ELEMENT COMPOSITION AND CARBON SEQUESTRATION OF SELECTED BAMBOO SPECIES IN AIZAWL DISTRICT, MIZORAM

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

KSHETRIMAYUM SURESH SINGH
MZU REGISTRATION NO: 1607384
Ph.D. REGN NO: MZU/PhD/1037 of 31.05.2017

DEPARTMENT OF ENVIRONMENTAL SCIENCE
SCHOOL OF EARTH SCIENCES AND NATURAL RESOURCES MANAGEMENT
JUNE, 2022

ELEMENT COMPOSITION AND CARBON SEQUESTRATION OF SELECTED BAMBOO SPECIES IN AIZAWL DISTRICT, MIZORAM

BY

KSHETRIMAYUM SURESH SINGH
DEPARTMENT OF ENVIRONMENTAL SCIENCE

SUPERVISOR

Dr. ANGOM SARJUBALA DEVI
DEPARTMENT OF ENVIRONMENTAL SCIENCE
MIZORAM UNIVERSITY

SUBMITTED
IN PARTIAL FULFILLMENT OF THE REQUIREMENT OF THE DEGREE OF DOCTOR PHILOSOPHY IN ENVIRONMENTAL SCIENCE OF MIZORAM UNIVERSITY, AIZAWL

CERTIFICATE

This is to certify that the thesis **“Element composition and carbon sequestration of selected bamboo species in Aizawl district, Mizoram”** submitted by Mr. Kshetrimayum Suresh Singh for the award of Doctor of Philosophy in Environmental Science is carried out under my guidance and incorporates the student‟s bonafide research and this has not been submitted for award of any degree in this or any other university or institute of learning.

Dr. Angom Sarjubala Devi
(Supervisor)
Department of Environmental Science,
Mizoram University

Mizoram University

June, 2022

Declaration

I, Kshetrimayum Suresh Singh, hereby declare that the subject matter of this thesis is the record of work done by me, that the contents of this thesis did not form basis of the award of any previous degree to me or to do the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other University/Institute.

This is being submitted to the Mizoram University for the degree of Doctor of Philosophy in Environmental Science.

(Kshetrimayum Suresh Singh)

(Head, Department of Environmental Science)   (Supervisor)

Mizoram University

Acknowledgement

The completion of this thesis was made possible by many individuals whose contributions provided pillars of direct and indirect supports throughout the journey to its present shape.

I would like to express my heartfelt appreciation to my supervisor, Dr. Angom Sarjubala Devi, Associate Professor, Department of Environmental Science, Mizoram University for her firm support of my Ph.D. studies and research, as well as her patience and encouragements. Her advices were invaluable throughout the course of my research work and writing this thesis.

I am thankful to Professor Moirangthem Rakesh Singh for allowing me to use Nanophotonics Lab (NPL), IIT (ISM) Dhanbad. My earnest gratitude to all the faculty and staff of the Department of Environmental Science, Mizoram University for their constant help and support.

I also thank all my field guides in different study sites without them collecting samples for this study might not possible. I also express my gratitude to all friends, fellow researchers and to those who extended their cooperation directly or indirectly for their valuable suggestions, inspirations and helps throughout the course of my research work.

Lastly, my sincere gratefulness and regards to my parents and well-wishers for their unconditional love and support during the course of this study without which it was not possible for me to complete this research work.

Place: (Kshetrimayum Suresh Singh)

Date:

CONTENTS

CHAPTERS

LIST OF TABLES

LIST OF FIGURES

LIST OF PHOTO PLATES

1. INTRODUCTION

1.1 Global climate change

Attention towards the changing pattern of earth‟s climatic condition is one of the most challenging concerns of this century. It is evident from geological time scale that climate of the planet earth has been changing subsequently on its own pace, but the global temperature has been increasing in an alarming rate since the end of 18th century and majority of the scientific communities believe that this alarming change is a result of anthropogenic activities. Increased in greenhouse gas (GHG) emissions and overloading amounts of these gases, mainly the CO_2 in atmosphere is the primary causes of global warming and frequent occurrence of extreme weather events worldwide in recent decades. According to Goddard Institute for Space Studies (GISS) analysis, the global surface temperature in 2020 was extremely deadly with heat waves; 2016 for warmest year in the modern era. The rate of global warming has dangerously accelerated in the past several years. The 2020 global temperature was +1.3°C (~2.3°F) warmer than in the 1880-1920 base period; global temperature in that base period is a sensible estimate of „pre-industrial‟ temperature (Hansen *et al*., 2021).

Human induced activities such as land use change and extensive use of fossil fuel have already affected the composition of Earth's atmosphere and experienced tremendous changes in biological diversity of the planet earth. As compared to the preindustrial times, the present atmospheric concentration of GHGs mainly the carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) have increased beyond imagination (Pepper *et al*., 1998). According to the reports showing possibilities of calamities and extinctions base on the present changing pattern over last three decades has predicted several changes in ecosystem, distribution and abundance of species promoting extinction risk of large number of species from the surface of earth by 2050 (Thomas *et al*., 2004). Available literatures have indicated the requirements on developing and swift implementation of mitigation strategies to minimize the emissions and the level of GHGs from the atmosphere.

The third conference of parties of The United Nations Framework Convention on Climate Change (UNFCCC) in Kyoto, 1997 had a unanimous agreement on incorporation of forestry activities as a sustainable way for the carbon emission reduction (Ramachandran *et al*., 2009). and to adopt the Clean Development Mechanism (CDM) a strategy for the mitigation of global warming by reducing CO_2 from the atmosphere, encouraging Global Environmental Facility (GEF), and Reduced Emission from Deforestation and Forest Degradation (REDD) to provide financial supports to the developing countries to promote forestry and reduction emission of CO_2 which is a green way for mitigation of CO_2 from the atmosphere. Importance of conserving the forest ecosystems including soil and role of soil microbes, in absorbing CO_2 from the atmosphere through photosynthesis by plants and capturing of carbon onto the forest soil has finally acknowledged and accepted as a sustainable and effective measure to mitigate and manage the climate change. Net increase in temperature related excess mortality rate analysis has shown higher death rate in 23 countries across the world comprised of 451 locations. The health effects due to increasing temperature could be avoided with mitigation strategies by limiting GHG emissions to alleviate the further warming of the planet (Besar *et al*., 2020).

1.2 Carbon stock (C-stock) and Sequestration of carbon (C-sequestration)

Carbon is stored on the Earth in various forms and the major reservoirs are organic compounds in living and dead organisms of the biosphere, CO_2 and CH_4 gases in the atmosphere, in the organic matter of soil, in the lithosphere as fossil fuel and sedimentary rocks, in the oceans as dissolved hydrocarbons, in the shells of marine creatures as calcium carbonate, etc. The movement of carbon in many forms among the atmosphere, hydrosphere, biosphere, pedosphere, and lithosphere is known as the global carbon cycle (Lebrato *et al*., 2010). Transformation of the natural ecosystem into various other land use system destroys the landscape and the deforested landscapes fail to capture and store CO_2, which is the main GHGs component (Besar *et al*., 2020).

Naturally, a portion of carbon dioxide emitted to the atmosphere by fossil-fuel burning and other forms of terrestrial processes like forest burning and volcanic eruptions are taken up by the oceans and the terrestrial biosphere (Schimel *et al*., 2001). Deforestation for urbanization and agriculture expansion drastically reduced the area of the Atlantic forest biome in different parts of the world. To reverse this process, restoration plantations with native tree species and rehabilitating degraded lands can significantly rebuild the forest environment and promoting carbon sequestration (Ferez *et al*., 2015). This process of capturing and long-term storage of the atmospheric carbon dioxide (CO_2) is known as carbon sequestration. Carbon sequestration is possible through a variety of processes, including those occurring naturally by plants and soils. In recent years, reduction emissions and carbon sequestration through afforestation has been receiving more attention as an eco-friendly method to reduce accumulation of greenhouse gases in the atmosphere (Sedjo & Sohngen, 2012). Terrestrial ecosystems in middle and high latitudes of the Northern hemisphere are performing as an excellent carbon (C) sink over the past 20 years (Schimel *et al*., 2001; Yang *et al*. 2009).

Basically, plants convert CO_2 into organic compounds as biomass through photosynthesis, and these biomasses are the primary source of energy in the food web of ecosystems, known as gross primary product (GPP). Terrestrial GPP is the largest global carbon flux, and it pushes several ecosystem functions, such as respiration and growth of different flora and fauna on the planet (Beer *et al*., 010). According to a study of satellite light detection and ranging (Lidar) samples of forest structure to estimate carbon storage plus optical and microwave imagery (1-km resolution), the total carbon stock in live biomass (above and belowground), in forests of three continents viz. Latin America, sub-Saharan Africa, and Southeast Asia, has concluded that terrestrial forests ecosystem as a huge carbon stock in the planet (Saatchi *et al*., 2011).

Different plant species have different potentials for capturing and sequestration of carbon. It is generally accepted that C_3 plants are advantageous over C_4 plants against the increase in atmospheric CO_2 concentration (Hamilton *et al*., 2008). Study on spatial variation of carbon sequestration potential in different types of forest can provide accurate information of global carbon sinks; 62% - 78% of the global terrestrial C is sequestered in forests of which about 70% C is stored in forest soil

(Dixon *et al*., 1994; Schimel, 1995). Plant species with low areal cover but high photosynthetic efficiency appears to have more tendency for sequestering carbon (Korrensalo *et al*., 2017). Thus, tropical forest ecosystems are playing a great role as global carbon sink.

According to Food and Agriculture Organization (FAO), 2010 report; bamboo forest covered a total area of around 31.5 million ha. which is 0.8% of the world‟s total forest coverage. Bamboo can adapt easily to a wide range of climatic and soil conditions, and is therefore widely distributed in tropical and subtropical zones between 46°N and 47°S latitude (Song *et al*., 2011). Comparing with other types of forest, bamboo forest generates varieties of ecosystem services, such as carbon storage, water and soil conservation because of its special root sprouting system, regenerated easily and culms having multiple utilities (Lobovikov *et al*., 2007)**;** bamboo forests also have high potential for sequestering carbon thus contributes tremendously in global carbon sink. China is the leading country in the world of bamboo research; a 2010 study report in China shows that carbon density of bamboo forest is much higher than country‟s average forest carbon density which is also higher than the global average of forest carbon density (Lou *et al*., 2010**).**

In recent years, the carbon sequestration (C-sequestration) capacity of various forests has become increasingly acknowledged worldwide because of its global warming mitigation potential. Bamboo forest is an important forest type with high C-sequestration potential. Further research on bamboo could provide valuable information on C-sequestration potential of various species in relation to their stand characteristics (Liu & Yen, 2021). Thus, there is need to have extensive research on bamboo in other parts of the world as well, especially in the North-east region of India where bamboo resources are enormous in nature.

1.3 Bamboo

Bamboo is a unique group of tall grasses with woody interconnected stems which belongs to the subfamily Bambusoideae of grass family Poaceae (Graminaceae) which is recognized for its fast-growing potential and its versatile nature among the plant‟s kingdom on earth. There are about 1,500 species in 90 genera worldwide

(Desalegn & Tadesse, 2014). Bamboo can be generally classified into two groups based on their types of rhizome system, they are: monopodia (non-clump) and sympodial (clump). Monopodial bamboos are hostile by nature and have the capability to spread fast; they do not form clumps. Some common genera of monopodial bamboos are *Melocanna*, *Arundinaria*, *Phyllostachys,* and *Pseudosasa* on the other hand. Sympodial bamboos generally grow in close proximity to the domain plant forming clumps in nature; *Bambusa* and *Dendrocalamus* are commonly found genera of sympodial bamboos.

Bamboo forests are indeed one of the most abundant non-timber plants on Earth and found extensively in tropical and subtropical regions around the globe. The plant itself is an amazing plant having unique potentials like rapid growth and multiple utilities which can play an important role in protecting our planet from pollution, improving the soil and water table and economic benefits. Bamboo can be used as a biofuel, food, and for architecture and construction applications etc. thus has a great economic potential (Emamverdian *et al*., 2020). China is the most bamboo diverse country in the world with around 300 species in 44 genera, and India stands next to China; approximately 148 species in 29 genera of bamboos are currently thought to occur in India (both wild and cultivated). About one-fourth of bamboo species identified worldwide are found in India, widely distributed in almost all states particularly abundant in the tropical moist deciduous forests of Western Ghats and the North-eastern states of India (Rai & Chauhan, 1998). The North-eastern hill States of India harbour nearly 90 species of bamboos, 41 of which are endemic to the region. There are 3 large genera of bamboo in India i.e *Bambusa*, *Dendrocalamus*, and *Ochlandra* with more than 10 species each; together these three genera represent about 45% of the total bamboo species found in the country (Sharma & Nirmala, 2015).

Bamboos are one of the C_3 grasses that can boosts in height and are capable of outcompeting with C_4 grasses for light in tropical and subtropical regions (Collatz *et al*., 1998). The ability of bamboo to sequester high amount of C per unit time can make bamboo-based agroforestry system a possible prototype for Clean Development Mechanism (CDM) type projects. A 2010 Chinese study report states that the carbon density for bamboo forests, which ranges from 168.7 to 259.1 t C/ha, is generally much higher than China‟s average forest carbon density (38.7 t C/ha), and is also higher than the global average forest carbon density of 86 t C/ha (Yiping et al., 2010); this indicates a huge carbon sequestration potential for bamboo forests in China (Song *et al*., 2011). Role of bamboo in C storage and sequestration has not been studied adequately in northeast India (Nath & Das, 2012). This research work is conducted with intentions to bridge at least some gaps of information on bamboo‟s carbon sequestration potential and its role in socio-economic development in north-eastern region of India where bamboo forests are found abundantly.

Beside a potential source of C sink, bamboo is also considered as one of the most important non-timber forest products (NTFPs) which has high potential of environmental protection and wide ecological adaptation by substituting wood products; it is versatile, cheap, efficient and fast growth which can grow up to 91cm per day (Mekonnen *et al*., 2014). When bamboo is well managed, harvesting selectively and if proper market linkage is facilitated, it can provide huge income to every level of stackholders, which can reduce poverty and boost rural development (Tinsley, B.L. 2015). Bamboo forest improves landscape and water quality of streams ensuring sustainable ecological micro-climate (Nath et al., 2020)**.** Compared with other types of forest, the bamboo forest generates better ecosystem services (Lobovikov *et al*., 2007). Therefore, it is essential to acknowledge the tremendous role of bamboo in ecological and socio-economic development of a region. According to Liu *et al*., (2018) the main application of bamboo in China is divided into two parts: economic use and ecological utilization. The economic utilization can be roughly divided into timber bamboo, shoots bamboo, skin bamboo, and art and crafts bamboo. Ecological value can be divided into water conservation forest and ecological forest tourism.

Recently, there has been increasing interest on role of bamboo in soil health improvement, biomass production, and climate change mitigation. However, knowledge on the contribution of bamboo-based agroforestry on ecosystem services is very limited. Thus, the role of bamboo and bamboo-based agroforestry in enhancing ecosystem services as well as its implications on social, economic and ecological advantages are of great importance (Abebe *et al*., 2021). It is of great scientific importance to explore the overall changing pattern of bamboo forest and impacts of changing climatic factors on global distribution of bamboo forest, especially to monitor the spatial patterns and sustainable utilization of bamboo forests in the context of future climate scenarios (Li *et al*., 2019).

The ancient Indian system of medicine "Ayurveda", recommends bamboo and its products such as Tabasheer, Banslochan, and Sitopaladi Churna for treatment of numerous ailments. This traditional knowledge, is now being used for the preparation of modern bamboo-derived pharmaceutical products such as bamboo salt, bamboo charcoal, bamboo vinegar, bamboo silica, bamboo extracts and more, for the cure of various illness (Park & Jhon, 2009; Nirmala & Bisht, 2017).

1.4 Socio-economy

According to a study on income generation and economic benefits of bamboo, reported in 2015, there are over 2.2 billion people worldwide benefiting from bamboo through income generation and non-market domestic uses including food and housing (Tinsley, 2015**)** over 1500 distinct uses of bamboo have been recorded around the world, and the number is growing rapidly with new development and innovative initiatives. Traditionally bamboo is used extensively in handicraft, mats, carpets, making of houses, blinders, and furniture but its true market potential is in industrial processed products like flooring and panels (Melorose *et al*., 2015) Bamboo enterprises are constantly nourishing the socio-economic development in different regions of developing countries providing employment opportunities for poor people, including raw material collection, processing and marketing etc. which are ultimately profiting the national economy (Rana *et al*., 2010). In China, annual output of the bamboo industry is worth 200 billion yuan and provides huge employment to over 8 million people. These in turn improve human livelihoods, help reduce poverty and develop green economy in respond to climate change. Therefore, understanding the potential spatial distribution and analysing the impacts of climate change on bamboo forest distribution are very necessary for the sustainable development and utilization of bamboo forest in a global scale (Li *et al*., 2019).

