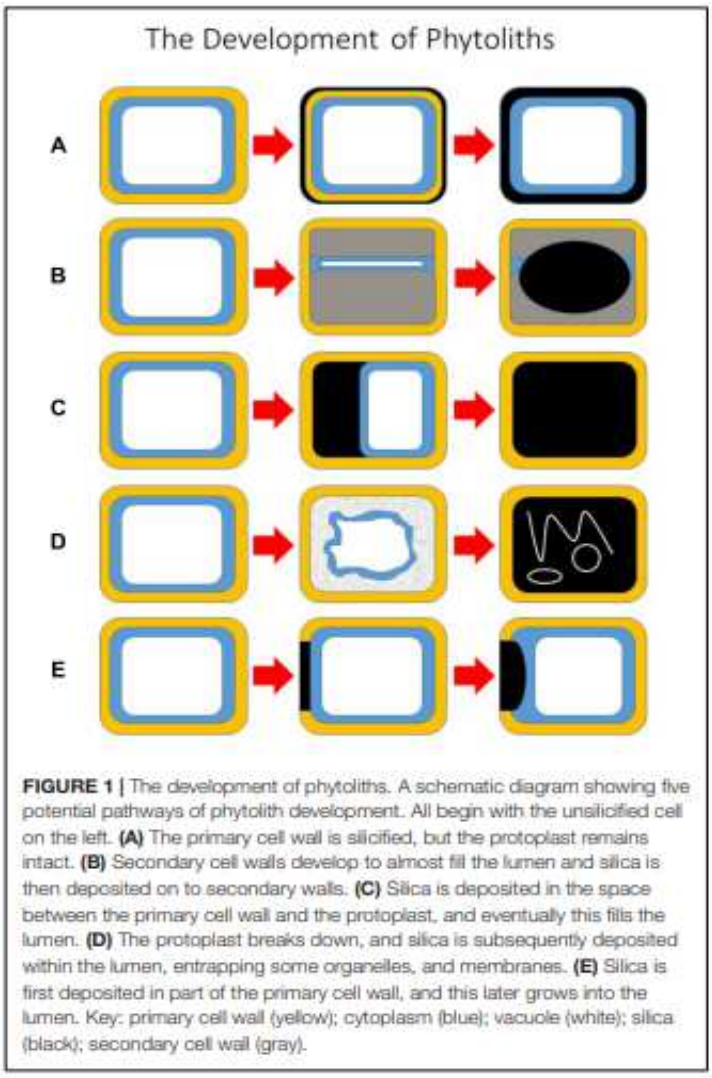


FIGURE 1 | The development of phytoliths. A schematic diagram showing five potential pathways of phytolith development. All begin with the unsilicified cell on the left. **(A)** The primary cell wall is silicified, but the protoplast remains intact. **(B)** Secondary cell walls develop to almost fill the lumen and silica is then deposited on to secondary walls. **(C)** Silica is deposited in the space between the primary cell wall and the protoplast, and eventually this fills the lumen. **(D)** The protoplast breaks down, and silica is subsequently deposited within the lumen, entrapping some organelles, and membranes. **(E)** Silica is first deposited in part of the primary cell wall, and this later grows into the lumen. Key: primary cell wall (yellow); cytoplasm (blue); vacuole (white); silica (black); secondary cell wall (gray).

Figure 1. Diagram showing development of phytolith

Hodson (2019)

Phytoliths majorly contain SiO_2 (66 to 91%) with minor to trace amounts of other elements like C, N, P, Al, Fe, K, Ca, Mg, and Cu (Bartoli and Wilding, 1980; Hodson *et al*., 2008; Kameník *et al*., 2013; Li Z *et al*., 2014; Anala and Nambisan, 2015). Phytoliths' size ranges from ~1 to 250 μm and they are more stable even though containing microscale internal cavities (Piperno, 1988; Lü *et al*., 2006; Strömberg, 2004, 2005). Expressed as % dry matter, phytoliths range in contents are less than 0.5% in most dicotyledons and as high as 15% in some parts of shoots for Gramineae (Epstein, 1994; Parr *et al*., 2010) which is mainly due to the phylogenetic difference of plant silicon (Si) requirement (Hodson *et al*., 2005) and the environmental variation of Si availability (Seyfferth *et al*., 2013; Guo *et al*., 2015). Grass dominant ecosystems such as croplands (Parr and Sullivan, 2011; Zuo and Lü, 2011; Li Z *et al*., 2013c), grasslands (Song *et al*., 2012), bamboo forests (Parr *et al*., 2010; Song *et al*., 2013a; Li B *et al*., 2014a, b) and wetlands (Li Z *et al*., 2013a, b) may contribute significantly to the global phytolith carbon sink mainly due to their extremely high phytolith production flux.

As for the organic carbon content in the extracted phytolith in various plants, they are reported as 5.0 to 5.8% in oats (Jones and Milne, 1963), 3.88 to 19.26% in sugarcane (Parr *et al.,*2009), 0.06 to 0.60 % of dry leaf and stem biomass of wheat (Parr & Sullivan,2011). Ding *et al*. (2005) reported that for rice phytolith content varied from 14.47 to 26.39 % in straw portion, 13.13 to 24.38 for husk ,7.05 to 11.4 %

for root, and 0.14 to 1.94 % for grains. The PhytOC bio sequestration fluxes from millet, wheat, sugarcane and bamboo amount to 0.04, 0.25, 0.36 and 0.71 Mg-e-CO2-ha^{-1} year^{-1} respectively (Parr and Sullivan, 2005, 2011; Parr *et al*., 2009, 2010; Zuo and Lu, 2011). The phytolith content is grassland is 1.3 to 5.8 times higher than that of other biomes (Song ,2017). Soils contain 400-1000 times more PhytOC than the aboveground biomass for most ecosystems, demonstrating that PhytOC is highly resistant to decomposition and may accumulate in soils and sediment for several hundreds of years (Parr and Sullivan ,2005). PhytOC is found to be an important long-term terrestrial C sink due to the significant C sequestration potential (Parr *et al*. 2010; Zuo *et al*. 2014; Zhang *et al*. 2016).

2.3 History - Sequestration of Carbon in Phytolith

It was the German botanist Struve observed phytoliths in living plants in 1835. Piperno (2006) called period of 1835-1895 as "Discovery and Exploratory Phase", 1955-1975 as Period of Ecological Research were various ecologists, agronomist, soil scientists, botanists conducted botanical, palaeobotanical, palaeoecological studies, 1978-2000 period is named as "Modern Period of Archaeological and Paleoenvironmental Research" and 2001- present period is called as "Period of Expanding Applications". Another German scientist Ehrenberg classified and organised several phytolith morphytes from the samples collected by Charles Darwin in 1835 and called them as Phytolitheria which means as plant stones in Greek (Piperno, 1988). Jones and Beavers (1963) was the first to measure the percentage of carbon occluded in phytolith as 0.86% in cisne silt loam. Carbon sequestration's foundation work was done by Parr and Sullivan. PhytOC from different plants like bamboo species (Parr *et al.* ,2010), sugarcane cultivars (Parr *et al.*,2009), wheat cultivars (Parr and

Sullivan,2011) and rice cultivars (Li *et al.*,2013b) (Sun *et al.*), millet species (Zuo and Li ,2011) were studied. Phytolith carbon sequestration taking place in various environments like grasslands (Song *et al*.,2012a); croplands (Song *et al*.,2014). PhytOC carbon sequestration in bamboo forests was studied by (Huang *et al*., 2014) and forests by (Song *et al*., 2013). (Song *et al*., 2012b) studied about the carbon sequestration at global scale.

A value of 3% PhytOC was used by Song *et al*. (2016) by using the microwave digestion method mentioned by Parr *et al*. (2001) while Santos and Alexandre (2017) used the value of 0.1-0.5% by using dry ashing and acid digestion or alternatively acid digestion and alkali immersion described in Corbineau *et al*. (2013). Hodson (2019) has pointed out that preparation of clean phytolith without extracting some carbon from inside is very difficult and this becomes more difficult with cell wall phytoliths. According to Song *et al*. (2017) carbon in the lumen phytolith is more stable than cell wall phytolith.

2.4 Characteristics of Phytolith – Physical and Chemical

Transmitted light shows phytolith in various colours like, fresh colour tint, brown, black or even colourless while phytoliths look porcelain or clear by reflected light. (Jones and Beaver,1963). Phytoliths are mainly made of amorphous silicon dioxide (SiO_2), 4-9% water, elements like carbon (C), copper (Cu), phosphorous (P), nitrogen (N), manganese (Mn), aluminium (Al), iron (Fe) in the form of occlusion, chemiabsorption or solid solution impurities. N, P, Al, Fe, Ca, Mg, Na, K, Mn, and Ti concentrations in phytoliths range from 0.1 to 5.6 % (Jones and Milne, 1963). The refractive index values are of the range 1.41 to 1.47. The specific gravity value ranges from 1.5 to 2.4

(Jones and Beaver,1963). Under normal physiological conditions, phytoliths form in the roots, stems, and leaves (as well as bulbs, corms, tubers, and other plant parts) and survive death and decomposition. Phytolith can take irregular shapes like dumbbells, saddles, bowls, boats, bulliform, tracheid, polylobate, etc. to regular shape like spherical, globular, cylindrical, hexagonal, cubical, and hair-cell, etc (Neethirajan *et al*. 2009). The type of cell and its location inside the plant body decides the phytolith shape but sometimes the cell lumen may be incompletely silicified thus the resulting phytolith shape may not be the cell shape (Piperno 2006). The PhytOC may indicate the prehistoric climate and CO2 concentrations at the time those phytoliths were produced (Gallagher *et al*.,2015).

2.4.1 Functions of Phytolith

The amount of Si deposited in different plants varies, giving them diverse abilities under various biotic and abiotic stresses by acting as barrier (Datnoff *et al*., 2001). The Si deposited as a thin layer in the epidermal cells and was embedded with trichomes in a simulated water stress research on wheat, providing the cells additional stiffness (Meunier *et al*.,2017). The significance of phytoliths deposited in the cell-wall matrix as a pathogen barrier in plant cells has been extensively researched (Alhousari *et al*.,2018). Dental microwear in mammalian grazers has been extensively addressed as a result of phytolith content in plants (Walker *et al*., 1978). Phytoliths, together with macro-remains, pollens, and carbon dating, have proven themselves as a valuable method in paleoethnobotany over the last few decades for identifying remains of crop plants and their wild ancestors (Ball *et al*., 2016). Phytoliths were utilised as proxies in many investigations to rebuild the flora landscape. In addition to providing information about climatic circumstances, human activity,

and important environmental events, dominant flora in ancient landscapes phytoliths also gives information about climatic conditions, human activity, and major environmental events (Chendev *et al*.,2018, Gavrilov *et al.,* 2018).

2.5 Studies of Phytolith

The first International Code for Phytolith Nomenclature 1.0 (ICPN 1.0) was developed by the International Working Group on Phytolith Nomenclature with standard protocols for different types of phytolith and glossary of different descriptors (Madella *et al*.,2005). Later on, Neumann *et al*. (2009), developed ICPN 2.0 with revised names, descriptions of phytolith morphytes and three more commonly seen phytolith assemblages. Another improvement in this area has been the development of an online database PhytCore ODB, the online database was developed to avail comparative keys for identification in plants. Rice straw phytoliths were heated by Yin *et al*. (2014) and found that at lower temperature carbon was released from cell wall phytolith (cavate) and at higher temperature carbon was released from lumen phytolith (solid). Phytoliths help us to date a sample as they can document the environmental conditions and vegetation of the past, thus act as climate proxies (Hodson ,2016). Depending on the quantity of Si in the substrate, plants of the same species can create various amounts of phytoliths in different soil and climate conditions (Henriet *et al*., 2008; Li Z *et al.*, 2013c). Monocots collect more phytoliths than non-monocots within the angiosperms, and the phytolith accumulation in the commelinoid monocot orders Poales and Arecales is much higher than in other monocot clades (Hodson *et al*.,

2005). Phytoliths are discharged into soils after plant death and decomposition or plant burning, retaining their morphological integrity and geochemical properties (Strömberg, 2004, 2005, McInerney *et al*., 2011). Because phytoliths are formed as a result of soil soluble Si uptake and regulated Si polymerization at a final site, the accumulation of phytoliths within a plant is influenced by plant phylogeny (Hodson *et al*., 2005; Yang *et al*., 2015) as well as soil Si availability (Henriet *et al*., 2008; Guo et al., 2015). Kim and Whang (1992) studied on the botanical aspect of phytoliths. Scanning electron microscope was used by Wang and Kim (1994) to study the morphology of rice phytolith. Wang *et al.* (1996) studied environmental effects on phytolith morphology from rice cultivar of Korea and different other countries.

Table 1. Research works conducted so far on phytolith

Sl no:	Family	Work on phytolith done by:
1	Arecaceae, Cyperaceae, Marantaceae, Aceraceae, Betulaceae, Ericaceae, Dilleniaceae, Cucurbitaceae, Euphorbiaceae, Fagaceae, Juglandaceae,	Piperno (2006)

	Moraceae, Asteraceae, Pinacea, Hymenophyllaceae	
2	Liliaceae	Thorne & Kishino (2002)
3	Poaceae	Korolûk (2010), Carneli *et al.* (2001), Beilei *et al*. (2014), Li *et al.* (2014)
4	Restionaceae	Novello *et al*. (2017)
5	Orchidaceae	Lentfer *et al.* (2002)
7	Anacardiaceae, Sapotaceae	Collura & Neumann (2017)
8	Ericaceae, Fabeaceae, Rosacea, Asteraceae	Mercader *et al*. (2009)
9	Proteaceae, Celastraceae	Novello *et al*. (2017)
11	Moracea	Geiset *et al*. (1973)
12	Rubiaceae, Ulmaceae, Epacridaceae	Thorn (2008)
13	Pinacea	Klein and Geis (1978), Yang *et al*. (2018)
14	Taxaceae	Carnelli *et al*. (2004)
15	Scrophulariacea	Yang *et al*. (2018)
16	Equisetaceae	Stromberg *et al*. (2002)
17	Lycopodiacea	Chauhan *et al*. (2011), Mazumdar (2011)
18	Selaginellaceae, Isoetaceae, Hymenophyllaceae, Marattiaceae, Gleicheniacea,	Mazumdar (2011)

	Lindsaeaceae, Dennstaedtiaceae, Thelypteridaceae, Blechnaceae, Dryopteridaceae, Oleandraceae, Polypodiaceae, Polypodiaceae	
19	Lygodiaceae, Pteridaceae	Chauhan *et al.* (2011)
20	Ophioglossaceae	Iriarte & Paz (2009)
21	Pteridaceae	Sundue (2009)
22	Zygophyllaceae, Moraceae	Morgan-Edel *et al*. (2015)

Sharma et al. (2018)

Table 2. Studies done on phytoliths outside India

Year	Author/s	Phytoliths studied from/in	Remarks
1835	Struver	Living plants	Pioneering work
1841, 1846 ,185 4	Ehrenberg	Soil samples	Samples from H.M.S Beagel collected by Charles Darwin. Developed 1st classification system, the 'Parataxanomic ' system. *Coined the term 'Phytolithera'

1855	Gegory	Plants and soil	Emphasised on morphology and location of silica cells.
1875	Hohnel	*Panicum miliaceum* (common millet), *Sorghum vulgare* (sorghum), *Avena sativa* (oat) *Triticum spelta* (spelt wheat) *Hordeum vulgare* (six rowed barley) *Secale cereale* (rye)	Detailed discussion on morphology of epidermal cells, prickle hair and bristle hairs
1896	Grob	Many plant families including monocotyledon, dicotyledons and fern.	Emphasised on morphology and location of silica cells.
1886	Guntz	130 species of grasses; bamboo, savannah, Meadow and steppe grass.	Emphasised on morphology and location of silica cells, especially from leaf structures.
1899	Formanek	*Oryza sativa*, *Hordeum, Lolium temulentum*, *Avena fatua, Avena sativa, Panicum*	Studied silicification of grass family

		miliaceum, Triticum repens, Setaria viridus, Triticum repens.	
1908	Mobius	*Chrysobalanaceae, Dilleniaceae, Palme, Orchidaceae, Urticaceae, Hymenophyllacea e* and a fern genus *Trichomanes.*	Studied silicification of grass family
1929	Netolitzhy	*Podostemaceae, Chrysabalanacea e, Burseraceae, Palme, Musaceae, Cannaceae*	Studied silicification of grass family
1936	Leeper, Nichollos and Wadham	Mineralogical sediments	Studied silicification of grass family
1937	Tyuria	Soil sediments	
1956	Usov	Soil sediments	
1956	Parfenova	Soil sediments	
1956	Yarilova	Soil sediments	
1960	Metcalf	*Gramineae*	classified silica types on the basis of grass families; Chloridoid, Festucoid, Panicoid.
1969	Sangster	*Oryza sativa,*	Studied

	and Parry	*Cynodon dactylon, Sieglingia decumbens*	bulliforms by plant culture and light microscope
1970	Sangster	*Oryza sativa, Cynodon dactylon and Sieglingia decumbens*	Studied leaves by plant culture and light microscope
1973	Soni and Parry	*Oryza sativa* Linn.	Studied inflorescence bracts by electron probe micro analysis.
1977	Parry and Kelso	*Saccharum officinarium*	Studied roots using scanning electron microscope, electron probe micro analysis and Corinth analytical microscope
1981	Wadham and Parry	*Oryza sativa* Linn.	Studied culms, bracts and awns using scanning electron microscope, electron probe micro analysis
1982	Bennett	*Hordeum sativum, Avena sativa and Triticum avestium*	Studied roots using electron probe micro analysis
1986	Hodson and Parry	*Phalaris canariensis*	Studied roots, culm and leaves by plant culture using light microscope, scanning

			electron microscope and electron probe micro analysis

Table 3. shows studies done on phytoliths in India

Year	Author	Silica bodies/phytoliths studied from	Investigation of /Remarks
1951	Ponnaiya	*Sorgum* sp.	Epidermal silica
1965	Sharma	Sedges	Conical silica bodies
1968	Govindrajul	*Eleocharis* sp., Rhyncospora sp. and *Scleria* sp.	Anatomical investigation
1970	Sharma and Rao	Timber species	Size form and distribution of silica
1970	Soni *et al*.	Oat plant	Anatomical investigations of leaf epidermis
1972	Sharma	*Scirpus squarrosus*	Anatomical investigation
1972a	Soni *et al*.	*Oryza sativa* L.	Anatomical investigation using Electron microprobe analysis

1972b	Soni and Parry	*Oryza sativa* L.	Anatomical investigation of inflorescence bracts using Electron microprobe analysis
1973a	Daynand and Kaufmann	Leaf epidermis	Guard cell using SEM
1973b	Daynand and Kaufmann	Equisetum	Guard cell using SEM
1977	Singh and Pande	Leaf epidermis	Stomatal types
1978	Srivastava	*Digitaria*	Morphology and location of silica bodies
1983	Dayanand *et al*	Silica in Plants	Anatomical investigation
1999	Eksambekar *et al.*	Archaeological sediments	surface ornamentation SEM
2000	Krishnan *et al.*	*Gramineae* sp.	Anatomical investigation. * Used the term ' Phytolith'

2.5.1 Presence of Phytolith

Phytoliths can be found in up to 5% of soils from practically all terrestrial ecosystems ((Alexandre *et al*., 1997; Meunier *et al*., 1999; Blecker *et al*., 2006; Li Z *et al*., 2013a). The balance of plant phytolith input and phytolith output determines phytolith distribution and storage in soils. Plant phytolith production (Bartoli, 1983; Lucas *et al*. 1993; Alexandre *et al*., 1997; Meunier *et al.*, 1999), is included in phytolith input, whereas phytolith output comprises harvesting loss (Song et al., 2013b), chemical dissolution (Blecker *et al*., 2006), erosion (Cary *et al*., 2005) and translocation (Fishkis *et al*., 2009) of phytoliths.

2.5.2 Stability, Turnover and Disintegration of Phytolith

Phytoliths accumulate at a maximum near the surface (usually near A horizon and less commonly near B horizon) and then decline sharply with depth in most soil profiles, demonstrating that phytolith distribution is mediated by plant phytolith input and subsequent phytolith translocation and breakdown within a profile (Blecker *et al.,* 2006; Fishkis *et al.,* 2009). Phytolith concentration and storage are higher in grass-dominant habitats (e.g., bamboo forests, rice ecosystems, and reed wetlands) than in other ecosystems (Bartoli, 1983; Alexandre *et al*., 1997; Meunier *et al*., 1999; Parr *et al*., 2010; Li Z *et al*., 2013c). According to Blecker *et al*. (2006), soil phytoliths in grasslands decrease with increased precipitation, but annual input flow of plant phytoliths increases, suggesting that phytolith distribution and storage in soils are influenced by factors other than phytoliths. The input flow from plants, as well as the geochemical stability and turnover of phytoliths, are all factors to consider.

Plant litter inputs, as well as geochemical stability and phytolith turnover, influence the rate of accumulation of phytoliths in soils (Alexandre *et al*., 1997; Blecker *et al*., 2006). Phytoliths are released into soil after plant degradation and may undergo translocation as well as weathering processes (Alexandre *et al*., 1997; Fishkis *et al*., 2009; Sommer *et al*., 2013). The weathering processes of phytoliths may release monosilic acid through partial dissolution and generate surfaces with pores or cavities (Kelly *et al*., 1998; Gérard *et al*., 2008; Borrelli *et al*., 2010). Phytolith solubility rises with temperature, and phytolith dissolution rate rises with both temperature and aqueous flux (Bartoli and Wilding (1980); Bartoli, 1985; Fraysse *et al*., 2006, 2009). According to Bartoli and Wilding (1980), and Bartoli (1985) phytoliths have a lower solubility in soil than plants due to their lower water

content and specific surface area. According to Borrelli *et al*. (2008) because of their increased solubility and dissolving rate, soil phytoliths may weather more quickly than other amorphous silica fractions and inorganic soil minerals. Alexandre *et al.* (1997) has pointed out that most soil profiles have an uneven porosity distribution, with porosity decreasing with depth, and only a tiny proportion of stable phytoliths can be translocated to the bottom and all phytolith do not dissolve in soil at same time. The occlusion of carbon can change the colour of phytoliths from translucent to dark brown or black under the oxidative conditions of an open-air fire.

Temperatures exceeding 500 degrees Celsius cause them to discolour, and temperatures above 800 degrees cause them to melt (Fritzsch *et al*., 2016). Fritzsch et al. (2016) also found that at 450°C, heat-induced changes can be seen. Stems have the most dramatic changes. Stem phytoliths are fully molten at 600°C, while leaf and husk phytoliths are generally unchanged and easily recognised. There are no intact phytoliths visible at 800°C. At 250°C, single phytoliths from all samples display minor colour. Even at 600°C, however, uncoloured phytoliths can be discovered.

2.6 Carbon sequestration in plant phytoliths

Phytoliths have been shown to have a high carbon sequestration potential in the terrestrial ecosystem due to their much higher geochemical stability than other organic forms. They may occlude 0.2–5.8% of organic carbon during their formation in plant tissues and have been shown to have a high carbon sequestration potential in the terrestrial ecosystem due to their much higher geochemical stability than other organic forms (Parr and Sullivan, 2005, 2011; Parr *et al*., 2010; Song *et al*., 2012, 2013a).

2.6.1 Chemical constitution of PhytOC

The main constituents of PhytOC are minor amount of alkyl carbon lignin and fragmented glycoproteins (Kelly *et al*., 1991; Krull *et al*., 2003; Elbaum

et al., 2009). δ 13C isotope values in phytoliths are used to record paleo vegetation (McInerney *et al*.,2011).

2.6.2 Distribution of PhytOC in Phytolith

Organic carbon is seen to occlude in three forms in the phytoliths – a) Organic carbon occluded in the microscale internal cavities which are weakly protected by phytoliths (Prycid *et al*., 2003; Carter, 2007, 2009; Parr and Sullivan, 2014); b) Individually occluded organic carbon aggregates that are protected by silica structure (Carter, 2009); c) Organic C in the form of amino acids is continuously dispersed throughout the silica structure and is protected by it (Alexandre *et al*., 2015). deposition sites and types of phytoliths (Parr *et al*., 2014).

According to Parr *et al*., (2014), deposition sites and types of phytoliths decides the relative distribution and organic carbon content. The cavate or hollow phytoliths are seen to form in the cell wall whereas lumina of plant cell or cell wall forms the solid phytoliths, cavities being the major site of carbon occlusion (Parr and Sullivan, 2014; Alexandre *et al*., 2015). Even though cavate phytolith occlude 50 times more carbon, it is less stable than the solid phytolith ((Madella *et al*., 2005; Parr and Sullivan, 2014). According to Parr and Sullivan (2005), 82% of organic carbon in the soil is represented by PhytOC. Among the global mean long-term sequestration of soil carbon, PhytOC makes up 15-37% (Parr and Sullivan ,2005).

2.6.3 Sequestration of Phytolith occluded carbon in various ecosystems

The average PhytOC content are estimated as 2.36% for (sub-) tropical forest, 2.37% for temperate forest, 3.06% for boreal forest, 1.85% for grassland (including tropical savanna and temperate steppe), 1.59% for wetland, 4.21% for cropland, 2.67% for shrubland, and 1.5% for tundra and desert. Phytolith C sequestration in global terrestrial biomes is 156.7 ± 91.6 Tg CO2 yr^{-1}. (Song *et al.*, 2017).

MATERIALS AND METHODS

CHAPTER 3

MATERIALS AND METHODS

3.1 STUDY AREA

The study was conducted in the parts of Western Ghats (Kerala region).

- **EXPERIMENT NO:1**

3.2 SOIL SAMPLE COLLECTION

A stratified random sampling method was adopted where the geological rock strata was used as the main strata and teak plantations as the substrata. Soil sample was collected from forested areas, continuously teak planted areas (70-80 years) adjacent to the forested areas and the degraded open lands of North Central Laterites (NCL). Soil pits were taken at the selected sites and samples were collected horizon wise up to the parent material. Enough number of such pits were taken in each system depending on on-site factors such as gradient, aspect etc. The details of the sampling site are provided in Table 4 and Figures 2a - c.

Table 4. Sampling site

Agroecological unit (AEU)	**Place**	**Systems**
North Central Laterite (NCL)	Thrissur	• Panamkutty Teak Plantation • Kalaparakunnu (Reserve Forest) • Kuthiran (Open land)

Figure 2a

Figure 2b

Figure 2c

Figures 2a- c. Soil sampling sites in NCL a. Forest; b. Teak plantation and c. Open land

3.3 ANALYSIS OF PHYSICAL PROPERTIES OF SOIL

The collected soil samples were air dried, sieved (2 mm sieve) and stored for further analysis.

3.3.1 SOIL TEXTURE

Soil texture of the experimental samples were estimated by International Pipette Method

3.3.2 SOIL BULK DENSITY

Soil bulk density of experimental samples were analysed by core sampler method

3.4 ANALYSIS OF CHEMICAL PROPERTIES OF SOIL

3.4.1 SOIL pH

20 g of air-dry soil passed through 2 mm sieve was transferred to a 100 ml beaker and 50 ml distilled water was added. The contents in the beaker were stirred intermittently and allowed to stand for half an hour. It was stirred again and readings were taken using a pH meter.

3.4.2 AVAILABLE NITROGEN

Available nitrogen of the soil samples was estimated by Alkaline – Permanganate method / Kjeldahl method.

3.4.3 AVAILABLE PHOSPHORUS

Available phosphorus of the soil samples was extracted through Bray 1 method and estimated by UV visible spectroscopy.

3.4.4 AVAILABLE POTASSIUM

Available potassium of the soil samples was extracted with neutral ammonium acetate method and calculated by Flame spectroscopy / photometer.

3.4.5 AVAILABLE CALCIUM

Available calcium of the soil sample was extracted through neutral ammonium acetate method and estimated by Atomic Absorption Spectrophotometry (AAS).

3.4.6 AVAILABLE MAGNESIUM

Available magnesium of the soil sample was extracted through neutral ammonium acetate method and estimated by Atomic Absorption Spectrophotometry (AAS).

3.4.7 AVAILABLE SULPHUR

10g of air-dried soil was processed with 50 ml of 0.15% $CaCl_2$ solution in a 250 ml conical flask for 30 minutes. This extract was filtered through Whatman No 42-filter paper and available sulphur was estimated at 440 nm by UV spectrophotometer.

3.4.8 SILICON

0.1 g of each soil sample was weighed and transferred to a Teflon vessel. To this conc. HNO_3 (Nitric acid) and HF (Hydrofluoric acid) was added in the ratio 9:3. This vessel was placed in a microwave sample preparation system for digestion. After few minutes the vessel was taken out and contents were transferred to a centrifuge tube and diluted up to 25 ml. Soil silicon was estimated by Inductively Coupled Plasma Atomic Emission spectrometry.

3.4.9 Soil Organic Carbon

Soil organic carbon was estimated using Walkley and Black (1934) method.

3.4.10 CATION EXCHANGE CAPACITY (CEC)

Cation exchange capacity of the soil sample was calculated using the Barium chloride ($BaCl_2$) method.

3.4.11 BASE SATURATION

The cations extracted using $BaCl_2$ was used to assess the exchangeable bases and base saturation as Exchangeable cations

M^+ cmol(p^+) kg^{-1} = C mol (+) L^{-1} *(0.03 L / wt. of soil g) *1000 g kg^{-1} *DF

Where M^+ is the concentration of an adsorbed cation, cmol(p^+) $kg^{-1,}$ C is the concentration of the same cation measured in the $BaCl_2$ extract (cmol (p^+) L^{-1}), and DF is the dilution factor, if applicable.

Base saturation was calculated by the formula

% BS = (Σ Ca +Mg +Na +K /Effective CEC) *100

Where Effective CEC cmol(p^+) kg^{-1} = Σ M^+ cmol (p^+) kg^{-1}

3.4.11 SOIL ORGANIC CARBON

The soil organic carbon was determined in the soil sample that was passed through a 0.2 mm sieve by wet digestion method of Walkley and Black (1934).

3.5 ANALYSIS OF PHYTOLITH AND PHYTOLITH OCCLUDED CARBON (PhytOC)

Phytoliths from each of the collected horizon was extracted as per the standard protocol of the closed microwave digestion method for extraction of phytoliths from plant material by Piperno (1988). Dry plant sample of 0.2g weight was taken and placed in digestion tubes. 3 ml of nitric acid (HNO_3), 2 ml of hydrogen peroxide (H_2O_2) and 0.5 ml of hydrochloric acid (HCl) were added to this digestion tube and secured with lids. The digestion tubes were placed in microwave in digestion mode for 30 minutes. The digested samples inside the digestion tube were decanted through a 180 µm Nylon Net filter onto a 0.5 µ filtered aspirator. After that filter paper was placed on a paper towel and kept inside an oven at 90 ºC for 3 minutes. The filters were removed from the microwave. The filter was then placed inside a 50 ml centrifuge tube to procure the phytolith sample and then stored. Into this tube 1-2 ml of 70-100% ethanol was added and shook. Small amount of the sample was removed using a transfer pipette and placed on a microscopic slide and this slide was dried on a hot plate, cooled and mounted using benzyl benzoate. This slide was the viewed using a compound microscope under 40x magnification.

Figure 3a **Figure 3b**

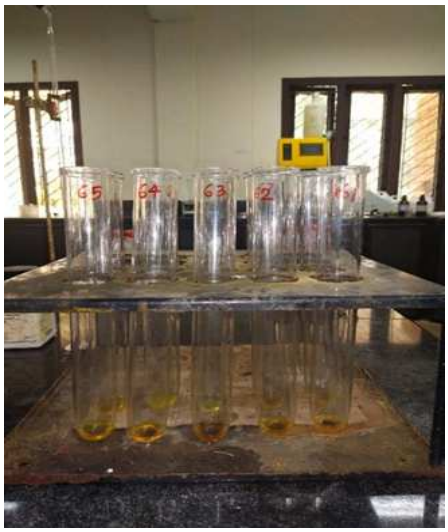


Figure 3a. Digestion unit and samples; 3b. Sample for digestion and 3c. Samples for digestion

Figure 3c

Figure 3d

Figure 3e

Figure 3d. Filtered aspirator; 3e. Samples after drying in the oven and 3f. Drying of samples on hot plate

Figure 3f

Phytolith occluded carbon or PhytOC analysis

The phytolith sample in ethanol was dried on a hot plate (Figure 7). The PhytOC content of dried sample was estimated by the wet digestion method of Walkley and Black (1934).

3.6 EFFECT OF pH AND ROOT EXUDATION ON PHYTOLITHS AND PhytOC CONTENTS IN SOIL

Batch dissolution experiments was conducted for the soil belonging to NCL (sample 1-Panamkutty teak plantation (Thrissur) at depth of 0-12 cm and O horizon) and (sample 5-Kalaparakunnu (Thrissur) reserve forest at depth of 0-1

cm and O horizon). 1 g of sample each soil was taken in centrifuge tubes (S1 and S2) and treated with 5 ml each of 0.01 N HCl and 0.05 N HCl to simulate the soil pH conditions. Another set of soil samples were treated with 1 mM and 5mM each of sodium oxalate solution to simulate the effects of root exudation. All the bottles of samples were made up to 10 ml. Then they were kept inside an Incubator shaker to shake continuously for 5 days. At the fifth day 25 ml quenching solution (0.5 M NaCl + 0.11 M $CuCl_2$) was added to each tube and dried on hot plate. This soil was then used to analyse Phytolith and PhytOC contents (Fig 8).