Agroforestry with bamboos has considerable potential for providing food and nutritional security and for contributing to economic development of developing countries in the tropics (Kittur *et al*., 2016). Significances of bamboo agroforestry is currently being acknowledged as a viable land use alternative to improve the management benefits of bamboo forest. The rhizosphere soil microbial community structures of the bamboo forest were significantly influenced by intercropping. In terms of the physical appearance of microbial community structures and soil properties, *Paris polyphylla* could be a very suitable medical herb for intercropping in moso bamboo forest (Zang *et al*., 2019). In Ghana, local people are encouraged to promoted bamboo agroforestry as an alternative land use practice to reduce dependence on natural forest for wood fuels. Traditional knowledge of farmers on bamboo and its varied utilisation as charcoal production and leaves for fodder are influential contributing factor of bamboo-based agroforestry adoption in the area (Akoto *et al*., 2018). An ICAR study on potential of bamboo-based agroforestry system and its financial analysis in central India has observed that, bamboo-based agroforestry system such as bamboo-sesame–chickpea intercrop plantation is successful and is more profitable than mono cropping and sole bamboo plantations. Therefore, the bamboo-based agroforestry system can be a potential alternative to arable cropping in semi-arid tropics of central India to enhance productivity and economic returns (Dev *et al*., 2020).

Bamboo is also a good source of nutritious food; different form of bamboo shoots has high demand in local as well as globally markets**.** Bamboo shoot is one of the favourite foods in Asian countries; China, India and Southeast Asian regions produces maximum of the bamboo shoot in the world. In India, bamboo shoots are considered as delicious food in north-eastern regions which are consumed as fresh and fermented. A thriving economy revolves around bamboo resource. Bamboo is well placed to address the food security through bamboo-based agro-forestry systems by maintaining the fertility of adjoining agricultural lands, and as a direct food source like edible bamboo shoots. Bamboo shoots hold the prospect of value-added economic activities at industrial and society levels through cultivation, processing, packaging and commercialization (Choudhury *et al*., 2012). Although the utilization of juvenile shoots of bamboo in tribal diet of Northeast India is a very old recognizable fact, its numerous health benefits and potentiality remains unfamiliar. Apart from being delicious, the bamboo shoots are also rich in minerals and nutrient components such as proteins, fibre, carbohydrates and are low in fat and sugar which could be helpful in alleviating the problem of malnutrition. Over and above the nutritional values of different species of bamboo shoots, the increasing inclinations towards health consciousness among the consumers have underlined its utilization in modern diet as a healthy food for improving the nutritional security (Basumatary *et al*., 2017).

Mizoram, one of the north-east Indian states is rich in bamboo resources; people of the state have strong bond with bamboo in different ways of their life traditionally and culturally which is being reflected in one of the most popular dance forms "bamboo dance" which use to perform in most of the festivals of the state. It also has close and effective relationship socially and economically with people in their livelihood. In villages bamboo is the main component of huts and houses; apart from different household items and handicrafts, it is also use in agricultural implements, snares/traps, rain sheds, water pipes, ornamentals, different forms of baskets etc. which in turn stands a good source of income.

According to Forest Survey of India Report (ISFR), 2021, total forest coverage of Mizoram is 17,820 Km^2 which is 84.53 % of the state geographical area. Bamboo forests occupied 4561 km^2 that is 21.63% of the geographical area of Mizoram. According to the department of Environment, Forests and Climate Change, Government of Mizoram (GOM), bamboo forests are found at altitudes ranging from 400m-1500m above mean sea level. Among different species of bamboo found in the state, the species *Melacanna baccifera* contributes more than 90% of the available bamboo in the state and this species is also considered as the most suitable bamboo species having multiple uses in day-to-day life as well as in ecological restorations on abandoned slash and burn agriculture sites which are located in close proximity to village habitations (Lalhruaitluanga & Prasad, 2009).

1.5 Elemental contents in bamboo vinegar

Vinegar is the liquid produced in the process of carbonisation of biomass through pyrolysis. Bamboo vinegar is a brown-red transparent liquid with a smoky odour and is composed of nearly 90% water and more than 200 kinds of chemical components; it has been widely used in agriculture and daily life since the time immemorable (Mu *et al*., 2006). Among the organic compounds present in bamboo vinegar, acetic acid is the major component which comprises of about 80% and some other volatile compounds such as syringol, butyric acid, furfural and propionic acids etc. are notable (Akakabe *et al*., 2006).

Various researchers have found several health benefits associated with antioxidants and bioactive compounds present in bamboo leaves and shoots. Synthetic chemical compounds, used as preservatives in food and medical products have harmful health effects and now consumers demand for natural and safe additive are increasing. Both bamboo shoots and leaves are good source of natural preservatives and antioxidants which can play a vital role in food and pharmaceutical industries (Nirmala *et al*., 2018). There are limited reports on extensive studies on elemental contents and chemical compounds found in different bamboo species. Bamboo shoots and leaves are valuable food sources for both humans and livestock. For many mineral elements, there was significant variability from the low end (4.2-fold, 2.27–9.52 mg/g calcium; 4.4-fold, 56.17–246.43 µg/g sodium) to the high end (61.5-fold, 17.67–1087.0 µg/g manganese; 40.8-fold, 42.0–1713.5 µg/g aluminium). Due to their variability in leaf nutritive value, bamboo species should be carefully chosen when they are used as a feedstock (Wang *et al*., 2018). It is of great essential to analyse the elemental content and characterization of chemical compounds present in bamboos as the young shoot of the plant is being consumed as a delicious food item, which is also reported having many health benefits.

The interior soft part of tender bamboo shoot gives a strong smell and bitter taste; the bitter taste in bamboo shoot is due to the presence of cyanogenic glycoside taxiphyllin, which is toxic in nature (Choudhury *et al*., 2012). Bamboo shoots are rich of iron, phosphorus, potassium, thiamin, riboflavin, Vitamin E(α-Tocopherol), Vitamin C, Vitamin B6, niacin, and dietary fibres like cellulose, lignin, hemicelluloses, pectin (Tripathi 1998; Park and John 2009), bamboo shoots contain about ten types of minerals like Cr, Zn, Mn, Mg, Ni, Co, Cu, etc. with different types of amino acids (Shimada, 1972; Reiss, 1993; Fu *et al*., 2002; Nirmala *et al*., 2007). Many nutritious and active materials such as Vitamins, amino acids and anti-oxidants such as flavones, phenols and steroids can be extracted from the bamboo shoots (Bhatt *et al*., 2005).

All the parts of the bamboo plant such as leaves, culm, rhizome, roots, shoots and seeds have clinical applications. Studies have discovered that bamboo is a rich source of antioxidants and regular consumption of bamboo-based products may reduce the risk of age-related chronic diseases including diabetes, cardiovascular diseases, cancer, Parkinson"s disease, and Alzheimer"s disease (Nirmala *et al*., 2018). Moreover, the use of biomass pellets as a renewable energy source is increasing, leading to the need for rapid assessment of biofuel pellet quality for production monitoring. The elemental and chemical components of bamboo biomass can be observed through line-scan near-infrared (NIR) hyperspectral image technology coupled with chemo-metric tools. Quantities of C, H, N and O contents in biomass are important indicators to understand the energy efficiency of biomass (Pitak *et al*., 2021). Acetic acids and variety of phenolic compounds are found to present predominantly apart from different quantities of micro and macro elements in bamboo vinegars extracted through pyrolysis process conducted as a part of this research work.

1.6 Outline of the study

The present study is undertaken to assess the soil physio-chemical dynamics of the bamboo forests and carbon sequestration potential of different species of bamboo found in Aizawl district, Mizoram. Bamboo samples were classified based on age classes. Further, analysed the component-wise (leaf, branch, culm) carbon content of the selected bamboo species. The role of bamboo forest as a carbon sink, environmental and socio-economic benefits are precisely discussed. Analysis of elemental content and characterisation of chemical compounds in pyrolyzed liquid product from two bamboo species i.e. *Melocanna baccifera* and *Bambusa tulda* are reported on this thesis. This study report will be helpful to the present and future researchers, about the great C-sequestration potential and role of bamboo in mitigation of global warming and the socio-economic prospects of the plant.

1.7 Objectives

1. To determine soil physio-chemical properties of the selected bamboo forests.

2. To determine aboveground biomass and carbon content of selected bamboo forest.

3. To determine Carbon Sequestration capabilities and elemental composition of selected bamboo species

2. REVIEW OF LITERATURE

Intergovernmental Panel on Climate Change (IPCC) in 2001 reported that during 1750 to 1999, concentration of CO_2 in the atmosphere increased from 280 ppm to 367 ppm and that of atmospheric CH_4 increased from 700 ppb to 1745 ppb. The radiative force of the main GHGs were reported as 1.46 wm^{-2} for CO_2, 0.5 wm^{-2} for CH_4 and 0.15 wm^{-2} for NO_2. The report also showed that the rate of increase of global mean temperature was above the critical rate of 0.1 j C per decade beyond which the ecosystems cannot adjust (Lal, 2004). The Fifth Assessment Report produced by the IPCC stated that the global temperature had increased by 0.85 °C in the past 130 years and will increase 0.3-4.5 °C by 2100 compared with 1986-2005 (Zhang et al., 2018). Extremely likely that more than half of the observed increase in global average surface temperature during 1951 to 2010 was caused by human activity; which mentioned that a probability between 95% and 100% of modern warming was due to anthropogenic activities (IPCC, 2013). Increase of heatwave days are projected which warned that 4-34 extra days per season are likely to increase per ºC of global warming. Increase in heatwave intensity are generally 0.5-1.5 ºC above a given global warming threshold. Some tropical regions may extremely affect according to the projected phenomenon, which could experience up to 120 extra heatwave days/season if 5ºC is reached (Kirkpatrick et al., 2017). The global average chance of a major heatwave phenomenon has increased from 5% in 1981–2010 to 28% at 1.5ºC and 92% at 4ºC, agricultural drought increases from 9 to 24% at 1.5ºC and 61% at 4ºC, and of the 50-year return period river flood increases from 2 to 2.4% at 1.5ºC and 5.4% at 4ºC (Arnell et al., 2019)**.** Decadal average surface temperature variances show that since 1970s each decade has been remarkably warmer than prior decade. Average warming over land is now about 3ºF (more than 1.5ºC). Modern warming is interrelated to raised concentration of long-lived greenhouse gases in the atmosphere, mainly CO_2 and CH_4 which are products of fossil fuel burning (Hansen et al., 2021).

According to a survey based on interviews with scientists, policy makers and policy analysts regarding the available facilities and scope of climate research in India, Europe and the United States; the assessment had concluded that, in India there is linkage-gap between national policy makers and climate researchers; minimal budgetary funds on climate researches which reflects poor political interest on the issues. The main monetary supports of the climate researches in India are funding from foreign countries (Kandalikar et al.,1999). India‟s domestic approach to climate change was addressed only in an ad hoc manner; the Government of India (GOI) had set up an "Expert Committee on Impacts of Climate Change" on 7^{th} May 2007, to monitor the impacts of climate change on human and to categorize the measures that GOI should take in future (Prasad & Kochher, 2009). And for the first time in 2008 as a gesture of concern, the GOI released National Action Plan on Climate Change (NAPCC) which is marked as a turning point of the country on climate issues (Rastogi, 2011).

It is widely accepted that to control over the changing aspects of global climate and its influences on ecosystems and economic systems, there needs profound technological changes particularly in energy sector. A new model termed as World Induced Technical Change Hybrid (WITCH) which is designed to partially bridge the gap of technological loopholes and climate policy analysis was introduced showing briefly the evolution of energy technologies and letting endogenous technological progress (Bosetti et al., 2006)**.** Global Carbon Budget 2020 highlighted that India emitted 2.6 billion tons of CO_2 in 2019 which being the world‟s third largest emitter of greenhouse gases (GHGs), after China and the US (Friedlingstein et al., 2020).

Annual removal of CO_2 by India‟s forests and tree cover neutralizes 11.25% of India‟s total GHG emission (CO_2 eq.) at 1994 levels (Anon., 2009). India, as an emerging and developing economy, climate change and its mitigation policies are hard challenges for the country. In global scale, India‟s contribution to anthropogenic GHG emissions is small (only 5%) compared to developed countries like US and China (20% each) but projection analysis shows that in the next few decades, India would likely to experience the highest growth rate of GHG emissions in the world (Rastogi, 2011).

India has a huge potential of renewable energy resources but as a result of technological challenges, in present only 12% of the total installed capacity are able to utilize in the country. Nearly half of the country"s carbon emission is contributing from energy sector which is largely based on fossil fuels. To fulfil demand and supply imbalances in energy sector, it is high lightened for the need of effective inputs on resource and technologically advanced mechanisms for renewable energy utilization in the country (Chandel et al., 2015).

Bamboo and climate change

Bamboo has the highest growth rate of all tropical plants. Bamboo can complete the growing process in both height and diameter in 35-40 days after emerging as a shoot. The growth rate has been detected up to approximately 2.5 cm per hour that is one meter per day (Emamverdian et al., 2020). Bamboo grows more rapidly than any other trees and reaches to give yield within 3-4 years after initial plantation. As it is one of the fastest growing plant and responding well against harsh environmental condition makes bamboo more acceptable to achieve the evergreen environment enabling soil and water conservation, carbon storage and rehabilitation of degraded lands (Terefe et al., 2016). The annual carbon budget of bamboo forest as carbon sink, and the average annual net ecosystem exchange of bamboo reached -105.2 g C m^{-2} (Liu et al., 2018).

Bamboo offers one of the quickest natural ways to eradicate huge amounts of CO_2 from the atmosphere. It reduces CO_2 gas and produces more amount of oxygen than an equivalent stand of other tree species. Under well-managed plantations, bamboo can achieve an effective carbon sink and shows better performance over other tree species grown under similar conditions (Terefe et al., 2019). Bamboo can aggressively absorb and store CO_2 from atmosphere in its various parts as biomass, it can decrease the negative effects of global warming (Emamverdian et al., 2020). The estimated global bamboo carbon stock is about 4 Pg, accounting for 0.43%-0.61% of total global forest carbon stock. The area coverage of bamboo forests in China is about 6Mha, which stores about 780 Tg carbon, accounting for 14% of total forest carbon stock of the country (Yuen et al., 2017). Forest Survey of India (FSI), 2019 reported that total forest coverage of India as 7,12,249 sq.km of which Bamboo forest covers a total area of 1,60,037 sq.km, which is equivalent to 22.5 % of the entire Indian forest (Sawarkar et al., 2020).

Bamboo has phytoremediation potential, which can also detoxify various heavy metal contaminations in the environment (Emamverdian et al., 2020). Bamboos, through their phytoremediation potential, can clean up polluted soils and can also accumulate silicon in their bodies to alleviate metal toxicity, and this accumulation in nature is up to 183 $mg \cdot g^{-1}$ of SiO2 (Collin et al., 2014).

The need for climate change mitigation has fascinated international attention to the environmental benefits of bamboo. With its numerous applications, bamboo helps human kind both economically and environmentally. In comparison to other plant-based options, the major advantage of bamboo is that all the requirements of farmers such as food, fuel, and timber can avail from the same plant. Bamboo is also one of the most suitable plants for the restoration of degraded land because of its adaptability and nutrient holding capacity (Dwivedi et al., 2019). Another interesting fact about bamboo is its high yield of lignocellulosic biomass accumulation in a short period of time, which is why the plant is considered a good option for use in biofuel production (Emamverdian et al., 2020).

Li et al., (2019) reported that precipitation and temperature are the two most important climate factors limiting bamboo forest growth. Seven climatic variables, such as Spring precipitation, Summer precipitation, Autumn precipitation, average annual relative humidity, Autumn average temperature, average annual temperature range and annual total radiation, were analysed and the favourable ranges for bamboo growth were found to be 337–794 mm, 496–705 mm, 213–929 mm, 74.3%–83.4%, 16.6–23.8 °C, 2.3–10.1 °C and 3.2 × 104–4.3 × 104 W m^{-2}, respectively. Another study report had mentioned that hyperthermia (>30°C) in bamboo shoot germination stage declines shoot bud differentiation and causes a decrease in the number of new bamboos in the following year (Li et al., 2016).

In recent decades, the role of bamboo forest on mitigating global warming and reducing the negative effects of climate change had acknowledged worldwide, which plays an important role in adjusting and improving natural as well as human ecosystems (Sudhakara & Jijeesh, 2015). The most crucial problems existing in bamboo are mainly the lack of awareness of enormous potentials of this plant as well as a lack of enough attention on development of proper market in this sector. So, governmental organizations, policy makers, researchers and interested groups should collaborate and help to raise awareness about the vast potential of bamboo (Emamverdian et al., 2020).