Figure 3g. Incubator shaker

- **EXPERIMENT NO 2**

4.1 ASSESSMENT OF PHYTOLITHS IN PLANTS GROWN UNDER AUGMENTED SILICON SUPPLY

The teak seedlings (age of 6 months) were grown in small plastic bottles filled with sand and raised in different set of treatments in a Completely Randomized Design with five treatment levels and 3 replications. The nutrient solution by Ingestad (1971) was used to provide nutrients to the seedlings. 2 L nutrient solution was made using:

4.8 mM Ca $(NO_3)_2$

1.6 mM $CaSO_4$

1.6 mM $CaCl_2$

4.0 mM KCl

4.0 mM K_2SO_4

0.4 mM $MgSO_4$

3.2 mM NH_4Cl

3.2 mM $(NH_4)_2\ SO_4$

0.2 mM NaH_2PO_4

90 µM H_3BO_3

80 µM FeEDTANa

8 µM $MnCl_2$

0.8 µM $ZnSO_4$

0.8 µM $CuSO_4$

5.6 µM $(NH_4)_6MO_7O_{24}$

Silicon was supplied at three different concentrations of 0.2, 0.8 and 1.6 mM by silicic acid which was obtained by dissolving sodium meta silicate in demineralized water.

Table 5. List of treatments done in hydroponics

Treatments	Particulars
T_1	Teak seedlings were provided with nutrient solution
T_2	Teak seedlings were provided a mixture of nutrient solution and 0.2 mM Si
T_3	Teak seedlings were provided a mixture of nutrient solution and 0.8 mM Si
T_4	Teak seedlings were provided a mixture of nutrient solution and 1.6 mM Si
T_5	Teak seedlings were provided only distilled water

This set up was kept for 3 weeks. All the treatments (T_1 to T_5) were provided with nutrient solution once in every week. At the end of the third week the plants were uprooted and cleaned in water. Then they were dried in oven at 40º C for 24 hours. The dried plant was grinded in a mixer. The plant sample was sieved by a 0.6mm sieve and analysed for phytolith. A subsample of 0.2 g sample was taken out for phytolith extraction and used to determine the PhytOC through Walkley and Black method.

Figure 4a. Week 1 of treatment

Figure 4b. Week 2 of treatment

Figure 4c. Week 3 of treatment

RESULTS AND DISCUSSION

CHAPTER 4

RESULTS AND DISCUSSION

4.1 EXPERIMENT 1

The clay content of the soils in the plantation of North Central laterites varied from 30.16 to 40.16 and was found increasing with depth. On the other hand, the clay contents in the natural forest and open land varied from 20.16 to 30.16 and 26.16 to 34.16, respectively, down the profile. There was a corresponding decrease in sand percent down the profile in all the systems of North Central Laterites (Table 6a). Soil profiles in the humid tropical conditions undergo rapid weathering and translocation, thereby increasing the clay percent down the profile (Table 6a).

Table 6a. Physical properties of soils of North Central laterite

		Texture			Bulk density
Horizon	**Depth**	**Clay**	**Silt**	**Sand**	
A) Plantation					
O horizon	0-12cm	30.16	8	61.84	1.41
A horizon	13-22 cm	36.16	8	55.84	1.21
B horizon	23-40 cm	36.16	6	57.84	1.41
C horizon	>40 cm	40.16	6	53.84	1.20
B) Forest					
1.O horizon	0-1 cm	20.16	6	73.84	1.14
2.A horizon	2-13 cm	28.16	4	67.84	1.14
3.B horizon	14-26 cm	28.16	4	67.84	1.38

4.C horizon	>26 cm	30.16	8	61.84	1.20
C) Open land					
1.A horizon	0-28 cm	26.16	8	65.84	1.30
2.B horizon	29-56 cm	28.16	6	65.84	1.30
3.C horizon	>56 cm	34.16	4	61.84	1.30

The soil pH was found to be acidic in all the soils and was found to decrease down the profile in all soils except, open land in North Central Laterite zone. The leaching of bases down the profile in open lands gets accumulated in the lower horizons increasing the pH (Chandran et al., 2005; Sandeep and Sujatha, 2014). All the soils (plantations, natural forests and open land) in this zone had low to medium available nitrogen and phosphorus. However, plantations were found to have high amounts of available potassium and such a trend was noticed in the other analysed systems. The potassium rich litter of teak plantations would have added more of this nutrient to this particular soil (Table 6b).

Available Ca was found to be highest in the surface soils of teak plantations (642 mg/kg soils) in the Northern Central Laterites (Table 6c). Teak being a calcifuge extracts and circulates large quantities of Ca. All the soils were deficient in Mg, the base saturation of the soils was > 99 % and the CEC values were found to vary from 52.59 to 105.93 cmols (p+) per kg in plantations, from 64.08 to 84.98 cmols (p+) per kg in natural forests and ranged from 45.24 to 91.04 cmols (p+) per kg in open lands (Table 6b).

Table 6b. Chemical properties of soils of North Central laterite

Horizon	P^H	N (kg/ha)	P (kg/ha)	K (kg/ha)
A) Plantation				
O horizon	7.30	339.19	48.97	971.04
A horizon	6.85	201.39	16.41	972.16
B horizon	5.40	180.19	9.64	619.36
C horizon	4.90	222.59	9.78	182.56
B) Forest				
O horizon	5.79	339.19	30.42	394.24
A horizon	5.20	377.96	23.93	232.96
B horizon	5.20	148.40	19.30	175.84
C horizon	5.02	201.39	15.53	179.20
C) Open land				
A horizon	4.96	243.79	15.40	266.56
B horizon	5	116.60	9.82	236.32
C horizon	5.10	169.60	30.12	143.36

Table 6c. Chemical properties of soils of North Central laterite

Horizon	Ca (mg/kg)	Mg (mg/kg)	S (mg/kg)	Si (mg/kg)	Base saturation (%)	CEC (cmol/ kg)
A) Plantation						
O horizon	642	316.45	0.82	36194.87	99.82	52.59
A horizon	255	145.40	6.39	52273.44	99.92	105.93

B horizon	186.5	90.85	2.91	48734.63	94.42	92.69
C horizon	159	67.7	0.84	49726.67	99.86	98.69
B) Forest						
O horizon	468.5	153.75	0.44	52859.85	99.08	66.05
A horizon	194	104.55	0.23	54560.48	98.66	82.48
B horizon	117	113.85	0.69	51775.4	99.68	78.56
C horizon	119.5	117.7	1.43	49529.27	99.69	84.98
C) Open land						
A horizon	135	75.60	27.26	52159.75	99.80	45.24
B horizon	125.5	86	25.78	49034.86	99.68	83.59
C horizon	174	65.25	20.44	45551.53	99.63	91.04

Table 6d. Soil organic carbon and PhytOC content of North Central laterite soil

Horizon	Soil Organic carbon (%)	PhytOC (%)	PhytOC in the soil (%)
A) Plantation			
O horizon	0.87	0.034	3.88
A horizon	0.94	0.0004	0.042
B horizon	0.39	0.017	4.35

C horizon	0.55	0.078	13.95
B) Forest			
O horizon	3.00	0.006	0.20
A horizon	1.79	0.042	2.35
B horizon	0.50	0.014	2.77
C horizon	0.49	0.003	0.60
C) Open land			
A horizon	1.75	0.019	1.08
B horizon	0.88	0.02	2.27
C horizon	0.40	0.040	10.02

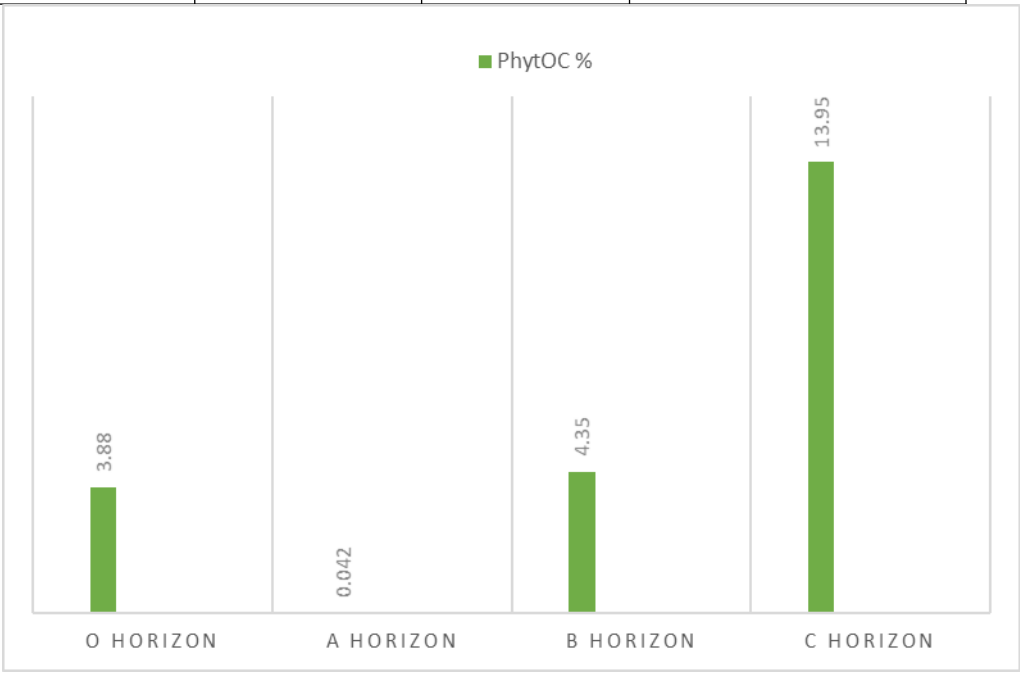


Figure 5a. PhytOC content as a % of total soil organic carbon (toc) in plantations of NCL

The PhytOC to TOC ratio for plantations in NCL was found to increase towards C horizon to reach the highest value (13.95) whereas the A horizon showed the least value (0.042) (Figure 15a). Though natural forests had the maximum PhytOC/ TOC ratio in the upper A and B horizons (> 2), the values were higher in the lower C horizon in both plantations (11.95) and open land (10.02). Natural forests with good canopy cover reduce the leachate for Phytolith transportation to lower layers. Further, PhytOC/ TOC ratio was lower in natural forests in all horizons than plantations and open lands. Plant diversity in plantations and open lands decreases the range of total phytolith and PhytOC contents by reducing species richness, and decreases phytolith and PhytOC production fluxes by reducing aboveground biomass (Ru *et al*., 2018). PhytOC/TOC ratio in the bamboo forest decreased slightly from 0 to 20 cm and then rapidly increased with depth (Zhang *et al*., 2016). This is mainly because the phytolith return flux in the bamboo forest) (Song *et al*. 2013a; Li *et al*. 2014). For a Si-rich accumulator forest, increasing the phytolith return of litter-fall might be a promising strategy to improve the phytolith accumulation in soil profile (Zhang *et al*.,2016; Blecker *et al*. 2006), reed wetland (Li *et al*. 2013a), paddy (Chen and Zhang 2011), and forest soils (Huang *et al*. 2014). The increase of PhytOC/ SOC ratio in soil profiles with soil depth suggests that PhytOC could be translocated to lower layers and could be one of the major stable sources of SOC in these layers (Zhang *et al*. 2016). These results are contrary to the observations of Piperno (2006), who suggested that the magnitude of transport of phytoliths down the profile was probably minimal and that their concentrations usually decrease in the subsoil. Fisher *et al*. (1995) considered the mobility of phytoliths to be negligible due to their large size. However, it was reported that long-term planting promoted phytolith translocation to a depth of 220 cm in a ferralitic soil profile, accumulation of phytolith in the impermeable clay layer to a depth of 130–140 cm in a rainforest was also reported by Alexandre *et al*. 1997. The process of phytolith assemblage and rejuvenation occurs by means of phytolith translocation, rather than the input of the younger soil carbon into phytoliths during their dissolution in the aggressive soil conditions. Besides that, the increased relative

concentration of phytoliths in E horizon of the soil at eluvial catenary position at the depth of 25-30 cm as compared with the E and A horizons at the same depths proves their translocation down the soil profile (Denis *et al*.,2017).

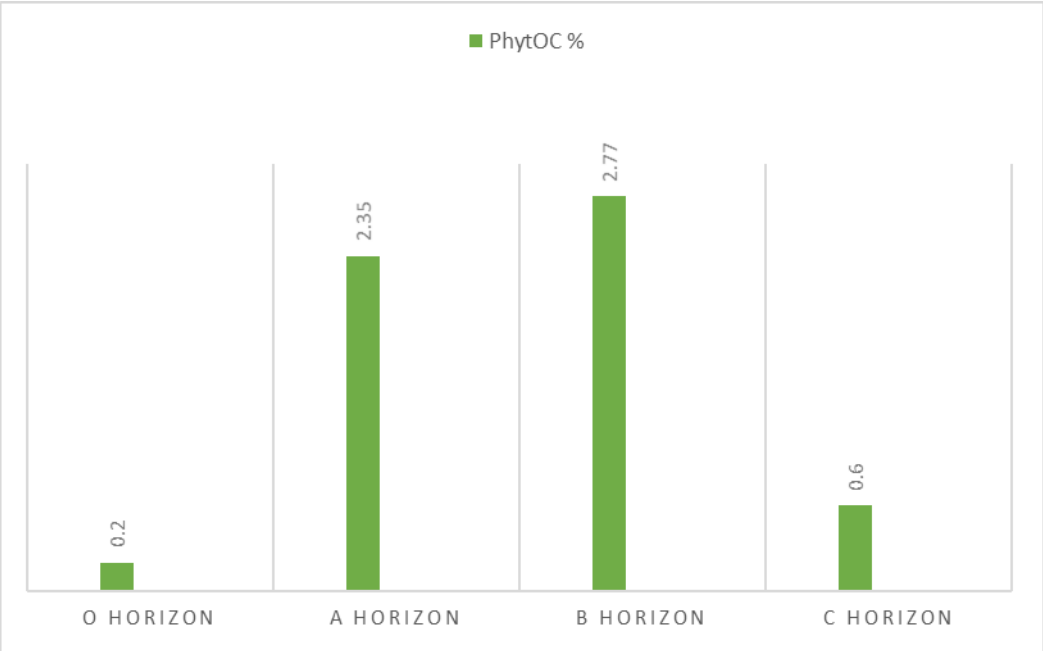


Figure 5b. PhytOC content as a % of total soil organic carbon in natural forest of NCL

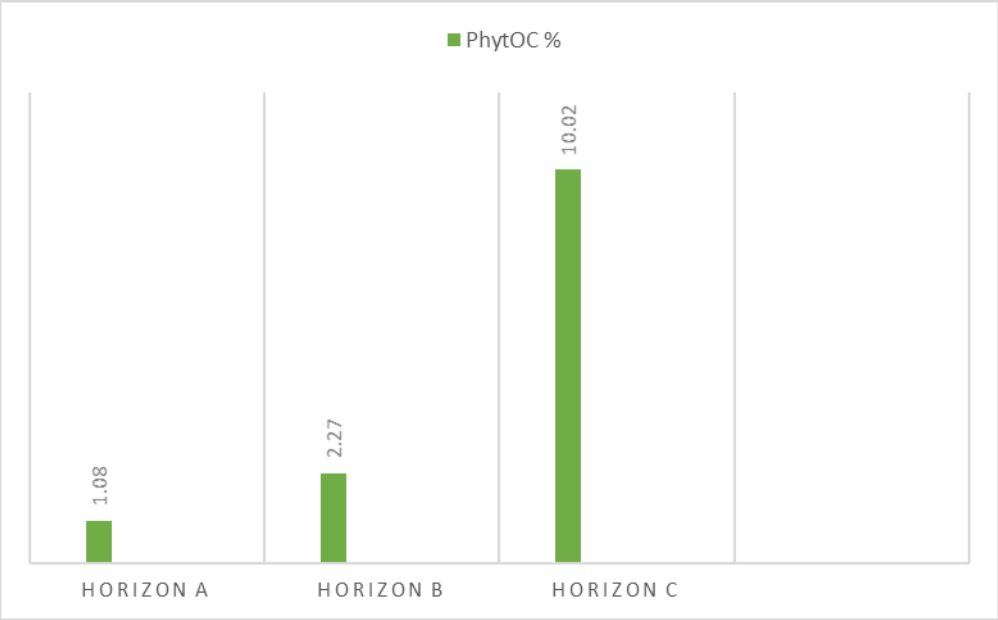


Figure 5c. PhytOC content as a % of total soil organic carbon in open land of NCL

4.1.1 Structural analysis of phytoliths

The structural analysis of phytoliths revealed the presence of various structures. NCL's plantation had trapeziform corniculate as the phytoliths. While the forest showed trapeziform, smooth elongate, parallelepipedal, elongate process and cuneiform bulliform shaped phytoliths, open lands exhibited trapeziform corniculate, trapeziform shaped phytoliths. Soodan *et al.* (2014) has viewed trapezoid phytolith in Oryza sativa L. Clavate, scutiform and rectangular shapes in the epidermal layer. Ball *et al.* (1999) found that trapeziform phytolith is the diagnostic type for *Triticum aestivum* L. He found the presence of trapeziform phytolith in tribe Triticeae (*Hordeum vulgare* L. and *Triticum aestivum* L.) and, smooth elongate shape as a less frequent shape in *Hordeum vulgare* L. Naskar and Bera (2018) has confirmed the presence of bulliform cells and trapeziform cells from the grasses. Bulliform cells are enlarged leaf epidermal cells found in nearly all members of Poaceae and in most monocots. Grass bulliform cells may be silicified to large size parallelepipedal or cuneiform shaped phytoliths (Chen *et*

al., 2020). Bulliform phytoliths are formed in bulliform cells and Bambusoideae had abundant bulliform cells and abundant bulliform phytoliths (Chen *et al.* ,2020). Mercader (2010) viewed bulliform phytolith in *Eragrostis hierniana* Rendle in (Culm/Leaf/Inflorescence), carinate, phytolith from *Leptaspis cochleata* Nees ex Steud. (Culm/Leaf/Inflorescence) and scutiform from *Pennisetum unisetum* (Nees) Benth. (Culm/Leaf/Inflorescence).

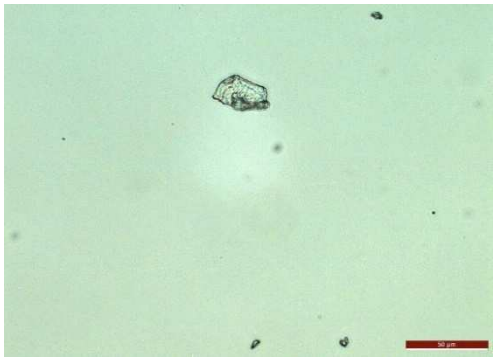


Figure 6a.

Figure 6b.

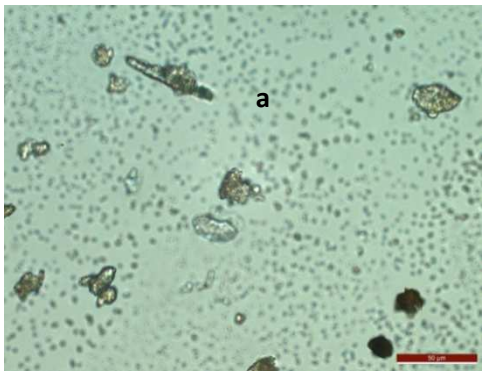


Figure 6c.

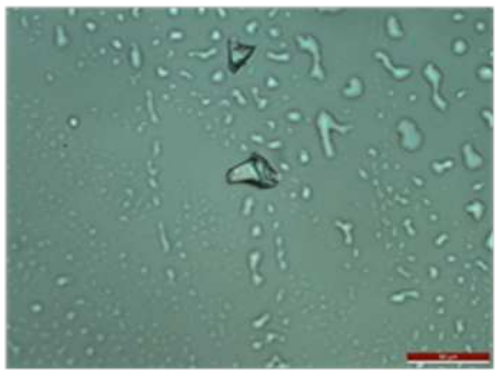


Figure 6d.

Figure *6*a – d: a Phytolith from plantation at >40 cm (NCL); Trapeziform corniculate –having outline of trapezoid with horn like projections*;* b. Phytolith from plantation at 23-40 cm (NCL); Trapeziform corniculate - having outline of a trapezoid with horn like projections corniculate - having outline of a trapezoid with horn like projections*;* c. Phytolith from forest at 14-26 cm (NCL); (a) Smooth Elongate; d. Phytolith from open land at >56 cm (NCL); Trapezium corniculate

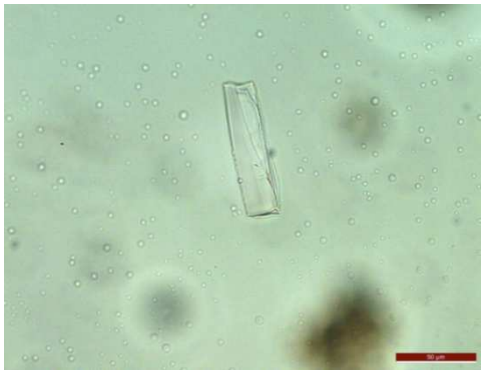


Figure 6e.

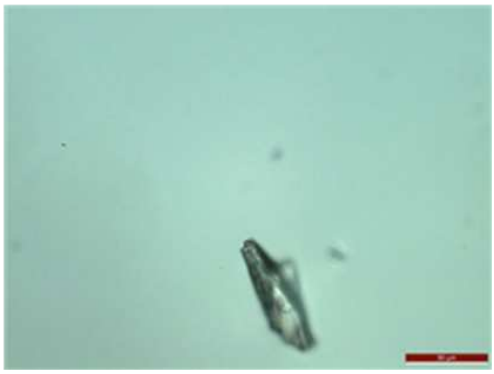


Figure 6f

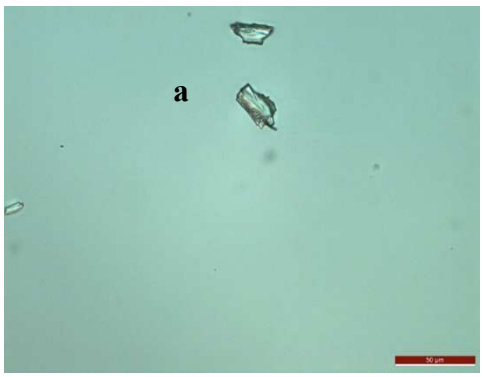


Figure 6g.

Figure 6h.

Figure 6e – h*: e.* Phytolith from forest at 2-13 cm (NCL); Parallelepipedal -four- sided geometrical figure in which every side is parallel to the side opposite*;* f. Phytolith from forest at 2-13 cm (NCL); Carinate - Keel shaped; g. Phytolith from forest at 0-1 cm (NCL); (a)Trapeziform; *6*h. Phytolith from forest at 2-13 cm (NCL); (a) Trapeziform

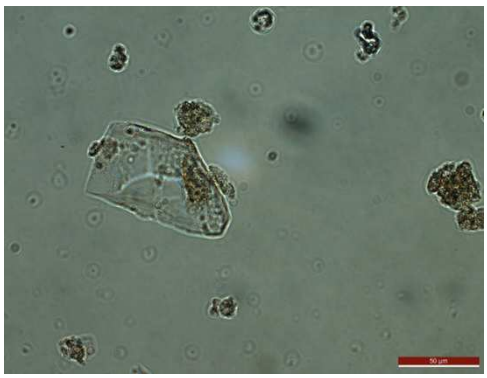


Figure 6i.

Figure 6j

Figure 6k.

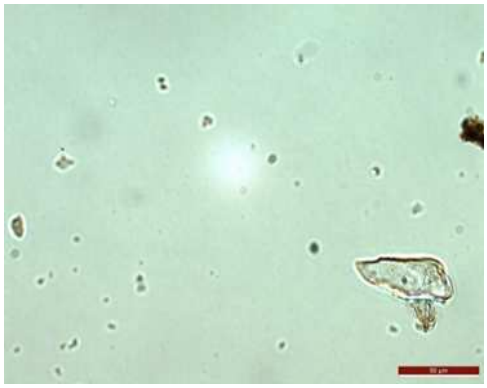


Figure 6l.

Figure 6i – l: i. Phytolith from forest at 2-13 cm (NCL); (a) Trapeziform; j. Phytolith from forest at 14-26 cm (NCL); Elongate process -elongated with protuberance; k. Phytolith from open land at 56 cm (NCL) Trapeziform; l. Phytolith from forest at >26 cm (NCL); Cuneiform bulliform

4.2 PHYTOLITH DISSOLUTION EXPERIMENTS

Table 7. Changes in PhytOC content of soil samples after HCl and oxalate treatments

Sl. no	Treatment	PhytOC %	Change in PhytOC from the untreated soil
1	S_1	0.011	+0.023
2	S_2	0.036	-0.03
3	S_3	0.023	+0.011
4	S_4	0.136	-0.13
5	S_5	0.082	-0.048
6	S_6	0.096	-0.09
7	S_7	0.087	-0.053
8	S_8	0.119	-0.113
S_1 - soil +0.01 N HCl, S_2 - soil+0.01 N HCl, S_3 - soil+0.05 N HCl, S_4 - soil+0.05 N HCl, S_5 - soil+1 mM sodium oxalate S_6 - soil+1 mM sodium oxalate, S_7 - soil+4 mM sodium oxalate, S_8 - soil+4 mM sodium oxalate			

Sodium oxalates mimicking plant root exudates were found to have more detrimental effects on PhytOC than soil reaction (Table 7). As the concentration of Na- oxalates increases, there was a corresponding decrease in the PhytOC contents of soil % (-0.048 to -0.113). The results indicate that biogenic carbon in rhizosphere may not be that stable as expected. However, P^H effects simulated by HCl addition gave contrasting results for forests and plantation. In plantation, the PhytOC contents were found to increase by 0.023% at lower HCl concentrations. Though there was an increase in PhytOC contents at 0.05N HCl as well, the change was not that much prominent and was only half of the treatment at 0.01N HCl. In natural forest soils, the PhytOC contents decreased in both the treatments.

The results suggest that silicon (Si) pools in plantation soils favour PhytOC formation (not biogenic) at lower soil P^H. The formation of PhytOC by means other than by plants needs further exploration

4.2.1 STRUCTURAL VARIATIONS IN PHYTOLITHS AFTER DISSOLUTION EXPERIMENTS

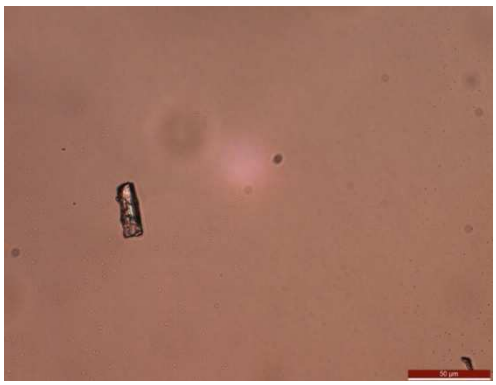


Figure 7a.

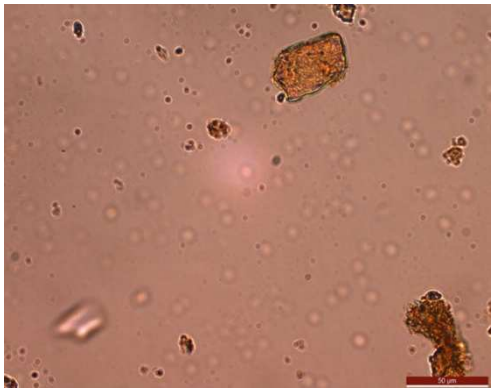
Figure 7b

Figure 7a – b: a. Phytolith from dissolution experiment S_8 (soil + 4Mm sodium oxalate); Elongate psilate; b. Phytolith from dissolution experiment S_7 (soil + 4Mm sodium oxalate); Parallepipedal bulliform

a

a

Figure 7c.



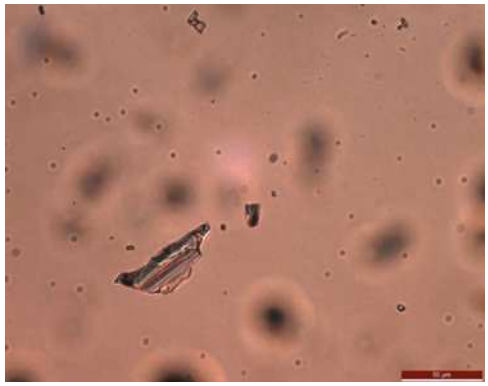


Figure 7d.

Figure 7e.

Figure 7f.

Figure 7c – f: c. Phytolith from dissolution experiment S_6 (soil + 1 mM sodium oxalate); (a) Parallepipedal bulliform; d. Phytolith from dissolution experiment S_6 (soil+ 1 mM sodium oxalate); (a) Scutiform; 7e. Phytolith from dissolution experiment S_4 (soil+ 0.05N HCl); (a) Lanceolate - shaped like a lance-head; f. Phytolith from dissolution experiment S_4 (soil+0.05 N HCl); (a) Trapeziform

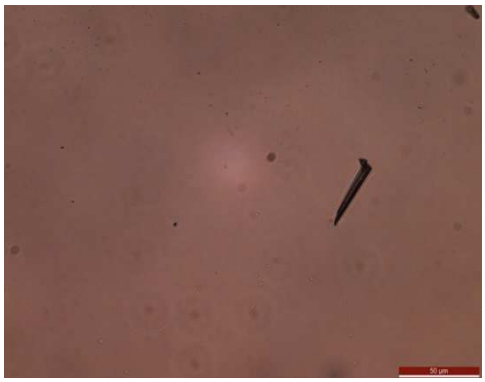


Figure 7g.

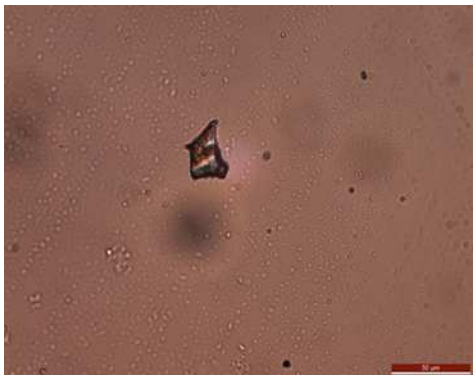


Figure 7h.

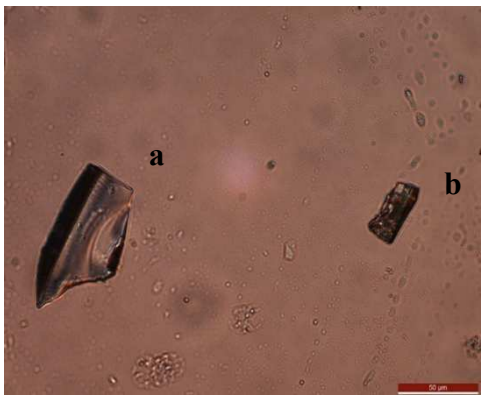


Figure 7i.

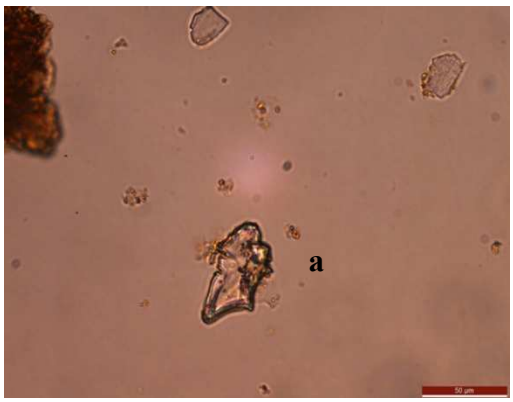


Figure 7j.

Figure 7g – j: g. Phytolith from dissolution experiment S_4 (soil +0.05 N HCl); Acicular - needle shape; h. Phytolith from dissolution experiment S_3 (soil+0.05 N HCl); Trapeziform; i. Phytolith from dissolution experiment S_3 (soil+0.05 N HCl); (a) Carinate, (b) Parallelepipedal; j. Phytolith from dissolution experiment S_6 (soil+1 mM sodium oxalate); (a) Trapeziform bilobate

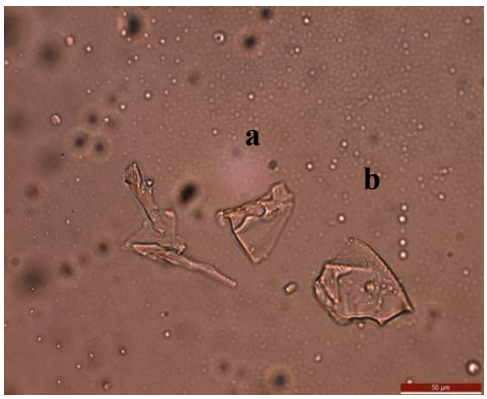


Figure 7k.