Soil characteristics

Globally, the soil C pool stores approximately 2500 gigatons (Gt) which includes 1550 Gt of soil organic carbon (SOC)and 950 Gt of soil inorganic carbon (SIC). Soil C pool is 4.5 times the size of the biotic C pool (560 Gt) and 3.3 times that of the atmospheric C pool (760 Gt). The rate of annual SOC sequestration potential is 0.9 ± 0.3 Pg C year^{-1}. Changes in land use pattern like conversion of natural to agricultural ecosystems causes depletion of the SOC pool by as much as 75% in soil of tropical regions and that of 60% in temperate regions (Lal, 2004)

A study on bamboo forests‟ soil physicochemical parameters of soil samples (209 samples) across different terrains in Jian‟ou City, China had reported that soil pH ranged from 3.85 to 6.02, gravel content ranged from 1.10% to 60.40%, bulk density ranged from 0.76 g cm^{-3} to 1.19 g cm^{-3}, and SOC ranged from 0.42% to 6.48% (Zhang et al., 2015).

An experiment conducted at Kasuya Research Forest, Kyushu University, Japan had reported that at any soil depth the average soil porosity was found 1.3-2.5% higher in moso-bamboo forest than broad leaved forest (Ide et al. 2010). Liu et al., (2011) and Deng et al., (2020) have reported that soil temperature and soil moisture can significantly affect the soil C and N pool dynamics in moso-bamboo forests.

A comparative study on soil characteristics such as pH, N and P in three different types of forests namely bamboo forest, broad leaved forest and mixed forest showed that soil pH was found maximum in bamboo forest (4.98±0.19) followed by mixed forest (4.43±0.27) and broad leave forest with 4.39±0.26. The N content was also found maximum in bamboo forest with 125.8±21.31 mg kg^{-1}, mixed forest with 121.6±10.77 mg kg^{-1} and least in broad leaved forest with 109.6±18.10 mg kg^{-1} they also found that P content in the soil was maximum in bamboo forest with 41.45±8.15 mg kg^{-1} followed by 32.32±8.00 mg kg^{-1} and 29.75±5.04 mg kg^{-1} in mixed and broad leaved forests respectively. The highest amount of SOC was also found in bamboo forest (29.74±4.36 g kg^{-1}) followed by mixed forest (25.38±2.74 g kg^{-1}) and broad-leaved forest (22.08±2.29 g kg^{-1}) (Qin et al., 2017).

In bamboo forest the soil pH, SOC, C/N ratio, NH_4^+ and available P were higher by 13.4, 33.5, 52.9, 58.6 and 140.4%, respectively as compared to the broad-leaved forest (Li et al., 2017). In *Schizostachyum pergracile* stands, soil pH ranged from 5.5 to 6.4 and soil moisture varied from 16 to 34%; bulk density ranged from 1.19g cm^{-3} to 1.27g cm^{-3}. Soil organic C ranged from 1.38 to 1.52%, total N varied from 0.24 to 0.28% and available P ranged from 0.075 to 0.077% (Thokchom & Yadava, 2017). Li et al., (2018) reported that, after three years of management, soil C-storage increased significantly from 53.09 to 82.95 Mg C ha^{-1}. With increase in soil depth, it was clear that both SOC concentrations and C-storage reached an equilibrium after a significant increased.

Fine root litter input of moso bamboo and Japanese cedar can impact soil CO_2 emission rates and the sensitivity of soil respiration rate. The soil temperature was reduced by moso bamboo fine root input which enhanced soil C-sequestration under warm climate (Pan et al., 2020).

According to a two years study conducted at Ecological Experimental Station of Red Soils, Chinese Academy of Sciences, Jiangxi Province, China; soil respiration on plots of two different types of bamboo viz *Phyllostachys praecox* and *Phyllostachys glauca* had reported that the rate of soil respiration was minimum during winter season with 0.38 μmol CO_2 $m^{-2}s^{-1}$ and gradually increased from spring and found peak soil respiration rate in June with 2.62 and 3.25 μmol CO_2 $m^{-2}s^{-1}$ for *Phyllostachys glauca* and *Phyllostachys praecox* respectively (Zhang et al., 2020).

Aboveground biomass and C-storage

Forest ecosystem stores more than 80% of all terrestrial aboveground C and more than 70% of all SOC (Batjes, 1996; Six et al., 2002). The annual CO_2 exchange between forests and the atmosphere via photosynthesis and respiration is ≈50 Pg C/yr, which is 7 times the anthropogenic C emission. An increase in soil respiration would increase the CO_2 emissions from forest ecosystems (Raich & Schlesinger, 1992). "Forestry experts with the IPCC suggested that up to 87 billion tons of carbon can be sequestered in the world‟s forests by 2050 but forests currently store approximately 800 billion tons of C in trees and soil, which is approximately 10% higher than the predicted data" (Sohngen & Mendelsohn 2003). According to reports on spatial variation of C-sequestration in different types of forest, 62% to 78% of the global terrestrial C is sequestered in forests ecosystems, of which 70% C is stored in the soil (Dixon et al., 1994; Schimel, 1995). Bamboo being a fast-growing plant with great potential having enormous utility makes it a green tool for global warming mitigation and adaptation, which is acknowledged for its higher level of C-sequestration than comparable fast-growing trees (Kuehl & Yipping, 2012).

A study on Brazilian endemic bamboo species *Aulonemia aristulata* had reported that higher atmospheric CO_2 concentration could improve the natural characteristic of bamboo to accumulate more biomass in culms and leaves (Grombone et al., 2013). The aboveground C storage (AGCS) is determined by the density of the bamboo stand in mature bamboo forests. According to a study on initial 10 years of reforestation of moso bamboo, in which plantation was design in two groups that is 3 plant per group and individual plant. It was found that the AGCS is influenced mainly by the development, quantity and quality of new culms. Age of the stand was positively correlated with DBH, height, the AGCS of new culms and the AGCS accumulation for both plantation designs (Li et al., 2021).

Nfornkah et al., (2020) reported that the potential of carbon stock varied significantly between different bamboo species. *Phyllostachys aurea* had higher amount of carbon stocks (67.78 tC ha^{-1}) as compared with *Oxytenanthera abyssinica* (13.13 tC ha^{-1}).

Phyllostachys praecox (Lei bamboo) stand acted as a C sink and they provide a large permanent C stock in bamboo biomass. Mean annual net ecosystem exchange (NEE), ecosystem respiration, and gross ecosystem productivity were found -105.2 ± 23.1, 1264.5 ± 45.2, and 1369.6 ± 52.5 g C m^{-2} respectively. The annual net C sinks ranged from -68.7 to -148.6 g C m^{-2} yr^{-1} with a mean annual NEE of -105.2 ± 23.1 g C m^{-2} yr^{-1} (Liu et al., 2018).

The tropical forest alone process about six times as much C as the anthropogenic emission (Ray et al., 2011). A study report collecting samples covering 2.5 billion ha of forest in three continents in early 2000s concluded that the total biomass carbon stock of whole tropical forest is around 247 Gt C, in which 193 Gt C is aboveground and 54 Gt C in belowground (White et al., 2010). Zhou and Ziang, (2004) reported that the total C-storage capacity of a natural moso bamboo forest ecosystem including in soil was 106.36 t·ha^{-1}, of which the aboveground biomass stored 34.3 t·ha^{-1}, accounting for 32.3% of the total, that of forest floor and soil (0 to 60 cm in depth) stored 72.2 t·ha^{-1}, contributing 67.7% of the total C-storage.

Above ground C-storage capacity for some important bamboo species of Taiwan had reported that *Dendrocalamus latiflorus* (48.94 Mg ha^{-1}) was significantly higher than that of *Phyllostachys pubescens* (33.18 Mg ha^{-1}) and *Phyllostachys makinoi* (22.22 Mg ha^{-1}) (Liu & Yen, 2021).

A comparative study of total biomass production of seven different species of bamboo viz *Bambusa tulda, Bambusa bamboos, Bambusa nutan, Bambusa asper, Dendrocalamus strictus*, *Bambusa vulgaris* and *Bambusa balcoa* at the School of Forestry and Environment, SHIATS, Allahabad had reported that *Bambusa balcoa* accumulated highest biomass with 104.7 t.ha^{-1} followed by *Bambusa bamboos* and *Bambusa tulda* with 75.69 t.ha^{-1} and 70.40 t.ha^{-1} respectively. Among the selected bamboo species, *Bambusa asper* had least biomass accumulation with 7.12 t.ha^{-1}(Pathak et al., 2015).

In *Schizostachyum pergracile* bamboo forest of Manipur, total biomass varied from 143.1 to 202.62 Mg ha^{-1} and annual productivity was found to be 61.85 Mg ha^{-1}. Aboveground C-stock ranged from 64.65 to 91.48 Mg ha^{-1} and SOC was reported to be 53.25 Mg ha^{-1}. The estimated rate of C-sequestration was 26.96 Mg ha^{-1} yr^{-1}of which aboveground biomass accounted 82% and 18% in belowground biomass. Culm density was higher in 1yr age class with 1920±38.58 culms ha^{-1} (in 2011) and 2195±110.05 culms ha^{-1} (in 2012) and lowest in 3yr age class with 1480±44.96 culms ha^{-1} and 1670±85.69 culms ha^{-1} in 2011 and 2012 respectively (Thokchom & Yadava, 2017).

In *Bambusa vulgaris* and *Bambusa balcooa* the AGB kg culm^{-1} varied with the age of the culms, which was found higher in older age class. The average culm densities were found 4800 and 2216 culms ha^{-1} for *Bambusa vulgaris* and *Bambusa balcooa* respectively. The AGB were estimated 81.7 Mg ha^{-1} for *Bambusa vulgaris* and 41.8 Mg ha^{-1} for *Bambusa balcooa*. The C-density was 38.4 Mg ha^{-1} in *Bambusa vulgaris* and 19.6 Mg ha^{-1} for *Bambusa balcooa*. The estimated C-sequestration rates were 2.3 and 1.6 Mg ha^{-1} yr^{-1} in *Bambusa vulgaris* and *Bambusa balcooa* respectively (Nath et al., 2018).

Carbonization of bamboo

Carbonisation is a process of burning under minimal amount or in absence of oxygen, the end product is a carbonised biomass called biochar. The process of carbonization of biomass produces liquid by-products which is known as pyroligneous acid, also called vinegar (Tiilikkala et al., 2010). Biochar has been recognized as a multifunctional material for energy and environmental applications (Lehmann & Joseph, 2015).

Bamboo charcoal (biochar) is a renewable biomass fuel that has calorific value per unit weight having half that of oil; which by value addition can replace the mineral coal and wood charcoal (Lobovikov et al., 2007). The bamboo biochar can be used as an effective supplement which enhances agricultural productivity in nutrient-poor soil (Major et al., 2009). It has potential for nutrient retention by hindering leaching of nutrients such as nitrogen in soil. In addition, it increases availability of water to plants and microbial activities in soil (El-Naggar et al., 2019).

The International Biochar Initiative (IBI) had graded biochar into three classes based on carbon content. These include Class 1 biochar (contains 60% carbon or more), Class 2 biochar (between 30 and 60% carbon) and Class 3 biochar (between 10% and 30% carbon) (Viglašová et al., 2018). Physical, chemical and mechanical properties of biochar are strongly dependent on production conditions which makes challenging to engineered biochar although it has tremendous potential for C-sequestration, nutrient storage, water-holding capacity and adsorption (Sun et al., 2012). In biochar, the amount of C was highest in comparison to other investigated elements such as H, N and S (Viglašová et al., 2018).

Bamboo vinegar, a by-product of carbonization process of bamboo is a brown to dark brown liquid having pungent smell is recognised for its diverse applications. Bamboo vinegar contains over 200 kinds of organic compounds such as phenolic compounds, organic acids, alkanes, alcohol, aldehydes and many more (Ikimoto & Ikeshima, 2000). Among the organic compounds present in bamboo vinegar, acetic acid is the major component which comprises of 80% and some other volatile compounds such as syringol, butyric acid, furfural and propionic acids etc. are notable (Akakabe et al., 2006).

Sustainable approach through hydrothermal treatment and subsequent carbonization process conducted to fabricate hierarchical N-doped carbon materials with nanostructures by using renewable bamboo shoots as the raw material to produce high-performance electrode for super capacitors resulting in advanced nanostructured N-doped carbons, which could be easily produced in large scale with cost-effective and a green approach. It holds great promise for various practical applications like Lithium-ion batteries, catalysis and biosensors (Chen et al., 2017).

Untreated bamboo residues are mainly composed of three elements including carbon, hydrogen, oxygen and a small amount of nitrogen. The C-content of hydrochar obtained by acid-catalyzed hydrothermal reaction at different temperatures ranges between 66.6% and 69.3%, the hydrogen content is 5.1%–6.3%. The ratio of carbon and oxygen of acids assisted-hydrochars are slightly higher than that of bamboo-derived hydrochar prepared at the same hydrothermal temperature (Zhang et al., 2021).

A carbonization study on biochar production of eight bamboo species available in Northeast India (*Bambusa bambos, Bambusa tulda, Bambusa balooca, M. bamboosoides, Bambusa pallida, T. dollooa, Bambusa nutan and Dendrocalamus hamiltonii*) had concluded that all the species under observation were found suitable for charcoal production (Saikia et al., 2007).

Elemental content of bamboo

Metals are naturally present in the pedo-geochemical background of soils at various levels and many metals are essential for plants, however they can be harmful at higher concentrations. Metals accumulated in soil due to anthropogenic contamination through fertilizer and organic manure applications, industrial and municipal wastes depositions (Novak et al. 2004; Doelsch et al., 2010). Bamboos have been found to be very efficient in accumulating high amounts of silicon in their tissues naturally up to 183 mg g^{-1}. There was substantial variation in silicon content in selected 16 bamboo species which were found to range from 5.7 mg g^{-1} in *Phyllostachys aurea* to 56 mg g^{-}1 in *Bambusa multiplex* at the stem tip, and from 82 mg g^{-1} in *Phyllostachys bissetii* to 159 mg g^{-1} in *Dendrocalamus strictus* in the leaves. Monopodial bamboos were found to accumulate significantly more copper and silicon than sympodial bamboos in a similar environment (Collin et al., 2012).

Copper and zinc were found in different components of bamboo. The concentrations of Cu and Zn were significantly higher in sympodial species than in monopodial bamboo species, both in stems and leaves. The range of Zn concentrations in leaves and at the stem base was high and varies between bamboo species; it ranged from 2.3 to 21.7 mg kg^{-1} in *Gigantochloa sp*. and *Thyrsostachys siamensis* respectively. *Bambusa multiplex* had the highest Cu concentration, with 7.6 mg kg^{-1} in stem tips, while *Phyllostachys bambusoides* had the lowest concentration with 2.0 mg kg^{-1} in stem tips and 3.5 mg kg^{-1} in leaves (Collin et al., 2012).

A comparative analysis of mineral elemental content in juvenile shoots of *Bambusa tulda* were Ca (4.06 mg/100g), cu (0.44 mg/100g), Fe (3.19 mg/100g), Mg (8.68 mg/100g), Mn (0.70 mg/100g), K (408 mg/100g), P (19.31 mg/100g), Se (0.4µg), Na (12.96 mg/100g) and Zn (0.72 mg/100g); in *Dendrocalamus hemiltonii* were Ca (3.00 mg/100g), cu (0.29 mg/100g), Fe (2.69 mg/100g), Mg (6.09 mg/100g), Mn (0.16 mg/100g), K (416 mg/100g), P (28.12 mg/100g), Se (0.8 µg), Na (9.32 mg/100g) and Zn (0.70 mg/100g). An examination on macronutrient contents of 14 different bamboo species had observed that the protein content in juvenile bamboo shoots ranged from 2.31 to 3.72 g/100 g fresh weight, the highest being in *Dendrocalamus hamiltonii* followed by *Bambusa bambos* (Chongtham et al., 2011). There was significant variability from the low end (4.2-fold, 2.27–9.52 mg/g calcium; 4.4-fold, 56.17–246.43 µg/g sodium) to the high end (61.5-fold, 17.67–1087.0 µg/g manganese; 40.8-fold, 42.0–1713.5 µg/g aluminium). There was also significant variability in zinc content (Zn, 7.8-fold, 9.37–73.0 µg/g) and iron content (Fe, 26.3-fold, 52.44–1376.3 µg/g) among different bamboo species. *Dendrocalamus calostachyus* and *Cephalostachum pergracile* produced leaves with the highest iron (1376.3 µg/g) and zinc content (73.0 µg/g), respectively (Wang et al., 2018).

Leaf protein content analysis of five bamboo species viz. *Phyllostachys propinqua*, *Gigantochloa nigrociliata*, *Bambusa maculate, Dendrocalamus calostachyus* and *Indocalamus tessellatus* had found that protein content ranged from 8.12 to 16.33% with an average of 12.84%. *Phyllostachys propinqua*, *Gigantochloa nigrociliata* and *Bambusa maculata* were identified as the species producing leaves with the highest protein content (16.33%, 16.30% and 16.23%, respectively). *Bambusa maculate* was found having higher amounts of seven essential amino acids (His, 2.58; Thr, 6.26; Tyr, 4.73; Lys, 6.26; Ile, 5.63; Leu, 11.7; and Phe, 7.65) than the average. The lowest protein content in leaves were observed in *Indocalamus tessellatus* and *Dendrocalamus calostachyus* with (9.64% and 8.12%, respectively) (Wang et al., 2018).

However, due to lack of natural antioxidants, nowadays most food and pharmaceutical products contain synthetic antioxidants that provoked concerns about their adverse effect on health. Hence, more emphasis is given to the use of natural antioxidants (Schillaci et al., 2014). Antioxidant compounds in bamboo shoots and leaves can be a natural alternative for the development of functional food and nutraceuticals. Bamboo shoot contain important trace elements like selenium, zinc, copper, iron and manganese which can facilitate vital biochemical reactions by acting as cofactors for antioxidant enzymes. Flavonoids, phenols, vitamin C and E are the predominant antioxidants found in bamboo shoots (Nirmala et al., 2018).

3. MATERIAL AND METHOD

3.1 Study site

3.1.1 Mizoram

Mizoram is situated in the North Eastern part of India and the state shares boundaries with three other states of India they are Manipur, Assam and Tripura. Mizoram also shares International boundaries with Myanmar on the east for 404 Km, with Bangladesh in the south-west for 318 km. The state has rich flora and fauna, and the region also comes under the Indo-Burma biodiversity hotspots. The geographical area of the state occupied 21,081 km^2 which is located between latitude 21°58' N to 24°35' N and longitude 92°15' E to 93°29' E and the tropic of cancer runs through the state nearly at its middle. According to Forest Survey of India Report (2021) the total forest coverage of the state is 17,820 km^2 which is 84.53 % of the state geographical area. Bamboo forests cover a large extent of area in Mizoram, that is 21.63% of the geographical area of Mizoram is under Bamboo forest coverage (ISFR,2021). There are so far 27 species of bamboo found in different terrains and altitudes of the state, some of the common bamboo species are *Melocanna baccifera*, *Bambusa tulda*, *Dendrocalamus longispathus*, *Dendrocalamus hamiltonii*, *Bambusa nutans* etc. *Melocanna baccifera* is predominant bamboo species which has diverse connections with socio-economy of the state.

3.1.2 Aizawl district

Aizawl district is a hilly district located in the northern part of the state Mizoram. The district has geographical expansion of 3576.31 km^2 which is located in between 23º43′37.59″ N and 92º43′3.5″ E which lies to north of the Tropic of cancer. The western part of Aizawl district is passed by two main rivers of the state, they are the Tlawng river which is the longest river in Mizoram and the Tuirial river. Tributaries of these main rivers are found in different parts of the district. The climate is moderate and pleasant with abundant rain in the monsoon season.

The district is blessed with rich flora and fauna and total forest coverage of 3185 km^2 which is 89.09% of the total geographic area. Forest classification such as very dense

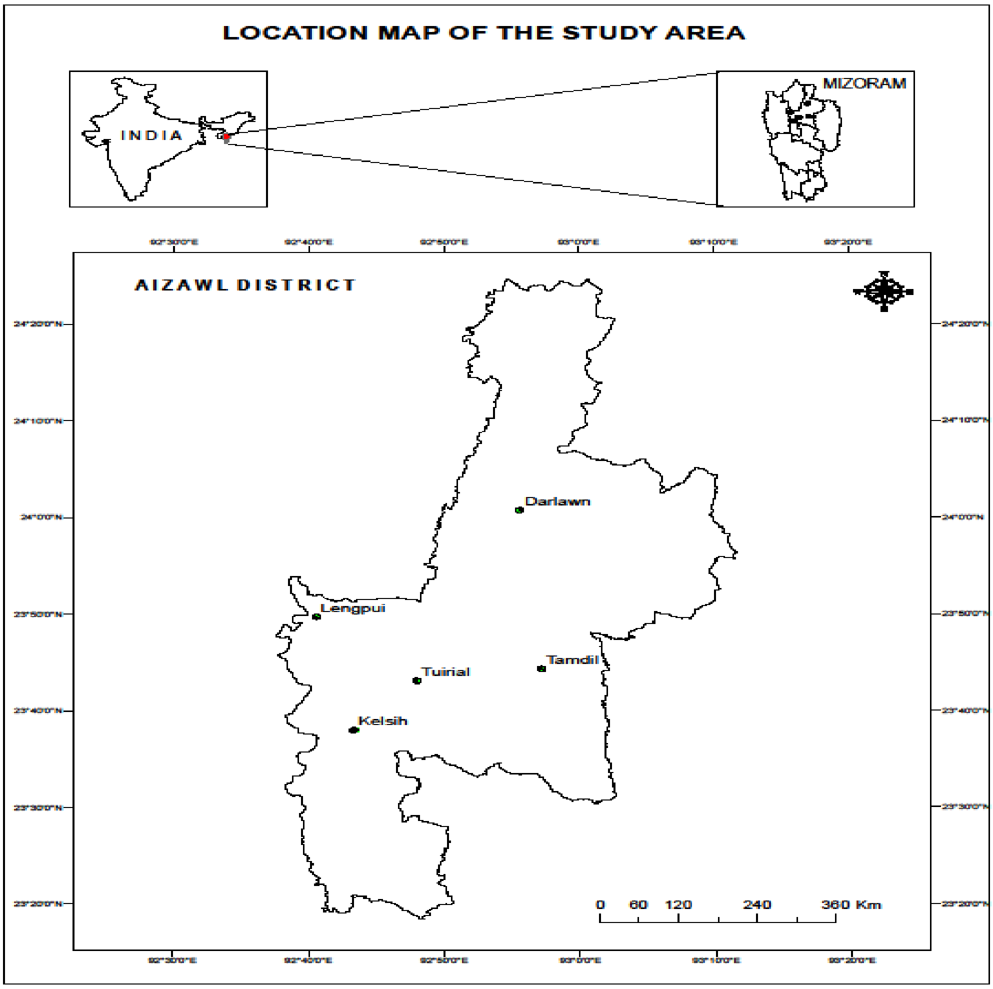

Figure 1: Location map of study sites, Aizawl district, Mizoram

forest, moderately dense forest and open forest has 28 km^2, 1135 km^2 and 2022 km^2 coverages respectively (ISFR, 2015). An area of 927.69 km^2 are under the bamboo forest coverage which is 25.94% of the total geographic area of the district and contributes 13.08% of the total bamboo area of Mizoram (MIRSAC, 2008).

3.1.3 Climate

According to Köppen-Geiger climate classification, the climate of Mizoram as whole and the Aizawl district is considered as humid subtropical climate (Cwa) with monsoon influences. The climate is warm and temperate in summer the temperature ranges from 20 to 30ºC, and in winter 11 to 21ºC (GOM,2020, Fig.1). The average annual temperature is 21.6ºC with annual rainfall of 1849 mm. January is the driest month with rainfall of only 9mm/day and in July, the peak reached with an average of 319 mm/day. Pleasant winter months are from November to February with very little or no rain. Spring starts from end of February till April. Rainy season starts from end-May and continued up to August. The highest number of daily hours of sunshine is measured in the month of March with around 10.1 hr/day and January being the lowest sunshine duration with an average of 7hr/day. The state has three main seasons such as summer season (March to May), rainy season (June to October) and winter season (November to February) (DST, Mizoram, 2020).

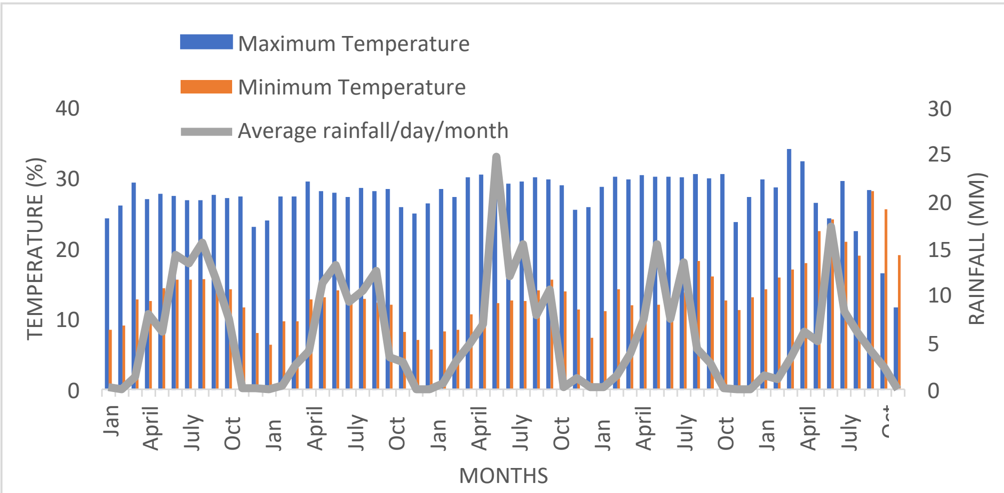

Figure 2: Weather data of Aizawl district showing temperature (°C) and average rainfall/month (mm) for five years, 2015-19. (Source: Meteorological center, Directorate of Science and Technology, Mizoram, 2020)

3.1.4. Study site

Within Aizawl district five sites were selected based upon the presence of different types of bamboo forests. They are Lengpui, Kelsih, Tamdil, Tuirial and Darlawn.

The altitude, location, slope aspect, distance from the main Aizawl city and along with the bamboo species selected in each site is provided in Table 1. Since *Melocanna baccifera* was the dominant bamboo species found in Mizoram, three study sites (Lengpui, Kelsih and Tamdil) were selected for collecting samples in this study. Detail description of the study sites are given in Table 1.

Lengpui:

Lengpui is in the vicinity of the longest river of Mizoram, the "Tlawng". Among the five study sites, Lengpui have the lowest altitude as a reason this site is more humid and warmer as compared with other selected study sites. The study was carried out in Mizoram Bamboo Centre, which was established by Environment and Forest Department under the National bamboo mission in the year, 2007 which is spread over around 3.5 ha area. Different species of bamboos were planted in the centre. However, natural forests of the bamboo species *Melocanna baccifera* (Roxb) and *Bambusa tulda* (Roxb) were found plenty in the site. Therefore, the study site was selected for a detailed study on C-sequestration potential of *Melocanna baccifera* and *Bambusa tulda.*

Kelsih:

The village has rich bamboo forests predominantly *Melocana baccifera*. The study site was chosen for the abundant naturally grown *Melocanna baccifera* forest. According to sayings in this village, this bamboo forest site was not affected by previous bamboo flowerings which caused widespread devastation in different parts of the state.

Table 1: Description of study sites

Site	Altitude (m a.s.l)	Location	Slope gradient	Slope orientation	Area (hectare)	Distance from Aizawl city (km)	Selected bamboo species
Lengpui	400-500	23º50′28″N 92º38′45″E	Moderate	North	1.4-2.0	41	*Melocanna baccifera, Bambusa tulda*
Kelsih	650-750	23º37′43″N 92º42′24″E	steep	North-West	0.09-1.8	19	*Melocanna baccifera*
Tamdil	900-1000	23º44′32″N 92º57′14″E	steep	South-East	1.2-2.0	88	*Melocanna baccifera*
Tuirial	700-1000	23º43′51″N 92º48′37″E	Very steep	South-East	0.5-1.0	27	*Dendrocalamus longispathus*
Darlawn	1000-1090	23º01′43″N 92º92′44″E	steep	South-East	0.5-1.0	123	*Melocalamus compactiflorus*

Tamdil:

Tamdil is the name given to a freshwater lake which is situated near Saitual village about 88 km away east from the Aizawl city. Tamdil/Tam-Dil literally means "Lake of mustard" has its own folklore in the Mizo community. The lake is a beautiful tourist spot and one of the most frequented lakes in Mizoram. The surrounding hills are covered with thick forest which enhances the beauty of the lake. The study site is located in the thick bamboo forests of *Melocanna baccifera* on the western side of the lake.

Tuirial:

Tuirial is the name of a river which is originated from Chawilung hills of Aizawl district, Mizoram and flowing northward to join the Barak River in Assam. *Dendrocalamus longispathus* (Kurz). was found abundantly along the banks of the river Tuirial.

Darlawn:

The special characteristic of the site was the availability of a rare species of bamboo *Melocalamus compactiflorus* (Kurz). a climbing bamboo species. The site was specifically selected for a detailed study on C-sequestration potential of the climbing bamboo.

3.2 Analysis of soil

Soil samples were collected monthly during 2015 and 2016 from two study sites, Lengpui and Kelsih. Collection of soil samples from the remaining three other study sites (Tamdil, Tuirial and Darlawn) could not be done due to heavy workload. Three plots were selected and earmarked for each *Melocanna baccifera* and *Bambusa tulda* stands in Lengpui. In Kelsih also three plots were earmarked for *Melocanna baccifera* stand. From each plot, three replicates of soil were sampled from a depth of 0-30cm. Soil temperature was recorded seasonally at the study sites using soil thermometer. Bulk density was also determined seasonally using a steel soil corer. Fresh soil samples were taken to the laboratory for analysis of the following physico-chemical properties. All the physico-chemical analysis of soil was carried out by following the methods outlined in Anderson and Ingram (1993).

3.2.1 Soil moisture

Soil moisture was determined by oven-dry method. The percentage of the soil moisture content was calculated by the following formula:

Moisture Content (%) ———

Where, W_1 = initial weight

W_2 = final weight

3.2.2 Bulk density

Bulk density of soil was measured by using soil corer and oven dry method. Calculation was done by using the formula:

Bulk density ( ) ——————— ( )

Where, vol. of soil corer = 3.14 x r^2 x h

r = radius of soil corer

h = height of soil corer

3.2.3 Soil pH

Soil pH was determined using fresh soil sample by using 1:5 soil : water ratio. 10g of freshly collected soil samples were dissolved in 50 ml of distilled water and stirred for 30 minutes and left overnight. The pH of the supernatant liquid was measured using digital pH meter.

3.2.4 Organic carbon

The organic carbon of soil was determined using Walkley and Black‟s titration Method. Oven dried soil was grinded and sieved through 0.2mm sieve. 0.50g of the soil was taken as sample and put in 500ml conical flask. 10ml of 1N potassium dichromate was added and let the soil dispersed uniformly in dichromate solution for few minutes. Then 20ml of conc. Sulphuric acid was added very carefully and swirl 2-3 times and the mixture were allowed to settled for 30 minutes. 200ml of distilled water was added 10ml of Ortho-phosphoric acid was also added. 1ml of diphenylamine indicator was added and the content was titrated with ferrous ammonium sulfate solution till the colour changes from blue to light green. The same process was run without soil sample to observe for the blank. Percentage of Organic carbon content was calculated by using the formula:

Organic carbon content (%) ( ) ——— —

Where, B = volume of ferrous ammonium sulphate for blank titration in ml

T = volume of ferrous ammonium sulphate needed for soil sample in ml

S = weight of soil sample

3.2.5 Total Nitrogen

Total Nitrogen content was determined by using CHNS/O Elemental Analyzer with autosampler and TCD detector- Euro Vector, model: EuroEA3000 installed in Central Instrumentation Laboratory, Mizoram University.

3.2.6 Available Phosphorus

The available phosphorous of soil was estimated by the Olsen‟s method. Oven dried finely grinded soil (2.5g) was added in a conical flask, 50ml of extracting solution ($NaOH_3$) was added, the mixture was shacked for 30 minutes in a shaker after which the suspension was filtered through Whatman filter paper (No. 40). 5ml of the filtered extract was taken into a 25ml volumetric flask to which 5ml of Dickman and Bray‟s reagent was added drop by drop with constant shaking of the flask till the effervescence was ceased. Then 1ml of diluted $SnCl_2$ was added and the volume was made up to mark (25ml) with distilled water. Finally, intensity of colour (blue) of the mixturewas measured at 660 nm using spectrophotometer and concentration of Phosphorus was obtained from the standard curve.

Olsen‟s phosphorous (kg/ha) = R x V/v x 1/S x (2.24 x 10^6) / 10^6

or = R x (50/5) x (1/2.5) x 2.24

or = R x 8.96

Where, V = Total volume of extract (50ml)

v = Volume of aliquot taken for analysis (5ml)

S = Wt. of soil (2.5g)

R = Wt. of P in the aliquot in µg (from standard curve)

3.2.7 Available Potassium

The exchangeable K in the soil was determined by using Flame photometer.

3.2.8 Soil respiration

Soil respiration was measured by using the Alkali absorption method outlined by Anderson and Ingram, (1993).

200g of fresh soil sample was kept in a glass jar and 100 ml beaker containing 20ml of 0.1N of KOH solution was kept inside the glass jar. The glass jar was closed and kept air-tight for 24 hours. The amount of CO_2 fixed by potassium hydroxide was estimated by titration with 0.1N Hcl solution using phenolphthalein indicator. A blank was prepared by using sterilized soil on a glass jar for estimation of atmospheric CO_2.

The estimated value of CO_2 evolved was calculated by using the formula:

$$CO_2 \text{ evolution} = (B-V) \times (N \times E)$$

Where,

B= volume of acid titrated for blank,

V= volume of acid titrated with sample,

N= normality of acid (0.1N) and

E= equivalent weight of CO_2

3.3 Soil C-storage

After the analysis of the soil organic carbon from the two sites the organic carbon storage in the top soil layer (0-30cm) was determined. Soil C-storage was calculated by following the method given by Quen et al., (2017). The formula is:

$$SOC = b \times p \times d$$

Where, b is the bulk density of soil in g/cm^3, p is the percentage (%) of organic C in soil and d is the depth of soil in cm, the units were accordingly converted into Mg/ha.