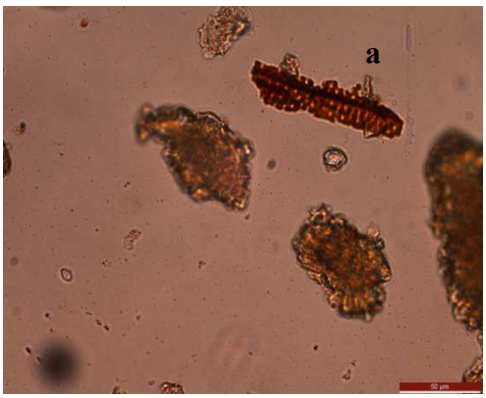


Figure 7l.

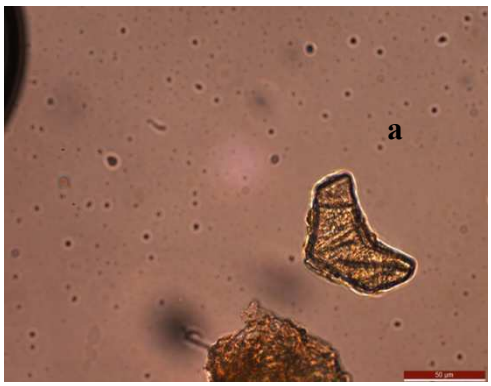


Figure 7m.

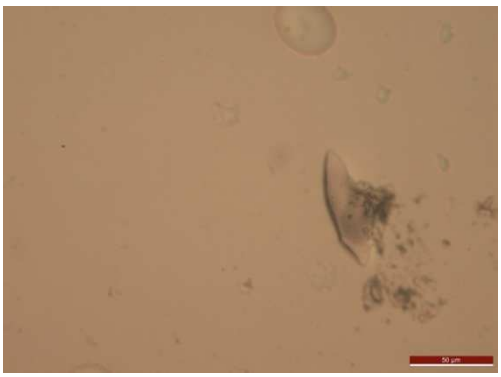


Figure 7n.

Figure 7k – n: k. Phytolith from dissolution experiment S_3 (soil+0.05 N HCl); (a) Carinate, b) Bulliform; l. Phytolith from mineral experiment S_1 (soil+0.01 N HCl); (a) Elongate echinate; m. Phytolith from dissolution experiment S_1(soil + 0.01 N HCl); (a) Cuneiform bulliform; n. Phytolith from dissolution experiment S_2 (soil+0.01 N HCl); (a) Trapeziform

Figure 7p.

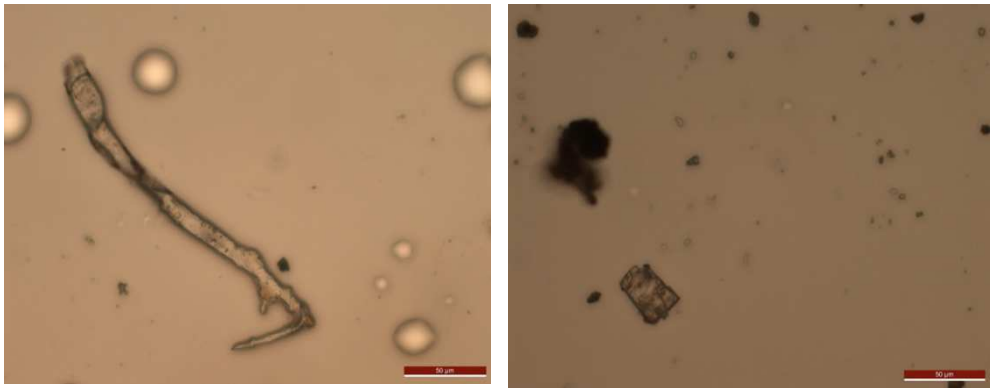


Figure 7o.

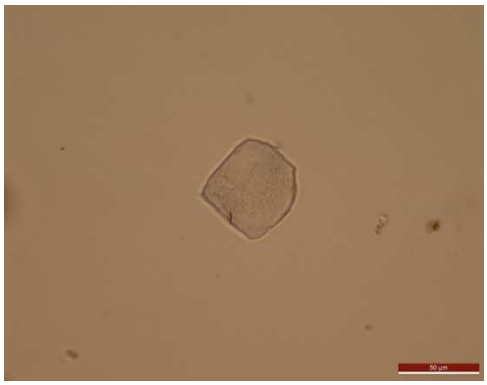


Figure 7q.

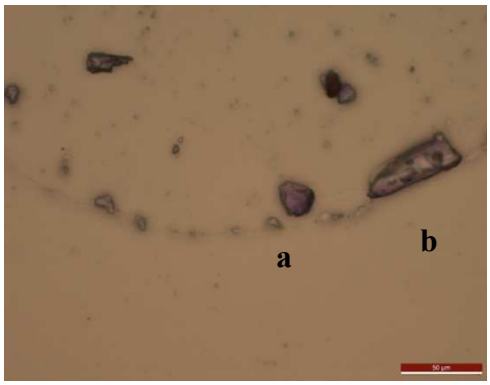


Figure 7r.

Figure 7o – r: o. Phytolith from dissolution experiment S_3 (soil+0.05 N HCl); Geniculate; p. Phytolith from dissolution experiment S_4 (soil+0.05 N HCl); Cubic phytolith; 7q. Phytolith from dissolution experiment S_5 (soil+1 mM sodium oxalate); Trapeziform; 7r. Phytolith from dissolution experiment S_5 (soil + 1mM sodium oxalate); (a) Globular (b) Carinate

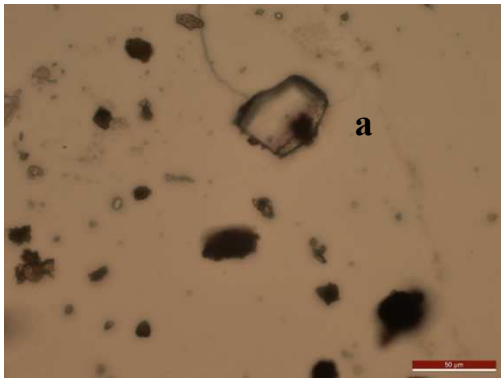


Figure 7s.

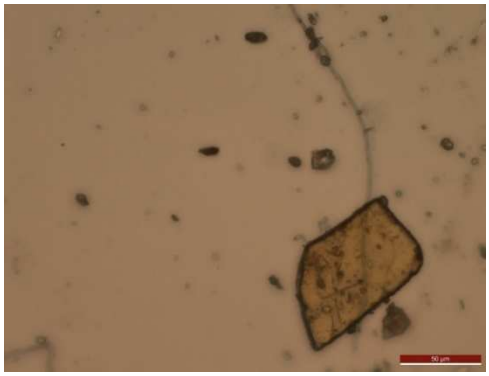


Figure 7t.

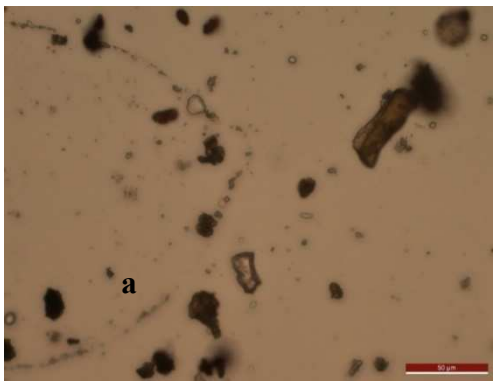


Figure 7u.

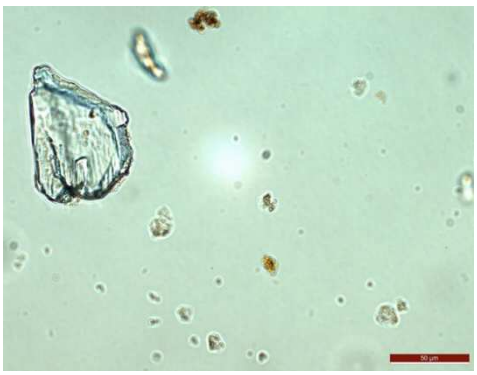


Figure 7v.

Figure 7s – v: s. Phytolith from dissolution experiment S_5 (soil+ 1mM sodium oxalate); (a) Cuboid; t. Phytolith from dissolution experiment S_6 (soil+1 mM sodium oxalate); Trapeziform; u. Phytolith from dissolution experiment S_6 (soil+1 mM sodium oxalate); (a) Bulliform; v. Phytolith from dissolution experiment S_3 (soil+0.05 N HCl); (a) Blocky irregular

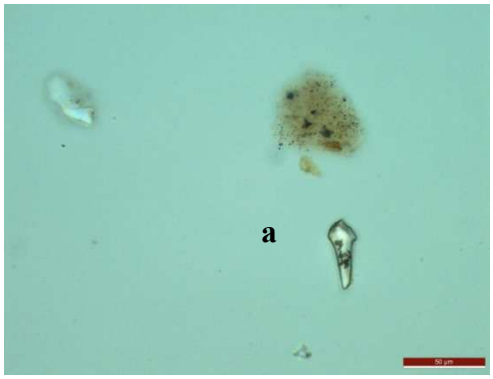


Figure 7w.

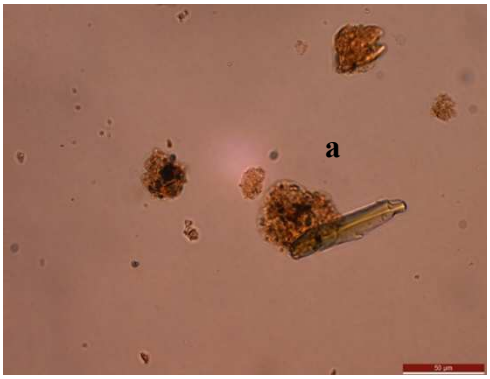


Figure 7x.

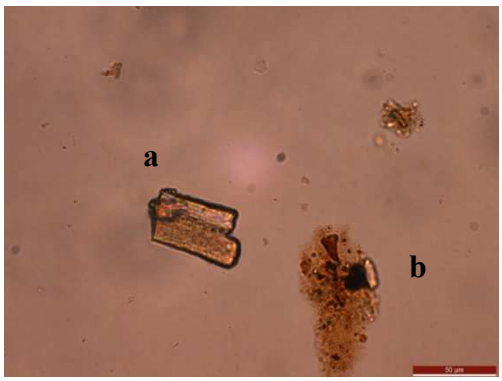


Figure 7y.

Figure 7z.

Figure 7w – z: w. Phytolith from dissolution experiment S_3 (soil+1 0.05N HCl); (a) Acute Acicular - sharp pointed, needle shaped; x. Phytolith from dissolution experiment S_8 (soil+4 mM sodium oxalate); (a) Cylindrical Echinate; y. Phytolith from dissolution experiment S_8 (soil+4 mM sodium oxalate); (a) Rectangle, (b) Scutiform; z. Phytolith from dissolution experiment S_8 (soil+4 mM sodium oxalate); Trapeziform

The untreated soils showed phytolith shapes like trapeziform corniculate, smooth elongate, parallepipedal, elongate process, cuneiform bulliform. After the treatment, many other shapes were able to be viewed along with some shapes viewed in the pre-treated soil. Trapeziform shaped phytolith was viewed in both the treated and pre-treated soils mostly. Treatment S_1 showed elongate echinate and cuneiform bulliform shaped phytoliths. In treatment S_2, fusiform process and trapeziform shapes were observed, and in treatment S_3, we observed trapeziform, geniculate, carinate, parallelepiped, carinate, bulliform, blocky irregular and acicular shaped phytoliths. Lanceolate, trapeziform and acicular are the phytolith shapes seen in treatment S_4. The treatment S_5 showed trapeziform, globular and carinate phytoliths. While treatment S_6 exhibited parallelepipedal, scutiform, trapeziform, bulliform, tabular elongate shaped phytoliths, treatment S_7 showed parallelepipedal bulliform phytoliths. Finally, the treatment S_8 exhibited elongate psilate, cylindrical echinate, rectangle, scutiform, smooth elongate and trapeziform shaped phytoliths.

Cubic phytoliths were identified by An (2016) in the conifer species of Picea and Abies. He had also concluded that this was one of the most common phytoliths in the coniferous phytoliths that are found in the sediments. Premathilake *et al.* has observed lanceolate phytolith was found from oryza spp. Parallelepipedal bulliform phytoliths were found by (Lisztes *et al*., 2014) in *Pao pratensis.*

❖ **EXPERIMENT 2**

4.3 PHYTOLITH CONTENTS IN TEAK PLANTS GROWN UNDER AUGMENTED SILICON SUPPLY

The PhytOC percent was found to be highest in T_1 (0.0815 %) and lowest in T_5 (0.005 %). Treatments T_3 and T_4 were found not to differ significantly with respect to phytolith contents. The results indicate that plant nutrients and silica may have a positive influence on the phytolith production in plants. Li *et al.* (2020) has concluded that the addition of Si fertiliser in the form of monosilicic acid (H_4SiO_4), which was absorbed by roots, resulted in silica build-up in plant tissues by phytolith production.

Table 8. Effect of Silicon treatments on PhytOC% intake

Sl. No	Treatment	PhytOC %
1	T_1 (Nutrient solution)	0.0815^a
2	T_2 (Nutrient solution + 0.2mM Si)	0.527^b
3	T_3 (Nutrient solution + 0.8mM Si)	0.135^c
4	T_4 (Nutrient solution + 1.6mM Si)	0.135^c
5	T_5 (Distilled water)	0.005^c
Values with same alphabetical subscripts doesn't vary significantly		

It is observed that nutrients help in the phytolith formation in the acidic soil considered in the study. Dove and Crerar (1990) observed that a decrease in soil pH can lead to decreased nucleophilic attack of OH– on Si-O-Si bonds, thus phytoliths can remain stable for extended periods of time ((Fraysse *et al*., 2009; Nguyen *et al.,* 2014).

4.3.1 STRUCTURE OF PHYTOLITHS FROM PLANTS GROWN UNDER AUGMENTED SILICON SUPPLY

Figure 8a.

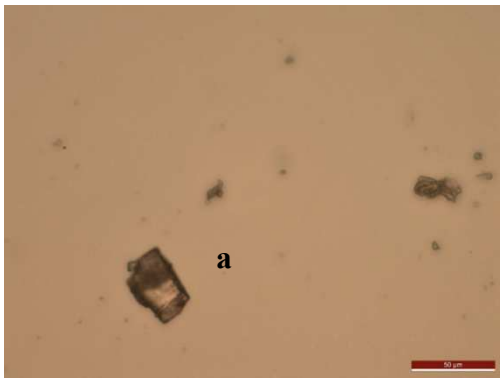


Figure 8b.

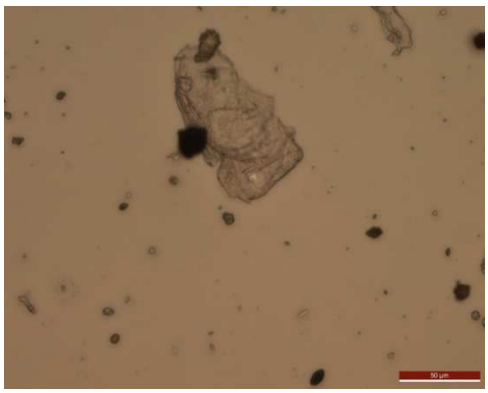


Figure 8c.

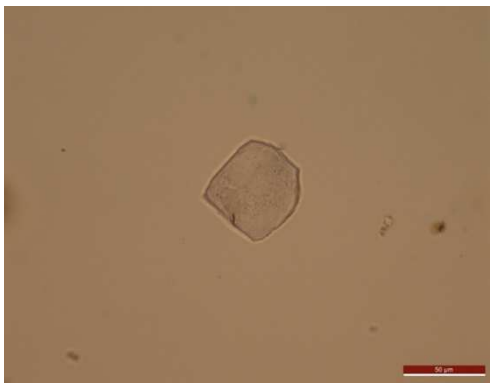


Figure 8d.

Figure 8a – d: a. Phytoliths from nutrient culture experiments (T_4 treatment 1) Elongate brachiate geniculate; b. Phytoliths from nutrient culture experiments (T_4 treatment 1) ;(a) Rectangle; c. Phytoliths from nutrient culture experiments (T_3 treatment 3); Blocky irregular; d. Phytoliths from nutrient culture experiments (T_1 treatment 1); Square

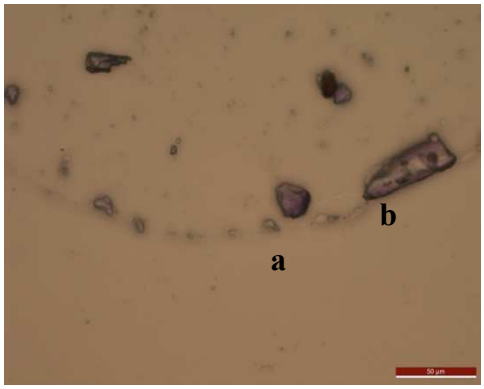


Figure 8e.