3.4 Soil C-sequestration

The rate of soil C-sequestration was determined following the formula given by Liu and Li (2012):

$$SCS = SOC_y - SOC_{y-1}/t$$

Where, SCS= Soil carbon sequestration,

SOC_y = the soil organic C-storage of inventory time in the y^{th} year

SOC_{y-1} = the soil organic C-storage of the inventory time in the $(y-1)^{th}$ year

t = time interval in years.

In the present study, y^{th} year is 2016 and $(y-1)^{th}$ year is 2015 and t is 1year.

3.6 Estimation of bamboo biomass

3.6.1 Culm density and aboveground biomass

In the five sites, Lengpui, Kelsih, Tamdil, Tuirial and Darlawn, three plots for different bamboo species namely, *Melocanna baccifera*, *Bambusa tulda*, *Dendrocalamus longispathus* and *Melocalamus compactiflorus* were earmarked in each site. In each plot, three quadrates of size (10x10) m were laid down. Laying of quadrates and analysis of biomass were done once during each year (2015 and 2016) for all the species. The study was carried out during the months December, January and February in each study year. Within every quadrate, bamboo culms were classified into three age classes namely 1yr, 2yr and ≥3yr based upon morphological characteristics used by Wimbush (1945) and Banik (1993). Less than 1year old culms were identified by their dark-green colour, fully or partially covered by hairy sheaths. In this age group, leaves and branches are very few or absent. 2-3-year-old were distinguished by their faded green or pale green culm, with no sheath or dirty and scruffy sheath if present on the lowest node. Branches and leaves are fully developed and slight moss may find at the nodes. Culms older than 3 years were distinguished by their yellowish color with dry appearance and rough surface with lichens and moss on the nodes and internodes (Embaye et al., 2005). Culm densities of every age class were recorded within each quadrate. Three culms of each age class were harvested from each quadrate, a total of 162 bamboo culms of the four different bamboo species from the study sites were harvested annually for the study. The plant components were separated for every individual culm into culm, branch and leaf components. The fresh net weight of each component was recorded separately in the field and samples of each plant components were taken back to the laboratory for further analysis as sub-samples. In laboratory the fresh weight of each sub-samples was recorded and oven dried for 48hours at 105^{o}C in order to found out dry weight. Biomass of the sub-samples was estimated by finding ratio of fresh to the oven dry weight method given by FAO (2012).

$$TDW = TFW \_\_$$

Where, TDW= total dry weight

TFW= total fresh weight

SDW= sample dry weight and

SFW= sample fresh weight.

The corresponding biomass of the samples were calculated (by using unitary-method) from biomass ratio of the sub-samples. Above ground biomass were further determined by multiplying the calculated biomass of samples and the corresponding culm densities.

3.6.2 Belowground biomass

Below ground biomass was determined for *Melocana baccifera* only. Rhizomes within 30×30 cm of the harvested culms were excavated and taken to the laboratory and washed with running water to remove all the soil. Fresh weight of the rhizome was recorded and oven dried for 48hours at 105^{o}C to found out the dry weight. The dry weight of the sample was recorded again when it is stabled. The biomass of the rhizomes was determined by following the same method used in aboveground biomass. As the excavation of the rhizomes was a very difficult task, the number of rhizomes excavated was 3 rhizomes from each age class totaling 9 rhizomes annually from each site. Below ground biomass in a quadrate was determined by multiplying the dry weight of the sample and the culm density.

3.6.3 C- content (%) of biomass

C- content in different components (culm, branch, leaf and rhizome) of bamboo biomass were determined by using CHNS-analyzer in the Central Instrumentation Laboratory (CIL), Mizoram University.

3.6.4 Litterfall

One Permanent tray of size 30x30 cm was set up in each quadrate and the litter was collected seasonally. The litterfall collected were separated into leaf, branch and sheath components and their dry weights were determined.

3.7 Carbon storage in aboveground biomass

Sub-samples of all the dried components of bamboo were separately grinded and determined for their C-content. C content in terms of percentage (%) was estimated by CHNS analyzer in Central Instrumentation Laboratory of Mizoram University. The aboveground biomass C-storage was determined by multiplying the percentage of C-concentration in dry mass with their respective biomass. C-storage for the litterfall was also determined.

3.8 C-sequestration in aboveground biomass

The rate of C-sequestration in aboveground biomass for all the species was determined by following the equation given by IPCC (2003):

$$C_s = C_n - C_{n-1} + L$$

Where, C_s = carbon sequestration

C_n = C-stock for n^{th} year

C_{n-1} = C-stock of the year preceding the n^{th} year

L = C-stored in total litter production during the period.

In the present study, n^{th} year is the record of 2016 and $(n-1)^{th}$ year is the record of 2015.

Belowground biomass C-sequestration of *Melocanna baccifera* was also found out by using the same formula after removing the litterfall component.

The aboveground biomass C-sequestration of *Melocanna baccifera* was determined for the three sites (Lengpui, Kelsih and Tamdil) separately. The average was taken as the rate of C-sequestered by aboveground biomass of *Melocanna baccifera.*

3.9 Extraction of bamboo vinegar

Vinegar was extracted from the oven dried culms of bamboo by the pyrolysis method. Oven dried culms were cut into small pieces and put inside a cleaned pressure cooker (Hawkins) of which the pressure regulator was removed and the vent pipe of the pressure cooker was fixed with an aluminum pipe (3 feet long) of suitable diameter to the vent pipe. The aluminum pipe was bended and wrapped with wet cloth. The closed air-tight pressure cooker was given heat by using a round electric cooking heater (1500 W) for 2 hours. The condensed smoky droplets (vinegar) were collected in a beaker.

3.9.1 Determination of elemental content in bamboo vinegar

Elemental content of bamboo vinegar was determined by using ICP-MS, make/model: Thermofisher Scientific/iCAP RQ(C2) in Department of Environmental science, Tezpur University.

3.9.2 Characterization of elemental compounds in bamboo vinegar

Characterization of chemical compounds in bamboo vinegar was determined by using Gas Chromatography; Model: GC2011; Make: CIC, India in the Department of Chemistry, IIT (ISM) Dhanbad.

4. RESULTS

4.1 Soil

4.1.1 Soil moisture (%)

Lengpui:

Soil moisture (SM) ranged from 8.63% to 23.30% during 2015 and it ranged from 8.72% to 35.14% during 2016 in Lengpui. By comparing between different months, maximum SM was recorded 35.14% in September (2016) and minimum was 8.63% in March (2015). Average annual SM were 18.19% and 25.62% in 2015 and 2016 respectively (Table 2).

There were significant variations of SM within the months during 2015 ($F_{9,18}$=1264.5; P<0.01) and in 2016 ($F_{9,18}$=6130.53; P<0.01) and within the two years ($F_{9,45}$=35.16; P<0.01)

Kelsih:

SM in Kelsih ranged from 8.57% to 32.56% during 2015 and it ranged from 12.10% to 32.36% during 2016 in Kelsih. By comparing between different months, maximum SM was recorded 32.56% in August (2015) and minimum was 8.57% in March (2015). Average annual SM were 22.74% and 24.55% in 2015 and 2016 respectively (Table 2).

There were significant variations of SM within the months in the year 2015 ($F_{9,18}$=11102.6; P<0.01), 2016 ($F_{9,18}$=8226.46; P<0.01) and within the two years ($F_{9,45}$=105.9; P<0.01).

The details are provided in appendix I and XXI.

Table 2: Monthly variation of soil moisture (%) along with standard error during 2015 and 2016 in Lengpui and Kelsih

Months	Lengpui		Kelsih	
	2015	2016	2015	2016
March	8.63±0.13	8.72±0.08	8.57±0.05	12.10±0.03
April	19.82±0.08	20.67±0.04	20.00±0.07	21.97±0.21
May	20.42±0.13	25.40±0.20	21.31±0.05	21.83±0.04
June	19.47±0.06	27.67±0.13	24.28±0.07	32.36±0.09
July	19.10±0.08	26.80±0.08	29.09±0.21	28.16±0.04
August	22.62±0.28	33.43±0.11	32.56±0.05	31.80±0.07
September	23.30±0.09	35.14±0.02	31.14±0.10	30.40±0.06
October	19.78±0.16	33.36±0.11	28.5±0.08	27.06±0.09
November	15.72±0.16	26.59±0.21	18.38±0.04	23.24±0.02
December	13.10±0.16	18.42±0.07	13.62±0.03	16.61±0.04
Average	18.19	25.62	22.74	24.55

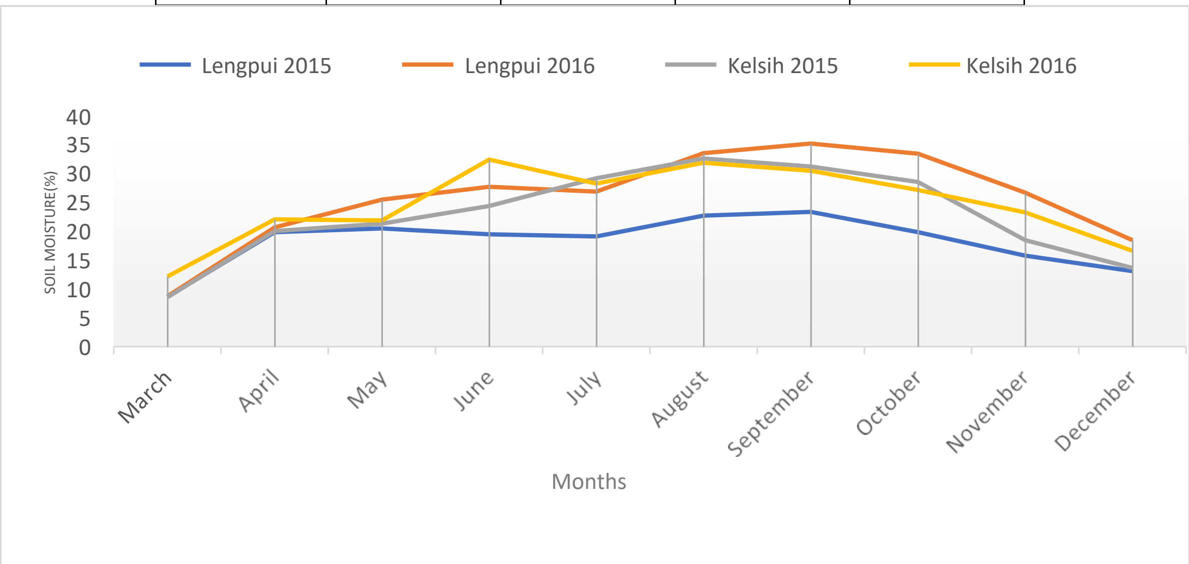

Figure 3: Monthly variations of Soil moisture (%) during 2015 and 2016 in Lengpui and Kelsih

By comparing between both study sites selected for soil analysis, SM content was found to be highest during the rainy months in both the years. Comparing the annual average SM contents of two study years, Lengpui during 2016 (25.62%) recorded highest and also lowest in Lengpui during 2015 (18.19%). In both the study sites, 2016 were found to have higher amount of average SM contents as compared to 2015 (Figure 2).

4.1.2. Soil pH

Lengpui:

Soil pH in Lengpui ranged from 5.20 (rainy, 2015) to 5.85 (summer, 2016). By comparing between different seasons, rainy season recorded the lowest pH and highest in summer season in both study years (Table 3).

There were significant variations of soil pH between different seasons during 2015 ($F_{2,4}$=170.4; P<0.01), during 2016 ($F_{2,4}$=455.2; P<0.01) and within the two years ($F_{2,10}$=123.1; P<0.01).

The details are provided in appendix II and XXIII.

Kelsih:

In Kelsih, soil pH ranged from 5.35 (rainy, 2016) to 6.06 (summer, 2015). By comparing between different seasons, rainy season recorded the lowest pH in both study years (Table 3).

Significant variation of soil pH between different seasons were not observed during 2015. Whereas there was significant variation in 2016 ($F_{2,4}$=35.36; P<0.01) and within the two years ($F_{2,10}$=11.94; P<0.01).

The details are provided in appendix II and XXIV.

In both study sites, summer seasons were found to have least soil pH and the highest was found in summer seasons during both 2015 and 2016 (Table 3).

(A)

(B)

(C)

Photo plate 1: Soil samples in the laboratory (A) Fresh soil samples, (B) Soil samples in oven and (C) Extracts of soil samples under experiment

Table 3: Seasonal variations of soil pH along with standard error during 2015 and 2016 in Lengpui and Kelsih

Seasons	Lengpui		Kelsih	
	2015	2016	2015	2016
Summer	5.65±0.02	5.85±0.02	6.06±0.02	5.65±0.03
Rainy	5.20±0.03	5.23±0.02	5.86±0.05	5.35±0.03
Winter	5.34±0.02	5.54±0.02	6.02±0.03	5.90±0.09

4.1.3 Soil temperature (ST)

Lengpui:

In Lengpui, ST ranged from 20.03ºC (winter season, 2016) to 32.89ºC (summer season, 2015). By comparing between the two study years, seasonal ST was more varied during 2015 with 20.52ºC (winter season) to 32.89ºC (summer season) whereas 20.03ºC (winter season) to 25.39ºC (rainy season) during 2016 (Table 4).

There were significant variations of ST between different seasons during 2015 ($F_{2,4}$=491864.1; P<0.01), in 2016 ($F_{2,4}$=7212.4; P<0.01) and within the two years ($F_{2,10}$=9.68; P<0.01).

The details are provided in appendix III and XXV.

Kelsih:

In Kelsih, ST ranged from 19.91ºC (winter season, 2016) to 26.43ºC (rainy season, 2015). By comparing between the seasons, rainy season had highest ST in both the studied years (Table 4).

There were significant variations of ST between different seasons during 2015 ($F_{2,4}$=81577.2; P<0.01), in 2016 ($F_{2,4}$=78492; P<0.01) and within the two years ($F_{2,10}$=513.86; P<0.01).

The details are provided in appendix III and XXVI.

Table 4: Seasonal variation of soil temperature (ºC) along with standard error for 2015 and 2016 in Lengpui and Kelsih

Seasons	Lengpui		Kelsih	
	2015	2016	2015	2016
Summer	32.89±0.01	22.41±0.04	23.31±0.02	22.27±0.01
Rainy	26.63±0.01	25.39±0.03	26.43±0.01	24.85±0.02
Winter	20.52±0.00	20.03±0.02	20.41±0.01	19.91±0.02

4.1.4 Bulk density (BD)

Lengpui:

In Lengpui, BD ranged from 0.651 g/cm^3 (rainy season, 2015) to 0.737 g/cm^3 (summer season, 2016). Lowest BD was recorded during rainy seasons and highest during the winter and summer seasons in both the study years (Table 5).

There were significant variations of soil BD between different seasons during 2015 ($F_{2,4}$=30.2; P<0.01), in 2016 ($F_{2,4}$=44.1; P<0.01) and within the two years ($F_{2,10}$=39.73; P<0.01).

The details are provided in appendix IV and XXVII.

Kelsih:

In Kelsih, BD ranged from 0.621 g/cm^3 (rainy season, 2016) to 0.708 g/cm^3 (winter season, 2015). By comparing between different seasons, rainy season had lowest BD whereas winter season had highest BD in both the study years (Table 5).

There were significant variations of soil bulk density between different seasons during 2015 ($F_{2,4}$=1058.6; P<0.01), in 2016 ($F_{2,4}$=56.74; P<0.01) and within the two years ($F_{2,10}$=12.41; P<0.01).

The details are provided in appendix IV and XXVIII.

Table 5: Seasonal variation of soil bulk density (g/cm^3) for 2015 and 2016 in Lengpui and Kelsih

Seasons	Lengpui		Kelsih	
	2015	**2016**	**2015**	**2016**
Summer	0.662	0.737	0.639	0.631
Rainy	0.651	0.723	0.632	0.621
Winter	0.664	0.732	0.708	0.642

4.1.5 Soil organic carbon (SOC)

Lengpui:

The monthly variation of SOC varied from 1.87% (May) to 2.85% (July) during 2015. Whereas in 2016, it ranged from 1.64% (December) to 3.15% (September) (Table 6).

There were significant variations of SOC within the months during 2015 ($F_{9,18}$=100.08; P<0.01), in 2016 ($F_{9,18}$=255.4; P<0.01) and within the two years ($F_{9,45}$=18.33; P<0.01).

The details are provided in appendix V and XXIX.

Kelsih:

The SOC ranged from 1.96% (March) to 3.32% (October) during 2015 and in 2016 the minimum SOC was recorded 2.00% (March) and the maximum was 4.06% (July) (Table 6).

There were significant variations of soil organic carbon within the months during 2015 ($F_{9,18}$=56.01; P<0.01), in 2016 ($F_{9,18}$=100.91; P<0.01) and within the two years ($F_{9,45}$=32.67; P<0.01).

The details are provided in appendix IV and XXX.

By comparing between the two sites, Kelsih was found to have higher SOC than in Lengpui (Figure 3).

Table 6: Monthly variation of SOC (%) along with standard error in Lengpui and Kelsih during 2015 and 2016

Months	Lengpui		Kelsih	
	2015	2016	2015	2016
March	2.02±0.02	2.00±0.02	1.96±0.04	2.00±0.07
April	2.34±0.04	2.45±0.02	2.09±0.05	2.21±0.07
May	1.87±0.03	2.28±0.02	2.14±0.02	2.23±0.02
June	2.44±0.03	3.13±0.03	3.14±0.04	3.51±0.07
July	2.85±0.03	2.86±0.06	3.03±0.02	4.06±0.09
August	2.82±0.02	2.29±0.02	2.73±0.05	4.01±0.17
September	2.61±0.07	3.15±0.03	2.84±0.07	3.60±0.07
October	2.55±0.03	2.54±0.04	3.32±0.08	3.63±0.07
November	1.96±0.04	2.36±0.03	3.17±0.05	3.29±0.08
December	1.97±0.01	1.64±0.03	2.47±0.17	2.94±0.12

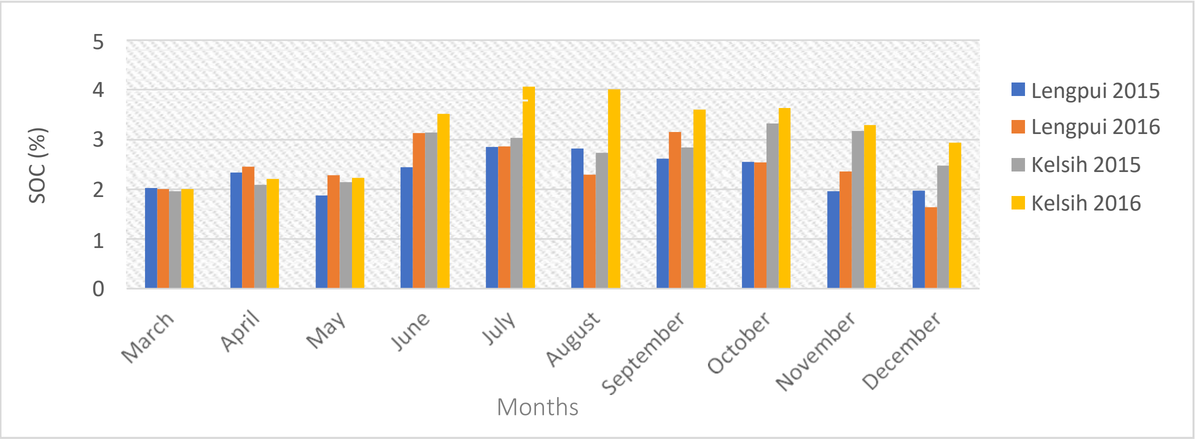

Figure 4: Monthly variation of SOC (%) in Lengpui and Kelsih during 2015 and 2016

4.1.6 Total Nitrogen (TN)

Lengpui:

In Lengpui, TN content in soil ranged from 0.58% (summer and winter season each, 2015) to 0.7% (winter season, 2016) (Table 7). The significant variation of TN in soil between different seasons during 2016 was ($F_{2,4}$=33.27; P<0.01).

The details are provided in appendix VI and XXXI.

Kelsih:

In Kelsih, it ranged from 0.65% (Pre-monsoons of 2015 and 2016) to 0.73% (Monsoon, 2016) (Table 7). There were significant variations of TN between different seasons during 2015 ($F_{2,4}$=38; P<0.01) and in 2016 ($F_{2,4}$=73; P<0.01).

The details are provided in appendix VI and XXXII.

By comparing between two study sites, Kelsih recorded higher amount of TN content in the soil.

Table 7: Seasonal variation of TN (%) along with standard error in Lengpui and Kelsih during 2015 and 2016

Seasons	**Lengpui**		**Kelsih**	
	2015	**2016**	**2015**	**2016**
Summer	0.58±0.02	0.61±0.006	0.65±0.02	0.65±0.01
Rainy	0.61±0.02	0.65±0.01	0.67±0.02	0.73±0.02
Winter	0.58±0.03	0.70±0.01	0.70±0.006	0.66±0.03

4.1.7 Available Phosphorus (AP)

Lengpui:

In Lengpui, the AP in soil ranged from 0.02% (winter season, 2015) to 0.11% (winter season, 2016). In 2015, summer and rainy seasons had similar AP (0.06 %). Whereas during 2016, it was highest in winter season (0.11%) and lowest during rainy season (0.05%) (Table 8).

There were significant variations of AP between different seasons during 2015 ($F_{2,4}$=73; P<0.01) and in 2016 ($F_{2,4}$=395.12; P<0.01).

The details are provided in appendix VII and XXXIII.

Kelsih:

In Kelsih, AP were varied from 0.05% (summer season, 2016) to 0.08% (winter season, 2015). Summer seasons were found to have lowest amount of AP (Table 8).

There were significant variations of AP between different seasons during 2015 ($F_{2,4}$=490.9; P<0.01), in 2016 ($F_{2,4}$=700; P<0.01) and within two years ($F_{2,10}$=139.22 P<0.01).

The details are provided in appendix VII and XXXIV.

Table 8: Seasonal variation of AP (%) along with standard error in Lengpui and Kelsih during 2015 and 2016

Seasons	**Lengpui**		**Kelsih**	
	2015	**2016**	**2015**	**2016**
Summer	0.06±0.002	0.08±0.001	0.05±0.001	0.05±0.001
Rainy	0.06±0.003	0.05±0.002	0.08±0.001	0.08±0.002
Winter	0.02±0.002	0.11±0.03	0.08±0.001	0.07±0.010

4.1.8 Available Potassium (AK)

Lengpui:

In Lengpui, the seasonal variation of AK ranged from 32 ppm (rainy season, 2015) to 62.77 ppm (summer season, 2016). In 2015, rainy season was found to have lowest AK (32 ppm) and highest amount during summer (50.6 ppm). Whereas in 2016, lowest was recorded during winter (44 ppm) and the highest during summer (Table 9). There were significant variations of AK between different seasons during 2015 ($F_{2,4}$=91962.5; P<0.01) and in 2016 ($F_{2,4}$=26897.06; P<0.01).

The details are provided in appendix VIII and XXXV.

Table 9: Seasonal variation of available AK (ppm) along with standard error in Lengpui and Kelsih during 2015 and 2016

Seasons	Lengpui		Kelsih	
	2015	2016	2015	2016
Summer	50.6±1.06	62.77±0.86	75.66±1.07	55±0.45
Rainy	32±1.05	56.11±0.99	79.33±4.92	63.33±1.08
Winter	47.2±2.40	44±1.07	69.88±1.49	63.77±0.98

Kelsih:

In 2015, AK was least during winter season (69.88ppm) and maximum during rainy season (79.33ppm). whereas in 2016, the least amount was recorded during summer (55ppm) and the maximum during winter season (63.77ppm) (Table 9). There were significant variations of AK between different seasons during 2015 ($F_{2,4}$=16021.15; P<0.01) and in 2016 ($F_{2,4}$=41073.48; P<0.01).

The details are provided in appendix VIII and XXVI.

By comparing between the two sites, Kelsih was found to have higher AK.

4.1.9 Soil respiration (SR)

Lengpui:

In Lengpui, monthly soil CO_2 emission rate ranged from 9.56 mg/kg/d (March, 2015) to 22.14 mg/kg/d (May, 2016). In 2015, monthly CO_2 emission were subsequently increased from March (9.56 mg/kg/d) to July. 18 mg/kg/d (July, 2015) being the highest rate. In 2016, the lowest and highest rate of CO_2 emission were 11.22 mg/kg/d (March) and 22.14 mg/kg/d (May) respectively (Table 10).

There were significant variations of SR between the months during 2015 ($F_{9,18}$=297.44; P<0.01), in 2016 ($F_{9,18}$=1116.47; P<0.01) and within the two years ($F_{9,45}$=20.73; P<0.01).

The details are provided in appendix IX and XXXVII.

Table 10: Monthly variation of soil respiration (mg/kg/d) along with standard error in Lengpui and Kelsih during 2015 and 2016

Months	Lengpui		Kelsih	
	2015	2016	2015	2016
March	9.56±0.18	11.22±0.11	11.18±0.01	14.33±0.02
April	12.61±0.34	15.57±0.14	13.72±0.09	19.11±0.09
May	12.80±0.32	22.14±0.01	15.94±0.05	20.00±0.09
June	15.28±0.24	18.73±0.12	20.37±0.02	25.00±0.06
July	18.72±0.12	19.89±0.23	21.60±0.02	24.71±0.11
August	14.88±0.10	14.23±0.07	21.53±0.10	23.98±0.06
September	15.64±0.07	20.16±0.18	20.80±0.12	24.56±0.16
October	15.29±0.14	20.60±0.02	19.16±0.06	21.04±0.05
November	12.34±0.14	16.98±0.04	17.43±0.16	19.62±0.14
December	11.03±0.14	14.39±0.17	14.53±0.02	16.48±0.22

Kelsih:

The monthly soil CO_2 emission rate ranged from 11.18 mg/kg/d (March, 2015) to 25.00 mg/kg/d (June, 2016). In 2015, the rate of CO_2 emission was found highest in July (21.60 mg/kg/d) and decreased in later months; the same pattern was also found in 2016 with March (14.33 mg/kg/d) being the lowest and June (25.00 mg/kg/d) the highest (Table 10).

There were significant variations of soil respiration in between the months during 2015 ($F_{9,18}$=2780.26; $P<0.01$), in 2016 ($F_{9,18}$=1121.65; $P<0.01$) and within the two years ($F_{9,45}$=144.46; $P<0.01$).

The details are provided in appendix IX and XXXVIII.

On an average the SR rate was higher in Kelsih as compared with Lengpui (Figure 4).

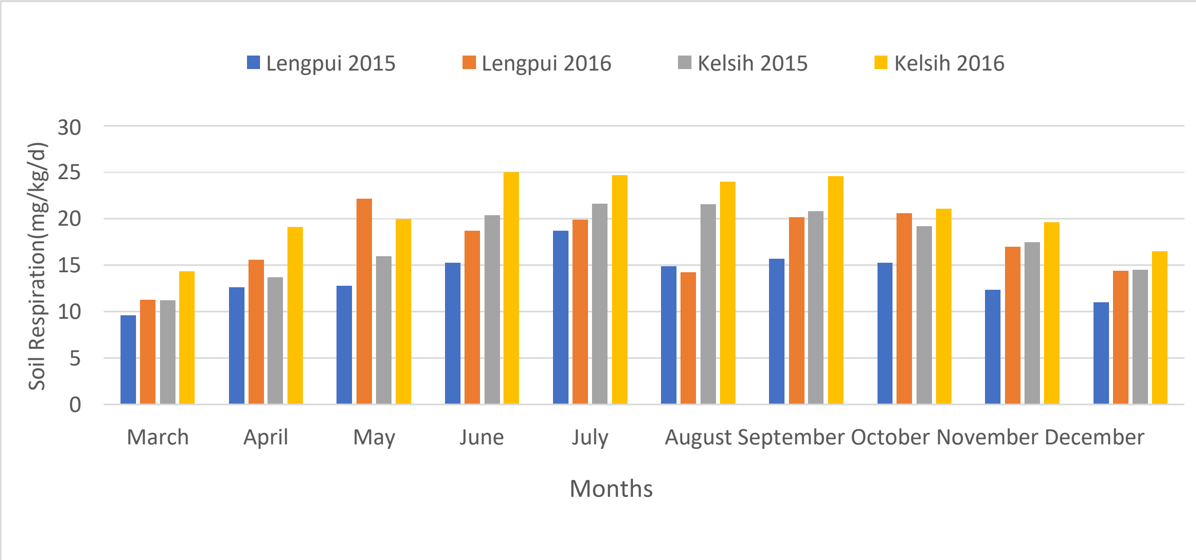

Figure 5: Monthly variation of soil respiration (mg/kg/d) in Lengpui and Kelsih during 2015 and 2016

4.1.10 Correlation

The Pearson‟s coefficient of correlation (r) was calculated for finding relationship between the different characteristics of soil in Lengpui and Kelsih during this study period.

Lengpui (2015):

Soil moisture (SM) was found to have significant positive correlation with soil respiration (SR) (r = 0.96), SOC (r = 0.99), TN (r = 0.96) and AP (r = 0.73); whereas it was found to have significant inverse correlation with bulk density (BD) (r = -0.80) and AK (r = -0.90). SR was found to have significant positive correlation with SOC (r=0.99) and TN (r=1) but have significant inverse correlation with pH (r= -0.74), BD (r= -0.94) and AK (r= -0.99). SOC was found to have significant positive correlation with TN (r=0.99) and AP (r=0.63) whereas significantly inverse correlation with pH (r= -0.63), BD (r= -0.87) and AK (r= -0.95) (Table 11).

Table 11: Correlation between different soil characteristics of Lengpui during 2015

	SM (n=10)	**SR (n=10)**	**SOC (n=10)**	**pH (n=3)**	**ST (n=3)**	**BD (n=3)**	**TN (n=3)**	**AP (n=3)**	**AK (n=3)**
SM	1.00	0.96*	0.99*	-0.52	0.28	-0.80*	0.96*	0.73*	-0.90*
SR		1.00	0.99*	-0.74*	-0.01	-0.94*	1.00*	0.50	-0.99*
SOC			1.00	-0.63*	0.14	-0.87*	0.99*	0.63*	-0.95*
pH				1.00	0.68*	0.93*	-0.74*	0.21	0.84*
ST					1.00	0.36	-0.01	0.86*	0.18
BD						1.00	-0.94*	-0.16	0.98*
TN							1.00	0.50	-0.99*
AP								1.00	-0.34
AK									1.00

* indicates significant at $p<0.05$

Lengpui (2016):

SM was found to have significant positive correlation with SR (r = 0.87), SOC (r = 0.81) and soil temperature (r = 0.71); whereas it was found to have significant inverse correlation with pH (r = -0.98) BD (r = -0.89) and AP (r = -0.66). SR was found to have significant positive correlation with SOC (r=0.99) and soil temperature (r=97) but significant inverse correlation with pH (r= -0.75), BD (r= -1) and AP (r= -0.95). SOC was found to have significant positive correlation with soil temperature (r=0.99); whereas significant inverse correlation with pH (r= -0.68), BD (r= -0.99) and AP (r= -0.98) (Table 12).

Kelsih (2015):

SM was found to have significant positive correlation with SR (r = 0.93), SOC (r = 0.62), soil temperature (r = 0.90) and AK (r = 0.82); whereas it was found significant inverse correlation with pH (r = -0.97) and BD (r = -0.60) SR was found to have significant positive correlation with SOC (r=0.87) soil temperature (r=0.67) and AP (r=0.76) but significant inverse correlation with pH (r= -0.99). SOC was found to have significant positive correlation with TN (r=0.67) and AP (r=0.98) whereas significant inverse correlation with pH (r= -0.99) (Table 13).

Table 12: Correlation between different soil characteristics of Lengpui during 2016

	SM (n=10)	**SR (n=10)**	**SOC (n=10)**	**pH (n=3)**	**ST (n=3)**	**BD (n=3)**	**TN (n=3)**	**AP (n=3)**	**AK (n=3)**
SM	1.00	0.87*	0.81*	-0.98*	0.71*	-0.89*	0.26	-0.66*	-0.16
SR		1.00	0.99*	-0.75*	0.97*	-1.00*	-0.26	-0.95*	0.35
SOC			1.00	-0.68*	0.99*	-0.99*	-0.36	-0.98*	0.45
pH				1.00	-0.55	0.79*	-0.44	0.50	0.35
ST					1.00	-0.95*	-0.50	-1.00*	0.59
BD						1.00	0.21	0.93*	-0.30
TN							1.00	0.55	-0.99*
AP								1.00	-0.64*
AK									1.00

*: indicates significant at $p<0.05$

Kelsih (2016):

SM was found to have significant positive correlation with all the analyzed parameters SR (r = 0.99), SOC (r = 0.86), pH (r=0.86) soil temperature (r = 0.86), BD (r=0.86), TN (r=0.86), AP (r=0.86) and AK (r = 0.82). SR was found to have significant positive correlation with SOC (r=0.78), soil temperature (r=0.90), TN (r=0.99) and AP (r=0.73); whereas significant inverse correlation with pH (r= -0.91) and BD (r= -0.87). SOC was found to have significant positive correlation with TN (r=0.87), AP (r=1) and AK (r=0.90) (Table 14).