Figure 8f.

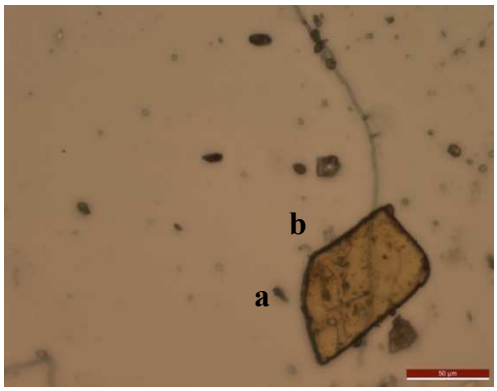


Figure 8g.

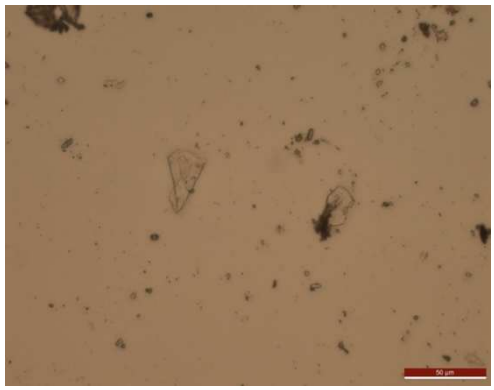


Figure 8h.

Figure *8*e – *h: e*. Phytoliths from nutrient culture experiments (T_2 treatment 2); (a) Globular, (b)Trapeziform*;* f. Phytoliths from nutrient culture experiments (T_4 treatment 1); Elongate process; Phytoliths from nutrient culture experiments (T_1 treatment 2); (a) Trapeziform psilate (b) Globular; h. Phytoliths from nutrient culture experiments (T_4 treatment 1); Scutiform - shield shaped

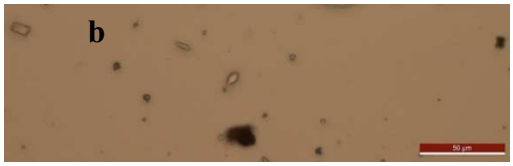


Figure 8i.

Figure 8j.

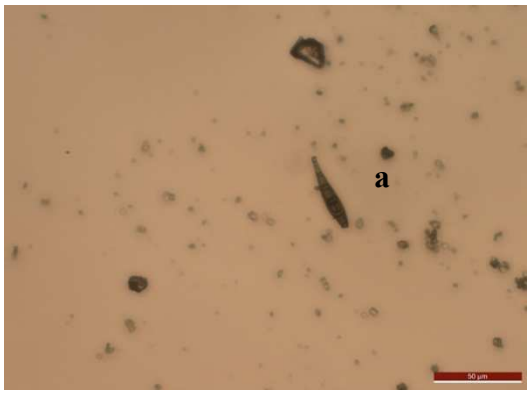


Figure 8k.

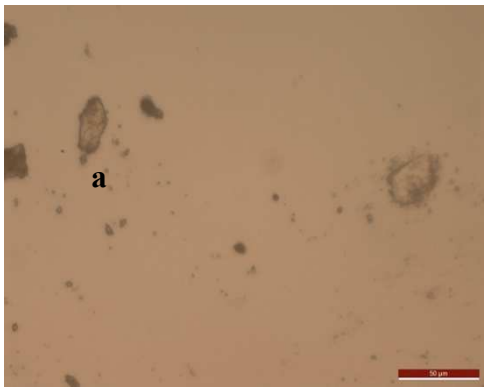


Figure 8l.

Figure 8i – l: i. Phytoliths from nutrient culture experiments (T_1 treatment 1); (a) Carinate - Keel shaped, (b) Rugose elongate, (c) Spiral; j. Phytoliths from nutrient culture experiments (T_1 treatment 2); (a) Trapeziform; 8k. Phytoliths from nutrient culture experiments (T_4 treatment 2); (a) Clavate with ornamentation; 8l. Phytoliths from nutrient culture experiments (T_5 treatment 1) ;((a) Blocky irregular

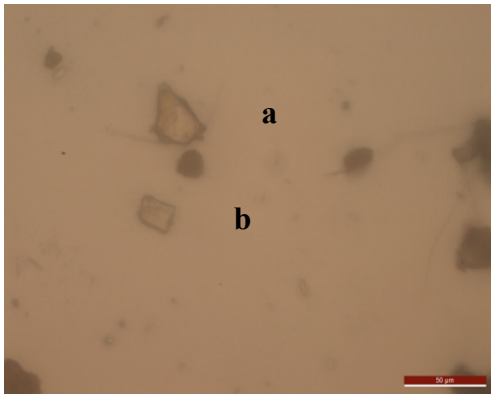


Figure 8m.

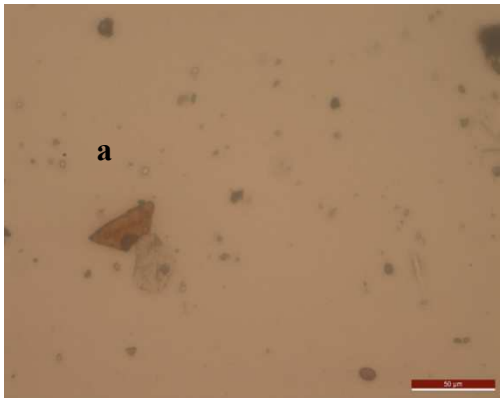


Figure 8n.

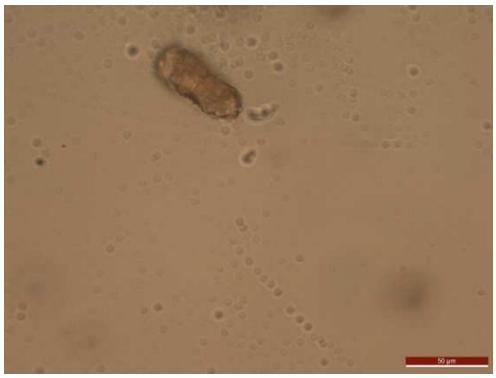


Figure 8o.

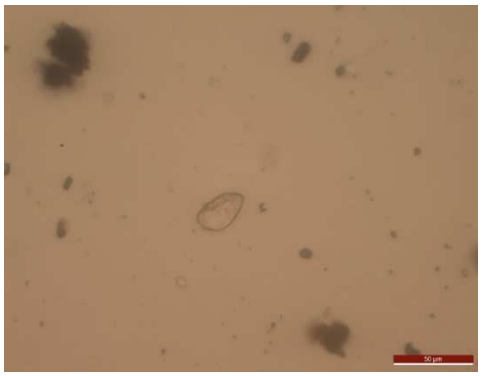


Figure 8p.

Figure 8m – p: m. Phytoliths from nutrient culture experiments (T_5 treatment 1); (a) Bulliform (b) Square; 8n. Phytoliths from nutrient culture experiments (T_2 treatment 1) ;((a) Trapeziform; 8o. Phytoliths from nutrient culture experiments (T_3 treatment 2); Blocky polyhedron; p. Phytoliths from nutrient culture experiments (T_2 treatment 2); Ellipsoidal

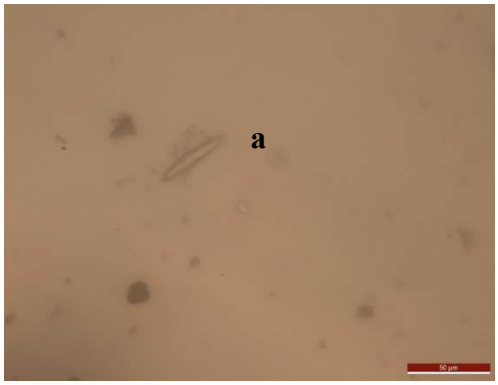


Figure 8q.

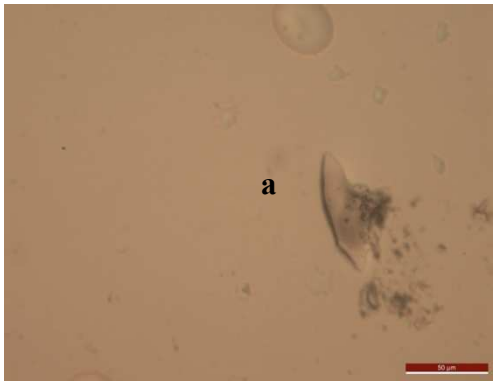


Figure 8r.

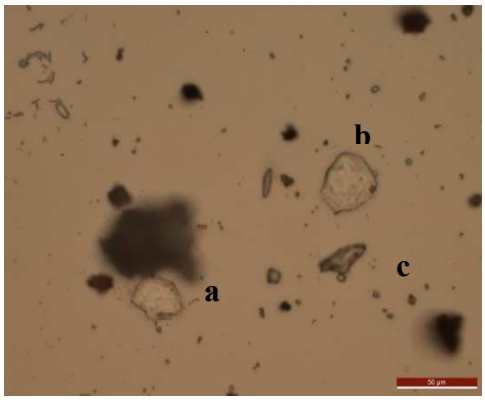


Figure 8s.

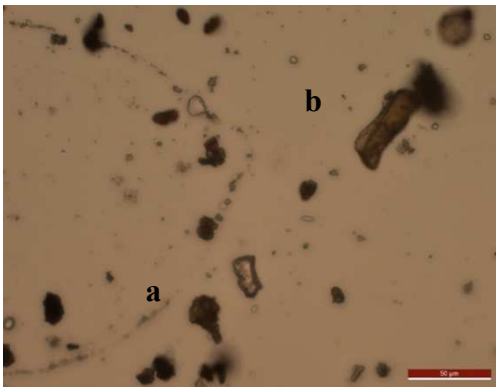


Figure 8t.

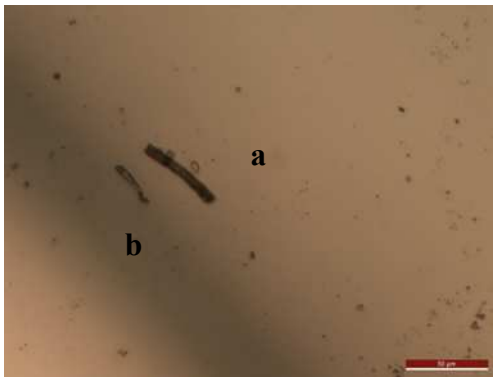


Figure 8u.

Figure 8q – t; q. Phytoliths from nutrient culture experiments (T_5 treatment 1); (a) Fusiform; r. Phytoliths from nutrient culture experiments (T_3 treatment 3) ;((a) Cuneiform bulliform; s. Phytoliths from nutrient culture experiments (T_3 treatment 3) ;((a, b) Bulliform (c) Cuneiform; t. Phytoliths from nutrient culture experiments (T_3 treatment 1); (a) Bulliform (b) Pyramidal; u. Phytoliths from nutrient culture experiments (T3 treatment 1); (a) Smooth elongate (b) Acicular

While, treatment T_1 exhibited blocky irregular, carinate, rugose, elongate spiral and trapeziform phytoliths, treatment T_2 showed square, trapeziform psilate, globular, trapeziform, ellipsoidal, bulliform, cuneiform phytoliths. In the treatment T_3, rectangle, bulliform, pyramidal, blocky polyhedron, smooth elongate, acicular, cuneiform bulliform shapes were observed. Treatment T_4, exhibited elongate brachiate geniculate, scutiform, clavate with ornamentation and elongate process phytoliths and treatment T_5 showed blocky irregular, bulliform, square, fusiform, pyramidal shaped phytoliths. In the untreated soils, trapeziform corniculate, smooth elongate, elongate process and cuneiform bulliform phytoliths were seen wand maximum density was for trapeziform shaped phytoliths.

Blocky polyhedral phytoliths were observed by An (2016) in the conifer species of Picea and Abies. He had also concluded that this was one of the most common phytoliths in the coniferous phytoliths that are found in the sediments. Ge *et al.* (2020) has observed elongate brachiate geniculate in *Quercus mongolica*, leaf, and these type of phytoliths are formed from silicified sclerenchyma, often bent and branched to form a "Y". Premathilake *et al.* has observed rectangle and square from woody dicot.

Phytolith is a storehouse of carbon and also very much resistant to degradation. Thus, a portion of carbon dioxide absorbed by plants is the occluded inside the phytolith to remain for a longer period of time. There are many ways to increase phytolith in the soil. Plants like bamboo which are the major phytolith producers can be planted. Besides that, the existing phytolith accumulators must be allowed to stand for encouraging the long term phytolith accumulation. In case of grasslands silicon fertilization, silicate powder amendment, increasing the ratio of Poaceae and Cyperaceae with rational grazing, restoration of deserted land and proper management of irrigation are worthy options. While considering the crop

plants, proper irrigation, silicon fertilization, enhancement of cereal area, organic mulching, silicate rock powder amendment, genetic engineering of high PhytOC production crop, enhancement of multi- cropping can be considered as the methods to increase phytolith production and there by trapping the carbon inside the PhytOC safely for a long period of time.

SUMMARY AND CONCLUSION

CHAPTER 4

SUMMARY AND CONCLUSION

- The clay content of the soils in the Northern Central laterites varied from 30.16 to 40.16 and was found increasing with depth. On the other hand, the clay contents in the natural forest and open land varied from 20.16 to 30.16 and 26.16 to 34.16, respectively, down the profile. There was a corresponding decrease in sand percent down the profile in all the systems of North Central Laterites
- The soil pH was found to be acidic in all the soils and was found to decrease down the profile in all soils except, open land in North Central Laterite zone.
- All the soils (plantations, natural forests and open land) in this zone had low to medium available nitrogen and phosphorus. However, plantations were found to have high amounts of available potassium and such a trend was noticed in the other analysed systems.
- Available Ca was found to be highest in the surface soils of teak plantations (642 mg/kg soils) in the Northern Central Laterites
- All the soils were deficient in Mg, the base saturation of the soils was > 99 % and the CEC values were found to vary from 52.59 to 105.93 cmols (p+) per kg in plantations, from 64.08 to 84.98 cmols (p+) per kg in natural forests and ranged from 45.24 to 91.04 cmols (p+) per kg in open lands
- The PhytOC to TOC ratio for plantations in NCL was found to increase towards C horizon to reach the highest value (13.95) whereas the A horizon showed the least value (0.042).
- Though natural forests had the maximum PhytOC/ TOC ratio in the upper A and B horizons (> 2), the values were higher in the lower C horizon in both plantations (11.95) and open land (10.02). Natural forests with good

canopy cover reduce the leachate for Phytolith transportation to lower layers.

- Further, PhytOC/ TOC ratio was lower in natural forests in all horizons than plantations and open lands. The reduction in plant diversity in plantations and open lands decreases the range of the total contents of phytolith and PhytOC by reducing species richness, and decreases the production fluxes of phytoliths and PhytOC by reducing aboveground biomass.
- The increase of PhytOC/ SOC ratio in soil profiles with soil depth suggests that PhytOC could be translocated to lower layers and could be one of the major stable sources of SOC in these layers and the process of phytolith assemblage and rejuvenation occurs by means of phytolith translocation, rather than the input of the younger soil carbon into phytoliths during their dissolution in the aggressive soil conditions.
- NCL's plantation had trapeziform corniculate as the phytoliths. While the forest showed trapeziform, smooth elongate, parallelepipedal, elongate process and cuneiform bulliform shaped phytoliths, open lands exhibited trapeziform corniculate, trapeziform shaped phytoliths.
- In the dissolution experiment, sodium oxalates mimicking plant root exudates were found to have more detrimental effects on PhytOC than soil reaction. As the concentration of Na- oxalates increases, there was a corresponding decrease in the PhytOC contents of soil % (-0.048 to -0.113). The results indicate that biogenic carbon in rhizosphere may not be that stable as expected. However, P^H effects simulated by HCl addition gave contrasting results for forests and plantation. In plantation, the PhytOC contents were found to increase by 0.023% at lower HCl concentrations. Though there was an increase in PhytOC contents at 0.05N HCl as well, the change was not that much prominent and was only half of the treatment at 0.01N HCl. In natural forest soils, the PhytOC contents decreased in both the treatments. The results suggest that silicon

(Si) pools in plantation soils favour PhytOC formation (not biogenic) at lower P^H.