Table 13: Correlation between different soil characteristics of Kelsih during 2015

	SM (n=10)	SR (n=10)	SOC (n=10)	pH (n=3)	ST (n=3)	BD (n=3)	TN (n=3)	AP (n=3)	AK (n=3)
SM	1.00	0.93*	0.62*	-0.97*	0.90*	-0.60*	-0.16	0.46	0.82*
SR		1.00	0.87*	-0.99*	0.67*	-0.27	0.22	0.76*	0.55
SOC			1.00	-0.79*	0.21	0.25	0.67*	0.98*	0.06
pH				1.00	-0.77*	0.40	-0.08	-0.65*	-0.67*
ST					1.00	-0.90*	-0.58	0.02	0.99*
BD						1.00	0.88*	0.43	-0.95*
TN							1.00	0.80*	-0.69*
AP								1.00	-0.13
AK									1.00

*: indicates significant at $p<0.05$

Table 14: Correlation between different soil characteristics of Kelsih during 2016

	SM (n=10)	SR (n=10)	SOC (n=10)	pH (n=3)	ST (n=3)	BD (n=3)	TN (n=3)	AP (n=3)	AK (n=3)
SM	1.00	0.99*	0.86*	0.86*	0.86*	0.86*	0.86*	0.86*	0.86*
SR		1.00	0.78*	-0.91*	0.90*	-0.87*	0.99*	0.73*	0.43
SOC			1.00	-0.45	0.42	-0.37	0.87*	1.00*	0.90*
pH				1.00	-1.00*	1.00*	-0.83*	-0.38	-0.01
ST					1.00	-1.00*	0.82*	0.35	-0.02
BD						1.00	-0.79*	-0.30	0.07
TN							1.00	0.83*	0.56
AP								1.00	0.93*
AK									1.00

*: indicates significant at $p<0.05$

4.1.10 Soil C-storage

Soil C-storage ranged from 39.04 MgC/ha (winter) to 60.51 MgC/ha (rainy) in Lengpui. In Kelsih, it ranged from 39.49 MgC/ha to 70.04 MgC/ha. By comparing between different seasons, rainy season had maximum C-storage in both the study sites. There were increase on average soil C-storage in the later year in both the study sites (Table 15).

Table 15: Soil C-storage (MgC/ha) in Lengpui and Kelsih during 2015 and 2016

Seasons	**Lengpui**		**Kelsih**	
	2015	**2016**	**2015**	**2016**
Summer	41.11	49.52	39.49	40.51
Rainy	51.75	60.51	57.06	70.04
Winter	39.04	43.92	59.89	59.89
Average	43.96	51.31	52.14	56.81

4.1.11 Soil C-sequestration

The average soil C-sequestration in bamboo forest of Lengpui and Kelsih were 7.35 MgC/ha/yr and 4.67 MgC/ha/yr respectively during 2015 and 2016. By comparing between the two selected sites, *Melocanna baccifera* forest in Lengpui had higher rate of soil C-sequestration (Table 16).

Table 16: Average C-sequestration (MgC/ha/yr) of soil in Lengpui and Kelsih during 2015 and 2016

	Lengpui	**Kelsih**
C-sequestration	7.35	4.67

Photo plate 2: Bamboo stands of different species, (A) *Melocanna baccifera*, (B) *Bambusa tulda*, (C) *Dendrocalamus longispathus* and (D) *Melocalamus compactiflorus*

4.2 Bamboo

4.2.1 Culm density

Among the selected five bamboo species, *Melocanna baccifera* had the highest average culm densities followed by *Dendrocalamus longispathus* and the lest culm density was in *Melocalamus compactiflorus* (Table 17).

Table17: Culm density (culm/ha) along with standard error of different bamboo species during 2015 and 2016

Bamboo species	Site	2015				2016			
		1yr	2yr	≥3yr	Average	1yr	2yr	≥3yr	Average
Melocanna baccifera	Lengpui	6766 ±3.84	7133 ±7.22	14866 ±17.90	9588	6666 ±3.28	8133 ±3.93	27066 ±34.84	13955
Melocanna baccifera	Kelsih	7050 ±3.88	6750 ±9.12	14750 ±10.87	9516	13200 ±5.57	12665 ±7.87	17066 ±12.1	14310
Melocanna baccifera	Tamdil	5400 ±3.79	6810 ±7.28	10400 ±3.21	7536	7067 ±4.84	10800 ±5.20	12400 ±4.04	10089
Bambusa tulda	Lengpui	2600 ±2.89	3266 ±1.33	4266 ±2.91	3377	2266 ±1.85	3200 ±1.00	9933 ±3.18	5133
Dendrocalamus longispathus	Tuirial	3050 ±2.18	2150 ±2.84	8560 ±7.25	4586	4720 ±2.80	3600 ±3.61	12400 ±14.42	6906
Melocalamus compactiflorus	Darlawn	1400 ±1.00	1950 ±0.87	4500 ±3.21	2616	3466 ±2.73	3333 ±3.75	8266 ±6.70	5021

Melocanna baccifera

Lengpui:

The culm density ranged from 6666 culms/ha to 27066 culms/ha during two studied years. By comparing between different age classes, maximum culm density was ≥3yr age class whereas, minimum was 1yr age class (Table 17).

Analysis of variance indicates significant variations of culm density among the three age classes were ($F_{2,4}$=12.07; $P < 0.05$) and ($F_{2,4}$=26.42; $P < 0.01$) during 2015 and 2016 respectively; significant variation was also observed during the two study years ($F_{2,10}$=17.47; $P < 0.01$) (Appendix XXXIX).

The details of culm density of *Melocanna baccifera* in Lengpui, Kelsih and Tamdil are provided in appendix X.

Kelsih:

The culm density ranged from 6750 culms/ha to 14750 culms/ha during the study period. Maximum culm density was recorded in ≥3yr age class followed by 1yr age class and minimum culm density was 2yr age class (Table 17).

Analysis of variance indicates significant variation of culm density among the three age classes during 2015 ($F_{2,4}$=29.65; $P < 0.01$) and within the two studied years ($F_{2,10}$=20.69; $P < 0.01$) (Appendix XL).

Tamdil:

The culm density ranged from 5400 culm/ha to 12400 culm/ha during the studied period. By comparing between different age classes, maximum culm density was found in ≥3yr age class whereas, minimum was 1yr age class (Table 17).

Analysis of variance indicates significant variations of culm density among the three age classes during 2015 and 2016 were respectively ($F_{2,4}$=45.92; $P < 0.01$) and ($F_{2,4}$=266.45; $P < 0.01$) as well as within the two years was ($F_{2,10}$=58.81; $P < 0.01$) (Appendix XLI).

By comparing between the three study sites selected for *Melocanna baccifera*, culm density was higher during 2016 as compared to 2015. By comparing between different age classes, the highest culm density was observed in ≥3year age class of Lengpui (27066 culm/ha) and the lowest culm density was found in 1year age class of Tamdil (5400 culm/ha). The average culm density was highest in lengpui (9588 culm/ha) followed by Kelsih (9516 culm/ha) and minimum in Tamdil (7536 culm/ha) during 2015, whereas in 2016 the highest culm density was Kelsih (14310 culm/ha) followed by Lengpui (13955 culm/ha) and Tamdil (10089 culm/ha) (Table 17).

There was an overall increase of 13100 culms/ha in Lengpui, 14381 culms/ha in Kelsih and 7657 culm/ha in Tamdil in the second year of this study. The data indicates that the maximum increase in culm density of *Melocanna baccifera* was found in Kelsih and lowest in Tamdil site (Table 18).

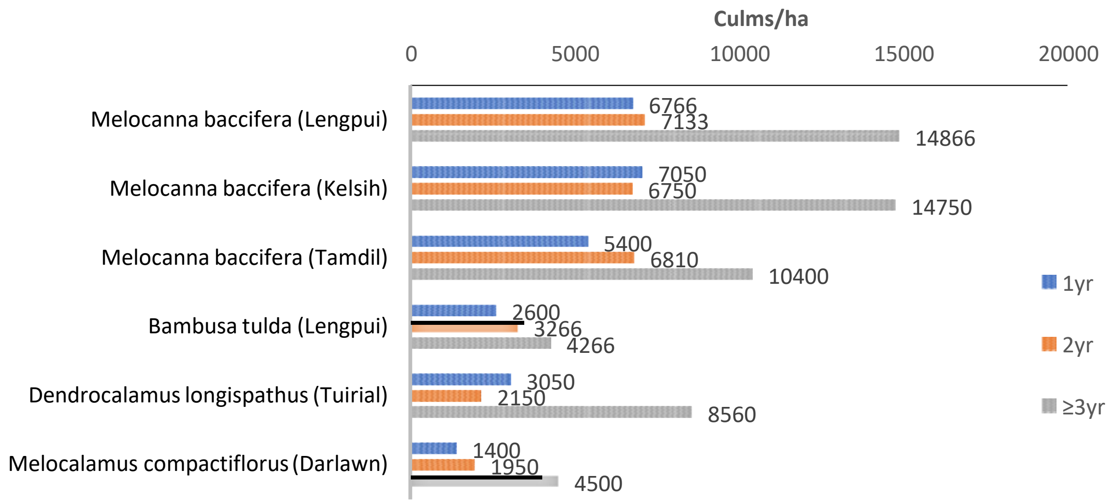

Figure 6: Culm density of different bamboo species during 2015

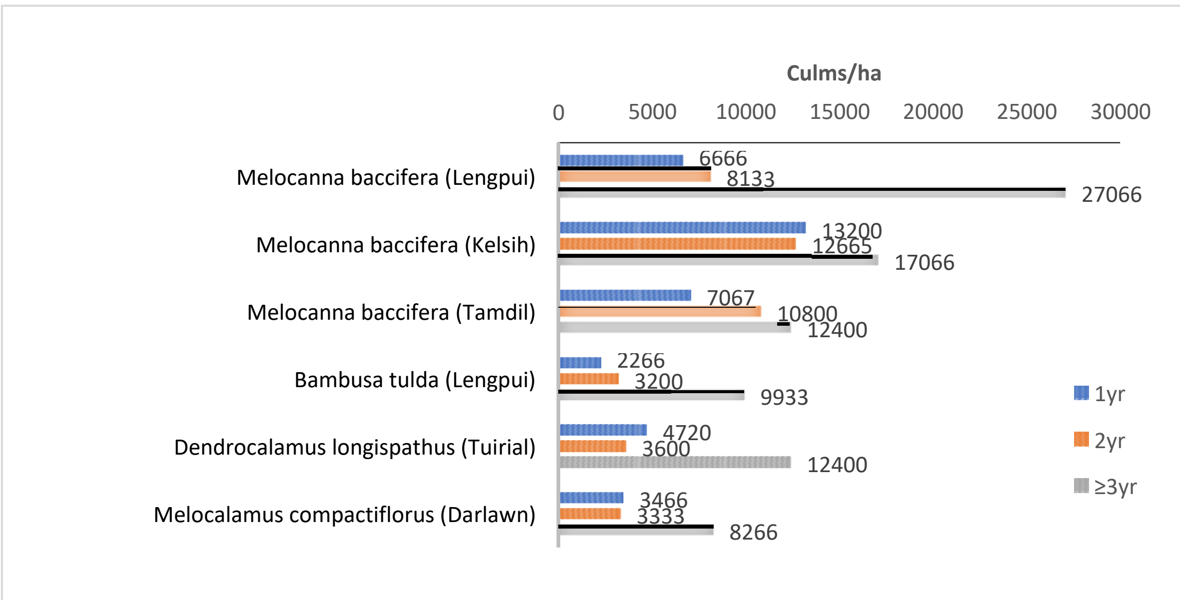

Figure 7: Culm density of different bamboo species during 2016

Bambusa tulda

The culm density in *Bambusa tulda* ranged from 2600 culm/ha to 9933 culm/ha during the studied years. By comparing between different age classes, ≥3year age had maximum culm density followed by 2year age class and the minimum was 1year age class (Table 17).

There were decreased of 334 culm/ha and 66 culm/ha respectively in 1year age class and 2year old age class in the later year (2016) but 5667 culm/ha was found increased in ≥3year old age class. The overall increase of culm density was 5267culm/ha, which was mainly contributed from ≥3year age class (Table 18). Details are provided in appendix XI.

Analysis of variance showed significant variation among different age classes during 2016 was ($F_{2,4}$=787.4; P < 0.01), there was no significant variation during 2015. Whereas within 2015 and 2016 significant variation was ($F_{2,10}$=10.45; P < 0.01) (Appendix XLII).

Dendrocalamus longispathus

Culm density ranged from 2150 culm/ha to 12400 culm/ha during the studied years. By comparing between different age classes, ≥3year age class had maximum culm density followed by 1year age class and minimum was recorded in 2year age class (Table 17).

During the two study years, there were increase of 1670 culm/ha in 1year age class, 1450 culm/ha in 2year old age class and 3840 culm/ha in ≥3year old age class. The overall increase was 6960 culm/ha of which ≥3year old age class contributed maximum (3840 culm/ha) culms followed by 1year old age class (1670 culm/ha) (Table 18). Detailts are provided in appendix XI.

Analysis of variance showed significant variations of culm density among different age classes were ($F_{2,4}$=56.97; P < 0.01), ($F_{2,4}$=29.79; P < 0.01) and ($F_{2,5}$=60.16; P < 0.01) during 2015, 2016 and within the two years respectively (Appendix XLIII).

Melocalamus compactiflorus

Culm density ranged from 1400 culm/ha to 8266 culm/ha during the two studied years. By comparing between different age classes, ≥3year age class had maximum culm density followed by 2year age class and the minimum was 1year age class (Table 17).

There was an overall increase of 7215 culm/ha, in which ≥3year old age class (3766 culm/ha) contributed maximum followed by 1year old age class (2066 culm/ha) and 2year old age class (1383 culm/ha) (Table 18). Detailts are provided in appendix XI.

There were significant variations of culm density between different age classes during 2015 ($F_{2,4}$=70.85; $P < 0.01$) and in 2016 ($F_{2,4}$=38.32; $P < 0.01$) as well as within these two years ($F_{2,10}$=39.77; $P < 0.01$) (Appendix XLIV).

Culm densities of all the studied bamboos were observed to have a pattern of ≥3year age class > 2year age class > 1year age class except in *Dendrocalamus longispathus* where the culm density of 1year old age class was higher than that of 2year old age class in both the study years (Figures 5 and 6).

Table 18: Net changes in culm density (culm/ha) of different bamboo species in different age classes during 2015 to 2016

Bamboo species	**Site**	**1yr**	**2yr**	**≥3yr**	**Net change**
Melocanna baccifera	Lengpui	-100	1000	12200	13100
Melocanna baccifera	Kelsih	6150	5915	2316	14381
Melocanna baccifera	Tamdil	1667	3990	2000	7657
Bambusa tulda	Lengpui	-334	-66	5667	5267
Dendrocalamus longispathus	Tuirial	1670	1450	3840	6960
Melocalamus compactiflorus	Darlawn	2066	1383	3766	7215

4.2.2 DBH

Melocanna baccifera

In Lengpui, mean DBH ranged from 2.32 cm to 3.9 cm during 2015 and 2016; it was ranged from 3.1cm to 3.6 cm in Kelsih. By comparing between three sites selected for *Melocanna baccifera*, maximum DBH was found in Tamdil which ranged from 4.5cm to 5.7cm (Table 19). Details are provided in appendix XII.