- In the structural analysis from the dissolution experiment, the untreated soils showed phytolith shapes like trapeziform corniculate, smooth elongate, Parallepipedal, elongate process, cuneiform bulliform. After the treatment, many other shapes were able to be viewed along with some shapes viewed in the pre-treated soil. Trapeziform shaped phytolith was viewed in both the treated and pre-treated soils mostly. The other phytolith shapes that were viewed includes elongate echinate, cuneiform bulliform shaped phytoliths, fusiform process, trapeziform shapes, geniculate, carinate, parallelepiped, carinate, bulliform, blocky irregular and acicular shaped phytoliths, lanceolate shaped phytoliths. Besides that, scutiform, tabular elongate shaped phytoliths parallelepipedal bulliform phytoliths, elongate psilate, cylindrical echinate, rectangle, smooth elongate and shaped phytoliths were also observed.
- The PhytOC percent was found to be highest in T_1 (0.0815 %) and lowest in T_5 (0.005 %). Treatments T_3 and T_4 were found not to differ significantly with respect to phytolith contents. The results indicate that plant nutrients and silica may have a positive influence on the phytolith production in plants.
- The silicon treatment exhibited blocky irregular, carinate, rugose, elongate spiral, trapeziform, square, trapeziform psilate, globular, ellipsoidal, bulliform, rectangle, bulliform, pyramidal, blocky polyhedron, smooth elongate, acicular, cuneiform bulliform, elongate brachiate geniculate, scutiform, clavate with ornamentation, elongate process, fusiform and pyramidal shaped phytoliths. In the untreated soils, trapeziform corniculate, smooth elongate, elongate process and cuneiform bulliform phytoliths were seen with trapeziform shaped phytoliths seen more density.

- Through the study we can see that teak accumulate phytolith and thereby carries lot of PhytOC. So teak plantations can contribute well to trapping the carbon dioxide inside the PhytOC.
- Encouraging the stand of phytolith accumulator plants, silicon fertilizing, silicate rock powder amendment, reforestation and afforestation with phytolith accumulators can improve phytolith production and thereby trapping of carbon inside PhytOC safely for a long period of time.

CHAPTER 5

REFERENCES

- [Anonymous]. 2021.Science & Climate [on line]. The University of California Davis campus. Available.https://climatechange.ucdavis.edu/science/carbon-sequestration/biological/ [20th August 2021].
- Albert, R. M., Ruíz, J. A., and Sans, A. (2016). PhytCore ODB: a new tool to improve efficiency in the management and exchange of information on phytoliths. *J. Archaeol. Sci. 68*: 98-105.
- Alexandre, A., Basile-Doelsch, I., Delhaye, T., Borshneck, D., Mazur, J. C., Reyerson, P., and Santos, G. M. 2015. New highlights of phytolith structure and occluded carbon location: 3-D X-ray microscopy and NanoSIMS results. *Biogeosciences*, *12*(3), 863-873.
- Alexandre, A., Meunier, J. D., Colin, F., and Koud, J. M. 1997. Plant impact on the biogeochemical cycle of silicon and related weathering processes. *Geochim. Cosmochim. Acta. 61*(3): 677-682.
- Alhousari, F. and Greger, M. 2018. Silicon and mechanisms of plant resistance to insect pests. *Plants*. 7(2): 33.
- An, X.H., 2016. Morphological characteristics of phytoliths from representative conifers in China. *Palaeoworld*, *25*(1), pp.116-127.
- Anala, R. and Nambisan, P. 2015. Study of morphology and chemical composition of phytoliths on the surface of paddy straw. *Paddy Water ssssEnviron.13*(4):521-527.

- Ball, T., Chandler-Ezell, K., Dickau, R., Duncan, N., Hart, T.C., Iriarte, J., Lentfer, C., Logan, A., Lu, H., and Madella, M. 2016. Phytoliths as a tool for investigations of agricultural origins and dispersals around the world. *J. Archaeol. Sci*. 68: 32–45.
- Bartoli, F., 1985. Crystallochemistry and surface properties of biogenic opal. *J. Soil Sci*. 36: 335–350.
- Bartoli, F., Wilding, L.P. 1980. Dissolution of biogenic opal as a function of its physical and chemical properties. *Soil Sci. Soc. Am. J*. 44: 873–878.
- Bartoli, F.1983. The biogeochemical cycle of silicon in two temperate forest ecosystems. *Ecol. Bullet*. 35: 469–476.
- Batjes, N.H., 1996.Total C and N in the soils of the world. *Eur. J. Soil Sci*.47: 151–163.
- Battelle. 2000. Global energy technology strategy: addressing climate change. Initial findings from an international public-private collaboration, Washington, D.C., 60pp.
- Beedlow, P. A., Tingey, D. T., Phillips, D. L., Hogsett, W. E., and Olszyk, D. M. 2004. Rising atmospheric CO2 and carbon sequestration in forests. *Frontiers in Ecology and the Environment*, *2*(6): 315–322.
- Blecker SW, McCulley RL, Chadwick OA, Kelly EF (2006) Biologic cycling of silica across a grassland bioclimosequence. Global Biogeochem Cy 20:1–11.
- Blecker, S.W., McCulley, R.L., Chadwick, O.A., and Kelly, E.F. 2006. Biologic cycling of silica across a grassland bioclimosequence. *Global Biogeochem. Cy*. 20: 1–11.

- Borrelli, N., Alvarez, M.F., Osterrieth, M.L., and Marcovecchio, J.E. 2010. Silica content in soil solution and its relation with phytolith weathering and silica biogeochemical cycle in Typical Argiudolls of the Pampean Plain, Argentina—a preliminary study. *J. Soil Sediment*. 10: 983–994.
- Carter, J.A. 2007. Ancient Climate and Environmental History from Phytolith-Occluded Carbon. Victoria University of Wellington, 1–168.
- Carter, J.A. 2009. Atmospheric carbon isotope signatures in phytolith-occluded carbon. *Quatern. Int*. 193: 20–29.
- Cary, L., Alexandre, A., Meunier, J.D., Boeglin, J.L., Braun, J.J., 2005. Contribution of phytoliths to the suspended load of biogenic silica in the Nyong basin rivers (Cameroon). *Biogeochemistry* .74: 101–114.
- Chan, K. Y., Heenan, D. P. and Oates, A.2002. Soil carbon fractions and relationship to soil quality under different tillage and stubble management. *Soil Till. Res*. 63: 133–139.
- Chandran, P., Ray, S.V., Bhattacharyya, T., Srivastava, P., Krishnan, P. and Pal, D.K., 2005. Lateritic soils of Kerala, India: their mineralogy, genesis, and taxonomy. *Soil Res.*, *43*(7):839-852.
- Chendev, Y., Khokhlova, O., Ponomarenko, E., Ershova, E., Alexandrovskiy, A., and Myakshina, T.2018. Holocene Environmental and Anthropogenic Changes of Soils and Vegetation in the Central Russian Upland: The Case Study in the "Belogorie" Natural Reserve. *Geosci.* 8: 473.
- Corbineau, R., Reyerson, P. R., Alexandre, A., and Santos, G. M. 2013. Towards producing pure phytolith concentrates from plants that are suitable for carbon

isotopic analysis. *Rev. Palaeobot. Palynol*. 197: 179–185. doi: 10.1016/j.revpalbo. 2013.06.001.

- Datnoff, L.E., Snyder, G.H., Korndörfer, G.H.2001. Silicon in agriculture; *Elsevier*: Cambridge, MA, USA, Volume 8.
- David, R., Byrt, C. S., Tyerman, S. D., Gilliham, M., & Wege, S. 2019. International Code for Phytolith Nomenclature 2.0 (ICPN 2.0). *Annals of Botany*. *124*(2): 209-220.
- Denis, A.G., 2017. Phytolith transport in texturally differentiated soils. *Annual Research & Review in Biology*.1-10.
- Ding TP, Ma GR, Shui MX, Wan DF, Li RH .2005. Silicon isotope study on rice plants from the Zhejiang province, China. *Chem Geol* .218:41–50.
- Dove, P.M. and Crerar, D.A. 1990. Kinetics of quartz dissolution in electrolyte solutions using a hydrothermal mixed flow reactor. *Geochimica et cosmochimica acta*. *54*(4): 955-969.
- Eksambekar, S. 2009. Review of phytolith research: Scope and applications. *The Korean Journal of Quaternary Research*,.*23*(2): 1-12.
- Elbaum, R., Melamed-Bessudo, C., Tuross, N., Levy, A.A., and Weiner, S. 2009. New methods to isolate organic materials from silicified phytoliths reveal fragmented glycoproteins but no DNA. *Quatern. Int*. 193: 11–19.
- Epstein, E.1994. The anomaly of silicon in plant biology. *Proc. Natl. Acad. Sci.* 91: 11–17.
- Eswaran, H., Van Den Berg, E. and Reich, P.1993. Organic carbon in soils of the world. *Soil Sci. Soc. Am. J.* 57: 192–194.

- Falkowski, P., Scholes, R.J., Boyle, E.E.A., Canadell, J., Canfield, D., Elser, J., Gruber, N., Hibbard, K., Högberg, P., Linder, S. and Mackenzie, F.T. 2000. The global carbon cycle: a test of our knowledge of earth as a system. *Science*.*290*(5490):291-296.
- Fang C, Smith P, Moncrieff J.B., and Smith J.U .2005. Similar response of labile and resistant soil organic matter pools to changes in temperature. *Nature*.433:57–59.
- Fisher, R.F., Bourn, C.N., Fisher, W.F. 1995. Opal phytoliths as an indicator of the floristics of prehistoric grasslands. Geoderma 68:243–255
- Fishkis, O., Ingwersen, J., and Streck, T. 2009. Phytolith transport in sandy sediment: Experiments and modeling. *Geoderma* .151:168–178.
- Fraysse, F., Pokrovsky, O.S., Schott, J., and Meunier, J.-D., 2006. Surface properties, solubility and dissolution kinetics of bamboo phytoliths. *Geochim. Cosmochim. Ac*. 70: 1939–1951.
- Fraysse, F., Pokrovsky, O.S., Schott, J., and Meunier, J.-D., 2009. Surface chemistry and reactivity of plant phytoliths in aqueous solutions. *Chem. Geol.* 258: 197–206.
- Fritzsch, D., Langan, C. and Röpke, A. 2019. Melted straw – burning experiments on grain and its importance for the interpretation of heated archaeological sediments. *Archaeological Reports*. 30:65-175.
- Gallagher, K.L., Alfonso-Garcia, A., Sanchez, J., Potma, E.O., and Santos, G.M.2015. Plant growth conditions alter phytolith carbon. *Front. Plant Sci.*6: 753.

- Gavrilov, D., Loiko, S., and Klimova, N.2018.Holocene Soil Evolution in South Siberia Based on Phytolith Records and Genetic Soil Analysis (Russia). *Geosciences*. 8: 402.
- Ge, Y., Lu, H., Wang, C. and Gao, X., 2020. Phytoliths in selected broad-leaved trees in China. *Scientific reports*, *10*(1), pp.1-15.
- Gérard, F., Mayer, K.U., Hodson, M.J., and Ranger, J. 2008. Modelling the biogeochemical cycle of silicon in soils: application to a temperate forest ecosystem. *Geochim. Cosmochim. Ac.* 72:741–758.
- Guo, F., Song, Z., Sullivan, L., Wang, H., Liu, X., Wang, X., Li, Z., and Zhao, Y., 2015. Enhancing phytolith carbon sequestration in rice ecosystems through basalt powder amendment. *Sci. Bull*. 60: 591–597.
- Henriet, C., Bodarwe, L., Dorel, M., Draye, X., and Delvaux, B. 2008. Leaf silicon content in banana (Musa spp.) reveals the weathering stage of volcanic ash soils in Guadeloupe. *Plant Soil* .313: 71–82.
- Hodson, M.J., Parker, A.G., Leng, M.J., and Sloane, H.J., 2008. Silicon, oxygen and carbon isotope composition of wheat (*Triticum aestivum L.*) phytoliths: implications for palaeoecology and archaeology. *J. Quaternary Sci.* 23: 331–339.
- Hodson, M.J., White, P.J., Mead, A., and Broadley, M.R., 2005. Phylogenetic variation in the silicon composition of plants. *Ann. Bot*. 96: 1027–1046.
- Hodson, M.J.2016. The development of phytoliths in plants and its influence on their chemistry and isotopic composition. Implications for palaeoecology and archaeology. *J. Archaeol. Sci*. 68: 62–69.

- Huang ZT, Li YF, Jiang PK, Chang SX, Song ZL, Liu J, Zhou GM (2014) Long-term intensive management increased carbon occluded in phytolith (PhytOC) in bamboo forest soils. Sci Rep 4:3602.
- Huang, Z., Li, Y., Jiang, P., Chang, S. X., Song, Z., Liu, J., et al. (2014). Long term intensive management increased carbon occluded in phytolith (PhytOC) in bamboo forest soils. *Sci. Rep*. 4:3602. doi: 10.1038/srep03602
- Huang, Z.T., Li, Y.F., Jiang, P.K., Chang, S.X., Song, Z.L., Liu, J. and Zhou, G.M., 2014. Long-term intensive management increased carbon occluded in phytolith (PhytOC) in bamboo forest soils. *Scientific reports*, *4*(1):1-5.
- Iju, C., Kuang-ti, L. and Cheng-hwa, T., 2020. Silicified bulliform cells of Poaceae: morphological characteristics that distinguish subfamilies. *Botanical Studies (Online)*, *61*(1).
- Iler, R..1979. The Chemistry of Silica. Solubility, Polymerization, Colloid and Surface Properties, and Biochemistry. (Chichester: John Wiley and Sons 1).
- Intergovernmental Panel on Climate Change. 2001. Climate Change: The Scientific Basis. Cambridge Univ. Press, Cambridge, UK.
- International Committee for Phytolith Taxonomy (ICPT) Neumann Katharina, K. de Strömberg Caroline A.E., Ball Terry Albert Rosa Maria, Vrydaghs Luc and Cummings Linda Scott. 2019. International code for phytolith nomenclature (ICPN) 2.0. *Annals of Botany*, *124*(2);189-199.
- Jansson, C., Wullschleger, S. D., Kalluri, U. C., and Tuskan, G. A. 2010. Phyto sequestration: carbon bio sequestration by plants and the prospects of genetic engineering. *Bioscience*. 60(9): 685–696.

- Jones L.H.P., Milne A.A. 1963. Studies of silica in the oat plant. *Plant Soil*. 18:207–220.
- Jones, M. B., and Donnelly, A. 2004. Carbon sequestration in temperate grassland ecosystems and the influence of management, climate and elevated CO_2. *New Phytologist*.164(3): 423–439.
- Jones, R. L., and Beavers, A. H. 1963. Some mineralogical and chemical properties of plant opal. *Soil Sci*. 96: 375–379.
- Kameník, J., Mizera, J., and Řanda, Z. 2013. Chemical composition of plant silica phytoliths. *Environ. Chem. Lett*. 11: 189–195.
- Kelly, E., Amundson, R., Marino, B.D., Deniro, M. 1991. Stable isotope ratios of carbon in phytoliths as a quantitative method of monitoring vegetation and climate change. *Quaternary Res*. 35: 222–233.
- Kelly, E., Chadwick, O., Hilinski, T., 1998. The effect of plants on mineral weathering. Biogeochemistry 42, 21–53.
- Kim, K.S. and Whang, S.S. 1992, Titles Nature of phytoliths and their applications in Botany (Chonbuk National Univ., Chonju (Korea Republic). Dept. of Biology)
- Krull, E.S., Skjemstad, J.O., Graetz, D., Grice, K., Dunning, W., Cook, G., and Parr, J.F., 2003. 13C-depleted charcoal from C4 grasses and the role of occluded carbon in phytoliths. *Org. Geochem*. 34: 1337–1352.
- Lal, R. 2008. Carbon sequestration. Philosophical Transactions of the Royal Society B: *Biological Sciences*, 3631492, 815–830.

- Lal, R.2003. Global potential of soil carbon sequestration to mitigate the greenhouse effect. Critical reviews in plant sciences. 22(2). 151–184.
- Lal, R.2003. Soil erosion and the global carbon budget. *Environ. Int*. 29:437–450.
- Li, B., Song, Z., Li, Z., Wang, H., Gui, R., and Song, R., 2014a. Phylogenetic variation of phytolith carbon sequestration in bamboos. *Sci. Rep*. 4: 4710. DOI: 10.1038/srep04710.
- Li, B., Song, Z., Wang, H., Li, Z., Jiang, P., and Zhou, G., 2014b. Lithological control on phytolith carbon sequestration in moso bamboo forests. *Sci. Rep*. 4: 5262. DOI: 10.1038/srep05262.
- Li, Z., Guo, F., Cornelis, J.T., Song, Z., Wang, X. and Delvaux, B., 2020. Combined silicon-phosphorus fertilization affects the biomass and phytolith stock of rice plants. *Front. Plant Sci.*, *11*, p.67.
- Li, Z., Song, Z., and Cornelis, J.T., 2014. Impact of rice cultivar and organ on elemental composition of phytoliths and the release of bio-available silicon. *Front. Plant Sci*. 5: 1–8.
- Li, Z., Song, Z., and Li B., 2013b. The production and accumulation of phytolith-occluded carbon in Baiyangdian reed wetland of China. *Appl. Geochem*. 37: 117–124.
- Li, Z., Song, Z., Jiang, P., 2013a. Biogeochemical sequestration of carbon within phytoliths of wetland plants: A case study of Xixi wetland, China. *Chinese Sci.Bull*. 58: 2480–2487.

- Li, Z., Song, Z., Parr, J.F., Wang, H., 2013c. Occluded C in rice phytoliths: implications to biogeochemical carbon sequestration. *Plant Soil* .370: 615–623.
- Lisztes_Szabo, Z.S.U.Z.S.A., Kovacs, S. and PETÖ, Á., 2014. Phytolith analysis of Poa pratensis (Poaceae) leaves. *Turkish Journal of Botany*, *38*(5).851-863.
- Liu, X., Li, L., Bian, R., Chen, D., Qu, J., Kibue, G.W., Pan G, Zhang X, Zheng J, and Zheng J., 2014. Effect of biochar amendment on soil-silicon availability and rice uptake. *J. Plant Nutr. Soil Sci*. 177: 91–96.
- Lü, H.Y., Wu, N.Q., Yang, X.D., Jiang, H., Liu, K.B., and Liu, T.S. 2006. Phytoliths as quantitative indicators for the reconstruction of past environmental conditions in China I: phytolith-based transfer functions. *Quaternary Sci. Rev.* 25: 945–959.
- Lucas, Y., Luizao, F.J., Chauvel, A., Rouiller, J., and Nahon, D. 1993. The relation between biological activity of the rain forest and mineral composition of soils. *Science* .260: 521–523.
- Madella, M., Alexandre, A., and Ball, T. 2005. International code for phytolith nomenclature 1.0. *Ann. Bot*. 96: 253–260.
- McInerney, F.A., Strömberg, C.A.E., and White, J.W.C. 2011. The Neogene transition from C3 to C4 grasslands in North America: stable carbon isotope ratios of fossil phytoliths. *Paleobiology* .37: 23–49.
- Mercader, J., Astudillo, F., Barkworth, M., Bennett, T., Esselmont, C., Kinyanjui, R., Grossman, D.L., Simpson, S. and Walde, D., 2010. Poaceae phytoliths from the niassa rift, Mozambique. *J. Archaeol. Sci. 37*(8): 1953-1967.

- Meunier, J.D., Barboni, D., Anwar-ul-Haq, M., Levard, C., Chaurand, P. Vidal, V., Grauby, O., Huc. R., Laffont-Schwob, I., and Rabier, J.2017. Effect of phytoliths for mitigating water stress in durum wheat. *New Phytol*. 215: 229–239.
- Meunier, J.-D., Colin, F., and Alarcon, C. 1999. Biogenic silica storage in soils. *Geology*.27: 835–838.
- Neethirajan, S., Gordon, R., and Wang, L.2009. Potential of silica bodies (phytoliths) for nanotechnology. *Trends Biotechnol*. 27: 461–467.
- Ngoc Nguyen, M., Dultz, S. and Guggenberger, G., 2014. Effects of pretreatment and solution chemistry on solubility of rice straw phytoliths. *J. Plant. Nutr. Soil Sci. 177*(3):349-359.
- Pachauri, R. K., Allen, M. R., Barros, V. R., Broome, J., Cramer, W., Christ, R., and van Ypserle, J. P. 2014. Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change (p. 151). Ipcc.
- Parr, J. F. and Sullivan, L.2011. A. Phytolith occluded carbon and silica variability in wheat cultivars. *Plant Soil* .342: 165–171.
- Parr, J. F., Dolic, V., Lancaster, G., and Boyd, W. E. 2001. A microwave digestion method for the extraction of phytoliths from herbarium. specimens. *Rev. Palaeobot. Palynol*. 116(3-4): 203-212.
- Parr, J. F., Sullivan, L. A., Chen, B., Ye, G. and Zheng, W.2010. Carbon bio-sequestration within the phytoliths of economic bamboo species. *Global Change Biol*. 16: 2661–2667.

- Parr, J.F., and Sullivan, L.A. 2014. Comparison of two methods for the isolation of phytolith occluded carbon from plant material. *Plant Soil* .374: 45–53.
- Parr, J.F., Sullivan, L.A. 2005. Soil carbon sequestration in phytoliths. *Soil Biol. Biochem.*37 :117–124.
- Parr, J.F., Sullivan, L.A. 2011. Phytolith occluded carbon and silica variability in wheat cultivars. *Plant Soil* .342:165–171.
- Parr, J.F., Sullivan, L.A., and Quirk, R. 2009. Sugarcane phytoliths: encapsulation and sequestration of a long-lived carbon fraction. *Sugar Techol* .11:17–21.
- Piperno, D.R. 1988. Phytolith Analysis: An Archaeological and Geological Perspective. Academic Press, London.
- Piperno, D.R., 2006. *Phytoliths: a comprehensive guide for archaeologists and paleoecologists*. Rowman Altamira.
- Piperno, D.R., Pearsall, D.M. 1998. The silica bodies of tropical American grasses: morphology, taxonomy, and implications for grass systematics and fossil phytolith identification. Smithsonian Institution Press, Washington, DC.
- Premathilake, R., Akhilesh, K., Anupama, K., Pappu, S., Prasad, S., Gunnell, Y. and Orukaimani, G., 2017. Phytoliths as indicators of Quaternary vegetation at the Paleolithic site of Attirampakkam, India. *J. of Archaeol. Sci.: Reports*, *14*: 479-499.
- Prychid, C.J., Rudall, P.J., and Gregory, M. 2003. Systematics and biology of phytoliths in monocotyledons. *Bot. Rev*. 69, 377–440.
- Sandeep, S. and Sujatha, M.P., 2014. Mineralogy of kaolin clays in different forest ecosystems of southern Western Ghats, India. *Curr. Sci*.875-882.

- Santos, G. M., and Alexandre, A. 2017. The phytolith carbon sequestration concept: fact or fiction? A comment on "occurrence, turnover and carbon sequestration potential of phytoliths in terrestrial ecosystems by Song et al.". *Earth Sci*. Rev. 164. 251–255.
- Schimel, D.S., House, J.I., Hibbard, K.A., Bousquet, P., Ciais, P., Peylin, P., Braswell, B.H., Apps, M.J., Baker, D., Bondeau, A. and Canadell, J. 2001. Recent patterns and mechanisms of carbon exchange by terrestrial ecosystems. *Nature*, *414*(6860):169-172.
- Schulp, C. J., Nabuurs, G., Verburg, P. H. and de Waal, R. W.2008. Effect of tree species on carbon stocks in forest floor and mineral soil and implications for soil carbon inventories. *Forest Ecol. Manage*. 256: 482–490.
- Seyfferth, A.L., Kocar, B.D., Lee, J.A., Fendorf, S., 2013. Seasonal dynamics of dissolved silicon in a rice cropping system after straw incorporation. *Geochim. Cosmochim. Ac*. 123: 120–133.
- Sharma, R., Kumar, V., and Kumar, R. 2019. Distribution of phytoliths in plants: A review. *Geol. ecol. Landsc*. *3*(2): 123-148.
- Siever R, Scott RA .1963. Organic geochemistry of silica. In: Berger IA (ed) Organic geochemistry. Pergammon Press, Elmsford, 579–595.
- Sommer, M., Jochheim, H., Höhn, A., Breuer, J., Zagorski, Z., Busse, J., Barkusky, D., Meier, K., Puppe, D., Wanner, M., and Kaczorek, D. 2013. Si cycling in a forest biogeosystem–the importance of transient state biogenic Si pools. *Biogeosciences* .10: 4991–5007.

- Song, A., Ning, D., Fan, F., Li, Z., Provance-Bowley, M and Liang, Y. 2015. The potential for carbon bio-sequestration in China's paddy rice (Oryza sativa L.) as impacted by slag-based silicate fertilizer. *Sci. Rep*. 5: 17354.
- Song, Z., Liu, H., Li, B., and Yang, X., 2013a. The production of phytolith-occluded carbon in China's forests: implications to biogeochemical carbon sequestration. *Global Change Biol*. 19: 2907–2915.
- Song, Z., Liu, H., Si, Y., and Yin, Y. 2012a. The production of phytoliths in China's grasslands: implications to the biogeochemical sequestration of atmospheric CO_2. *Glob. Change Biol*. 18, 3647–3653.
- Song, Z., Liu, H., Si, Y., Yin, Y., 2012. The production of phytoliths in China's grasslands: implications to the biogeochemical sequestration of atmospheric CO2. Global Change Biol. 18, 3647–3653.
- Song, Z., Liu, H., Strömberg, C. A., Yang, X., and Zhang, X. 2017. Phytolith carbon sequestration in global terrestrial biomes. *Sci. Total Environ.* 603: 502-509.
- Song, Z., McGrouther, K., and Wang, H. 2016. Occurrence, turnover and carbon sequestration potential of phytoliths in terrestrial ecosystems. *Earth Sci. Rev.* 158: 19–30. doi: 10.1016/j.earscirev.2016.04.007
- Song, Z., Parr, J.F., and Guo, F., 2013b. Potential of global cropland phytolith carbon sink from optimization of cropping system and fertilization. *Plos One 8*, 73747.

- Song, Z., Wang, H., Strong, P. J., and Guo, F. 2014. Phytolith carbon sequestration in China's croplands. *Eur. J. Agron*. 53: 10–15. doi: 10.1016/j.eja.2013. 11.004
- Song, Z., Wang, H., Strong, P. J., Li, Z., and Jiang, P. 2012b. Plant impact on the coupled terrestrial biogeochemical cycles of silicon and carbon: implications for biogeochemical carbon sequestration. *Earth Sci. Rev*. 115: 319–331. doi: 10.1016/j.earscirev.2012.09.006
- Song, Z., Wang, H., Strong, P. J., Shan, S. 2014. Increase of available soil silicon by Si-rich manure for sustainable rice production. *Agron. Sustain. Dev*. 34, 813–819.
- Strömberg, C.A.E., 2004. Using phytolith assemblages to reconstruct the origin and spread of grass-dominated habitats in the Great Plains of North America during the late Eocene to early Miocene. *Palaeogeogr. Palaeoclim. Palaeoecol.* 207: 239– 275.
- Strömberg, C.A.E., 2005. Decoupled taxonomic radiation and ecological expansion of open-habitat grasses in the Cenozoic of North America. *Proc. Natl. Acad. Sci*. U. S. A. 102, 11980–11984.
- Sun, X., Liu, Q., Zhao, G., Chen, X., Tang, T., and Xiang, Y. 2017. Comparison of phytolith-occluded carbon in 51 main cultivated rice (Oryza sativa) cultivars of China. *RSC Adv*. 7, 54726–54733.
- Von Lützow, M., Kögel-Knabner, Ekschmitt, K., Flessa, H., Guggenberger, G., Matzner, E., and Marschner, B. 2007. SOM fractionation methods: relevance to

functional pools and to stabilization mechanisms. *Soil Biol Biochem* .39:2183 –2207.

- Walker, A., Hoeck, H.N.; Perez, L.1978. Microwear of mammalian teeth as an indicator of diet. *Science*. 201, 908–910.
- Wang Cailin, Udatsu, Tetsuro., and Fujiwara, Hiroshi. 1996, effects of cultivated environment on phytolith morphology in rice motor cells (Oryza sativa L.). presented partially on the 13th japan cultural assets academic Committee of Science (Tokyo Gakugei University), June, 1996. East Jiangsu Province Agricultural Academy of Science; now United Graduate School of Agricultural Sciences, Kagoshima University, Miyazaki, 889 21, Japan.
- Watson, R. T.2000. Land use, land-use change, and forestry: a special report of the intergovernmental panel on climate change, (Cambridge University Press, Cambridge).
- Wilding LP, Brown RE, Holowaychuk N .1967. Accessibility and properties of occluded carbon in biogenetic opal. *Soil Science*. 103: 56–61.
- Yang, X., Song, Z., Liu, H., Bolan, N.S., Wang, H., and Li, Z. 2015. Phytologenic variations of silicon in leaves of North-China's forests. *Ecol. Res.* 30: 347–355.
- Yin, J., Yang, X., and Zheng, Y. 2014. Influence of increasing combustion temperature on the AMS 14C dating of modern crop phytoliths. *Sci. Rep*. 4:6511. doi: 10.1038/srep06511
- Zhang, X.D., Song, Z.L., Zhao, Z.Q., Van Zwieten, L., Li, J.W., Liu, L., Xu S, Wang HL (2016) Impact of climate and lithology on soil phytolith-occluded carbon accumulation in eastern China. *J Soils Sediments* .17(2):481–490.

- Zuo, X. X., and Lü, H. Y. 2011. Carbon sequestration within millet phytoliths from dry-farming of crops in China. *Chin. Sci. Bull.* 56, 3451–3456. doi: 10. 1007/s11434-011-4674-x
- Zuo, X.X., Lu, H.Y., Gu, Z.Y.2014. Distribution of soil phytolith-occluded carbon in the Chinese Loess Plateau and its implications for silica-carbon cycles. *Plant Soil* .374(1–2):223–232.

ABSTRACT

DISTRIBUTION AND TRANSFORMATION OF PHYTOLITHS UNDER CONTINUOUS TEAK ROTATION

By

GAYATRI A S

(2016-20-030)

ABSTRACT

Submitted in partial fulfilment of the requirement for the degree

of

B.Sc. - M.Sc. (Integrated) Climate Change Adaptation

Faculty of Agriculture

Kerala Agricultural University, Thrissur

COLLEGE OF CLIMATE CHANGE AND ENVIRONMENTAL SCIENCE

VELLANIKKARA, THRISSUR – 680656

KERALA, INDIA

2021

ABSTRACT

Climate change is a very pressing issue that we are facing, where CO_2 plays the pivotal role in elevating this climate crisis. With this alarming rise in CO_2 concentrations, bio sequestration turns out to be of prime importance. Phytoliths are the siliceous bodies formed in the plants and later passed on to the soil. They occlude carbon to form PhytOC, highly renitent to disintegration. The objectives of the study were to evaluate the changes in the vertical distribution of phytoliths in soil, assess soil phytolith transformations under continuous teak rotation and evaluate nutrient factors affecting the efficiency of teak plants in bio sequestering carbon as phytolith.

Eleven soil samples were collected depth wise from the teak plantation, forest and open land of North Central Laterite system. These soils were analysed for physical parameters like soil texture and bulk density. Chemical parameters of the soil including soil pH, available N, P, K, Mg, S, organic carbon, silicon, cation exchange capacity and base saturation was assessed using standard protocols. Phytolith was extracted as per Piperno (1988) and PhytOC was measured using Dissolution experiment was carried out on the soils using various concentrations of HCl and Na oxalate to determine the effects of pH and root exudation on phytoliths. Teak plants were raised using nutrient solution and different concentrations of silicon to assess their phytolith formation potential.

The PhytOC to TOC ratio of plantation was found to increase towards the C horizon to reach the highest value of 13.95%, natural forest having maximum at upper A and B horizon whereas both plantations and open land had maximum contents at lower C horizon. Na oxalate enacting the root exudates was observed to be detrimental for phytoliths. With the increase in the Na oxalate, there was a decrease in the PhytOC contents of soil (changes varied from -0.048 to -0.113). PhytOC contents increased by 0.023% for plantations at lower HCl concentrations while decreased for natural forest soils. The result suggests that silicon pools in plantation favour PhytOC formation at higher soil acidity. The nutrient solution

experiment using augmented nutrient and silicon supply showed the highest PhytOC content of 0.0815% in the treatment using nutrient solution only and no silicon, whereas the treatment including silicon yielded an amount of PhytOC content slightly lower than nutrient solution alone but higher than control. This shows the positive influence of nutrients and silicon on phytolith production in the acidic soil.

Parallelepipedal, trapeziform, scutiform, bulliform, elongate process, carinate, blocky irregular, geniculate, globular, lanceolate, rectangular, square was found to be some of the major phytolith shapes observed in the studied soils samples. Parallelepipedal and trapeziform had the maximum density among the different phytolith forms. The study generated valuable information on the vertical distribution of phytoliths in soil, soil phytolith transformations under continuous teak rotation and nutrient factors affecting the efficiency of teak plants in bio sequestering carbon as phytolith.