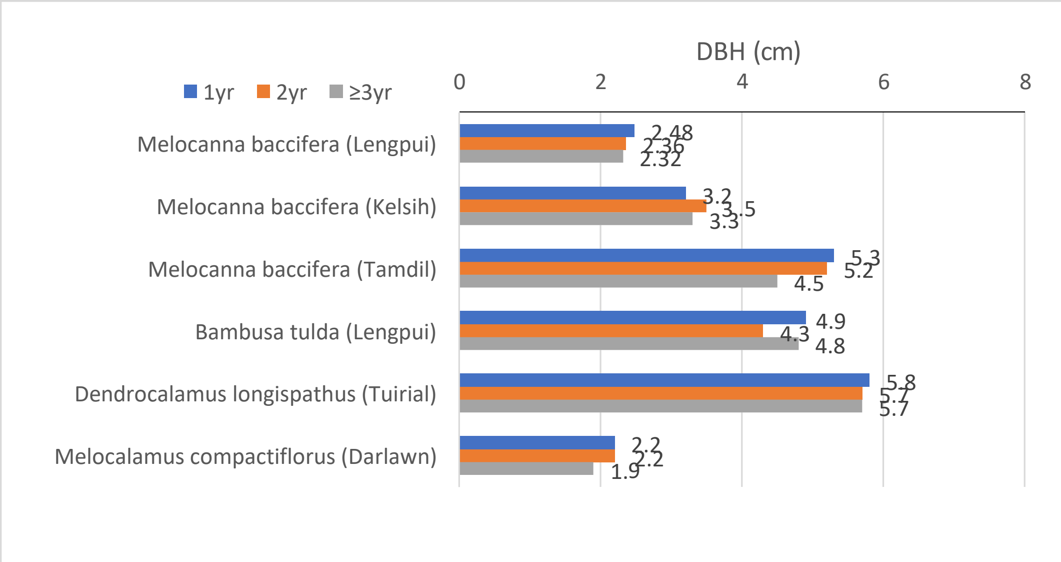

Figure 8: DBH of different bamboo species during 2015

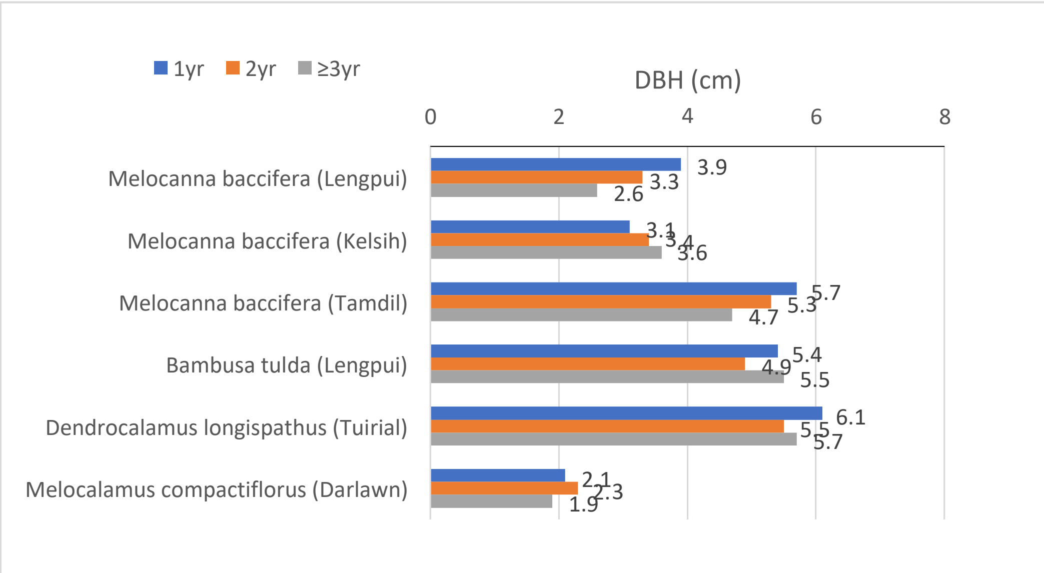

Figure 9: DBH of different bamboo species during 2016

Table 19: Mean DBH (cm) of different age classes of bamboo species along with standard error in different sites during 2015 and 2016

Bamboo species	Site	2015			2016		
		1yr	2yr	≥3yr	1yr	2yr	≥3yr
Melocanna baccifera	Lengpui	2.5±0.14	2.3±0.11	2.3±0.44	3.9±0.15	3.3±0.15	2.6±0.36
Melocanna baccifera	Kelsih	3.2±0.12	3.5±0.26	3.3±0.21	3.1±0.10	3.4±0.20	3.6±0.12
Melocanna baccifera	Tamdil	5.3±0.26	5.2±0.23	4.5±0.17	5.7±0.17	5.3±0.26	4.7±0.15
Bambusa tulda	Lengpui	4.9±0.30	4.3±0.25	4.8±0.25	5.4±0.31	4.9±0.23	5.5±0.10
Dendrocalamus longispathus	Tuirial	5.8±0.15	5.7±0.15	5.7±0.12	6.1±0.21	5.5±0.25	5.7±0.21
Melocalamus compactiflorus	Darlawn	2.2±0.06	2.2±0.15	1.9±0.10	2.1±0.12	2.3±0.06	1.9±0.06

Bambusa tulda

The mean DBH ranged from 4.3 cm to 5.5 cm during the studied two years. By comparing between different age classes, DBH was maximum with 1year age class during 2015; whereas ≥3year age class greater during 2016 (Table 19). Details are provided in appendix XII.

Dendrocalamus longispathus

The mean DBH ranged from 5.5 cm to 6.1 cm during the two studied years. 1year age class culms were found to have greater mean DBH in both the study years (Table 19). Details are provided in appendix XII.

Melocalamus compactiflorus

Mean DBH ranged from 1.9 cm to 2.3 cm during 2015 and 2016. By comparing between different age classes, ≥3year age class was recorded minimum DBH during both the studied years (Table 19). Details are provided in appendix XII.

There was significant variation within the two years ($F_{2,10}$=6.03; P= 0.01) (Appendix XLVI).

By comparing between DBHs of four studied bamboo species, maximum was recorded in *Dendrocalamus longispathus* during both 2015 and 2016 and minimum DBH was recorded in *Melocalamus compactiflorus*. Significant variations of DBH were found among the four selected bamboo species during 2015 ($F_{17,34}$=44.04; $P< 0.01$) and in 2016 ($F_{17,34}$=52.37; $P<0.01$) and within the two years ($F_{17,85}$=76.73; $P<0.01$).

Photo plate 3: Field work, (A) Identifying different age classes of bamboo, (B) Recording DBH, (C) Measuring the sample weight and (D) Excavation of rhizome (*Melocanna baccifera*)

4.2.3 C-content

Melocanna baccifera

Lengpui:

C-content of different components of bamboo ranged from 29.72% to 46.56% during the two studied years. Among the components, 2year old branch (46.56%) recorded highest C-content followed by ≥3year old leaf (45.90%) and lowest was recorded in sheath (29.72%) (Table 20).

By comparing between the age classes, ≥3year old age class had highest average C-content (44.02%) followed by 2year old age class (42.15%) and 1year age class (35.93%). Overall component-wise C-content were culm (25.7%), branch (19.66%), rhizome (27.73%) and sheath (6.56%) (Appendix XIII).

Kelsih:

C-content in different components ranged from 29.46% (sheath) to 44.80% (leaf, ≥3year) during the two studied years (Table 20).

By comparing between different age classes, ≥3year old age class had highest average C-content (43.3%) followed by 2year old age class (40.26%) and 1year age class (36.39%). Overall component-wise contribution in percentage (%) of C-content were culm (27.03%), branch (18.62%), rhizome (28.72%) and sheath (6.64%) (Appendix XIII).

Tamdil:

C-content in different components ranged from 29.65% (sheath) to 44.90% (branch, ≥3year) during the two studied years (Table 20).

By comparing between different age classes, ≥3year old age class had highest average C-content (43.35%) followed by 2year old age class (40.95%) and 1year age class (36.5%). Overall component-wise contribution in percentage (%) of C-content were culm (26.78%), branch (18.95%), rhizome (28.99%) and sheath (6.63%) (Appendix XIII).

In *Melocanna baccifera,* C-content (%) was following a pattern of ≥3year old age class > 2year old age class > 1year age class and rhizome component had the highest C-content in all the selected three study sites (Appendix XIII).

Bambusa tulda

The C-content of different components ranged from 30.14% (sheath) to 54.75% (branch, 2year age class) (Table 20).

By comparing between different age classes, 2year old age class had highest average C-content (49.44%) followed by ≥3year old age class (49.25%) and 1year age class (39.32%). Overall component-wise contribution in percentage (%) of C-content were culm (39.58%), branch (28.35%), leaf (24.01%) and sheath (8.04%) (Appendix XIII).

Dendrocalamus longispathus

The C-content in different components ranged from 29.14% (sheath) to 44.50% (culm, 1year age class).

By comparing between different age classes, ≥3year old age class had highest average C-content (42.85%) followed by 2year old age class (40.96%) and 1year age class (39.7%). Overall component-wise contribution in percentage (%) of C-content were culm (31.30%), branch (31.29%), leaf (30.29%) and sheath (7.10%) (Appendix XIII).

The C-content of *Melocalamus compactiflorus* could not be carried out due to unavoidable circumstances. Therefore, while calculating C-storage, 40% of the biomass was considered as average C-content (%).

Table 20: Component-wise average C-content (%) of different bamboo species along with standard error

Bamboo species	Site	Age class	Culm	Branch	Leaf	Rhizome	Sheath
Melocanna baccifera	Lengpui	1yr	36.71 ±0.94	-	-	41.37 ±0.58	29.72 ±0.56
		2yr	36.63 ±1.10	46.56 ±1.08	43.08 ±0.56	42.36 ±0.37	-
		≥3yr	43.0 ±0.56	45.40 ±1.33	45.90 ±0.74	41.80 ±0.38	-
Melocanna baccifera	Kelsih	1yr	38.35 ±1.05	-	-	41.38 ±0.56	29.46 ±0.80
		2yr	39.50 ±0.41	39.25 ±0.84	39.30 ±0.83	43.02 ±0.57	-
		≥3yr	42.05 ±1.16	43.35 ±0.50	44.80 ±1.04	43.00 ±0.08	-
Melocanna baccifera	Tamdil	1yr	36.35 ±0.99	-	-	43.50 ±0.33	29.65 ±0.73
		2yr	39.80 ±0.75	39.75 ±0.70	39.75 ±0.87	44.50 ±0.48	-
		≥3yr	43.50 ±0.51	44.90 ±0.31	43.50 ±0.66	41.50 ±0.49	-
Bambusa tulda	Lengpui	1yr	48.5 ±0.84	-	-	-	30.14 ±1.33
		2yr	47.82 ±0.83	54.75 ±0.97	45.75 ±1.08	-	-
		≥3yr	52.0 ±1.42	51.50 ±1.06	44.25 ±1.66	-	-
Dendrocalamus longispathus	Tuirial	1yr	44.50 ±1.48	43.56 ±0.43	41.60 ±0.90	-	29.14 ±1.16
		2yr	39.58 ±1.37	40.72 ±1.07	42.60 ±2.15	-	-
		≥3yr	44.35 ±0.80	44.11 ±1.12	40.11 ±1.32	-	-

Photo plate 4: Bamboo sub-samples in the laboratory, (A) Culms of *Dendrocalamus longispathus,* (B) Culms of *Melocanna baccifera*, (C) Fresh culms of *Bambusa tulda* before oven dry, (D) Oven dried culms of *Bambusa tulda*, (E) Collected culms and rhizomes of *Melocanna baccifer* and (F) Leave samples in oven

4.2.4 Biomass

Melocanna baccifera

Lengpui:

The total biomass (above and belowground) during 2015 was 36.92 Mg/ha. 1year age class contributed 6.63 Mg/ha, 2year old age class and ≥3year old age classes contributed 10.46 Mg/ha and 19.83 Mg/ha respectively. In 2016, the total biomass was 47.99 Mg/ha; 1year age class, 2year old age class and ≥3year old age classes contributed 10.89Mg/ha, 17.51Mg/ha and 19.59 Mg/ha respectively (Table 21)

By comparing between different components, the culm (24.1Mg/ha) had highest biomass accumulation followed by rhizome (8.24Mg/ha), branch (2.21Mg/ha), leaf (2Mg/ha) and sheath (0.37Mg/ha) during 2015. Also, in 2016 the culm component (30.01Mg/ha) had highest biomass content which was followed by rhizome (11.88Mg/ha), leaf (2.97Mg/ha), branch (2.79Mg/ha) and sheath (0.34Mg/ha) (Table 21).

There were significant variations of the biomass between different age classes in 2015 ($F_{2,4}$=351.96; P< 0.01) and in 2016 ($F_{2,4}$=112.6; P< 0.01) and within two years ($F_{2,10}$=40.57; P<0.01). Details are provided in appendix XIV.

Kelsih:

In 2015, the total biomass was recorded 96.24 Mg/ha. 1year age class contributed 13.01Mg/ha, 2year old age class and ≥3year old age classes contributed 33.62Mg/ha and 49.61Mg/ha respectively. In 2016, the total biomass was 117.31Mg/ha; 1year, 2year and ≥3year old age classes contributed 16.35Mg/ha, 42.85Mg/ha and 58.11Mg/ha respectively.

By comparing among different components, the culm (55.65Mg/ha) had highest biomass content followed by rhizome (16.24Mg/ha), leaf (12.46Mg/ha), branch (10.77Mg/ha) and sheath (1.12Mg/ha) during 2015. In 2016, the culm component (75.39Mg/ha) had the highest biomass followed by rhizome (18.98Mg/ha), leaf (10.98Mg/ha), branch (10.25Mg/ha) and sheath (1.71Mg/ha) (Table 21).

There were significant variations among the three age classes during 2015 ($F_{2,4}$=196.2; P< 0.01) and 2016 ($F_{2,4}$=1919; P< 0.01) and within the two years ($F_{2,10}$=429.79; P< 0.01). Details are provided in appendix XV.

Tamdil:

The total biomass during 2015 was 85.64Mg/ha. 1year old age class contributed 16.63Mg/ha, 2year and ≥3year old age classes contributed 34.65Mg/ha and 34.36Mg/ha respectively. In 2016, the total biomass was found 178.72Mg/ha; 1year, 2year and ≥3year old age classes contributed 46.66Mg/ha, 79.09Mg/ha and 52.97Mg/ha respectively. By comparing between different components, the culm (55.65Mg/ha) had highest biomass content followed by rhizome (16.47Mg/ha), leaf (7.3Mg/ha), branch (5.62Mg/ha) and sheath (0.6Mg/ha) during 2015. Also, during 2016 the culm component (141.45Mg/ha) had the highest biomass content followed by rhizome (20.18Mg/ha), leaf (8.42Mg/ha), branch (7.12Mg/ha) and sheath (1.55Mg/ha) (Table 21).

There were significant variations among the three age classes during 2015 ($F_{2,4}$=7049.53; P< 0.01) and 2016 ($F_{2,4}$=321.18; P< 0.01) and within the two years ($F_{2,10}$=18.58; P< 0.01). Details are provided in appendix XVI.

By comparing between the three sites selected for *Melocanna baccifera*, minimum biomass content was recorded in Lengpui during this study period and maximum biomass content was recorded in Kelsih during 2015 whereas during 2016 Tamdil recorded maximum (Table 21). There were significant variations of biomass accumulation in *Melocanna baccifera* among the three different sites during 2015 ($F_{8,16}$=430.37; P< 0.01) and 2016 ($F_{8,16}$=1451; P< 0.01) and within the two years of study period ($F_{8,40}$=29.60; P< 0.01)

By comparing between the components, maximum biomass was recorded in culm component and minimum in sheath component in all the three sites. By comparing between the three age classes, it was observed that the maximum total biomass was found in the ≥3year old age class followed by 2year old age class and the minimum in 1year old age class in both the years. However, in Tamdil the 2year old age class showed more biomass than that of ≥3year old age class in 2016 (Table 21).

21: Total biomass (aboveground and belowground) (Mg/ha) of *Melocanna baccifera* in three study sites during 2015 and 2016

Site	Age class	2015						2016					
		Culm	Branch	Leaf	Rhizome	Sheath	Total	Culm	Branch	Leaf	Rhizome	Sheath	Total
Lengpui	1yr	4.00 ±0.37	-	-	2.26 ±0.12	0.37±0.04	**6.63**	7.76±0.69	-	-	2.79 ±0.34	0.34 ±0.04	**10.89**
	2yr	6.20 ±0.40	1.40 ±0.25	0.96 ±0.13	1.90 ±0.32	-	**10.46**	11.02±0.48	1.62 ±0.27	2.27 ±0.14	2.60 ±0.32	-	**17.51**
	≥3yr	13.90 ±0.60	0.81 ±0.07	1.04 ±0.05	4.08 ±0.09	-	**19.83**	11.23±0.19	1.17 ±0.08	0.70 ±0.02	6.49 ±0.70	-	**19.59**
	Total	**24.1**	**2.21**	**2**	**8.24**	**0.37**	**36.92**	**30.01**	**2.79**	**2.97**	**11.88**	**0.34**	**47.99**
Kelsih	1yr	7.74 ±0.32	-	-	4.15 ±0.25	1.12 ±0.08	**13.01**	11.28±0.24	-	-	3.36 ±0.18	1.71 ±0.24	**16.35**
	2yr	19.67 ±0.48	3.47 ±0.28	5.83 ±0.63	4.65 ±0.33	-	**33.62**	28.87±0.74	2.91 ±0.31	5.95 ±0.44	5.12 ±0.10	-	**42.85**
	≥3yr	28.24 ±0.81	7.30 ±0.21	6.63 ±0.25	7.44 ±0.36	-	**49.61**	35.24±0.37	7.34 ±0.26	5.03 ±0.25	10.50 ±0.46	-	**58.11**
	Total	**55.65**	**10.77**	**12.46**	**16.24**	**1.12**	**96.24**	**75.39**	**10.25**	**10.98**	**18.98**	**1.71**	**117.31**
Tamdil	1yr	11.28 ±0.26	-	-	4.75 ±0.31	0.60 ±0.06	**16.63**	39.46±0.60	-	-	5.65 ±0.20	1.55 ±0.16	**46.66**
	2yr	21.55 ±0.24	2.92 ±0.23	4.18 ±0.07	6.00 ±0.10	-	**34.65**	59.77±0.84	4.80 ±0.36	7.18 ±0.09	7.34 ±0.13	-	**79.09**
	≥3yr	22.82 ±0.35	2.70 ±0.29	3.12 ±0.04	5.72 ±0.11	-	**34.36**	42.22±0.46	2.32 ±0.20	1.24 ±0.12	7.19 ±0.03	-	**52.97**
	Total	**55.65**	**5.62**	**7.3**	**16.47**	**0.6**	**85.64**	**141.45**	**7.12**	**8.42**	**20.18**	**1.55**	**178.72**

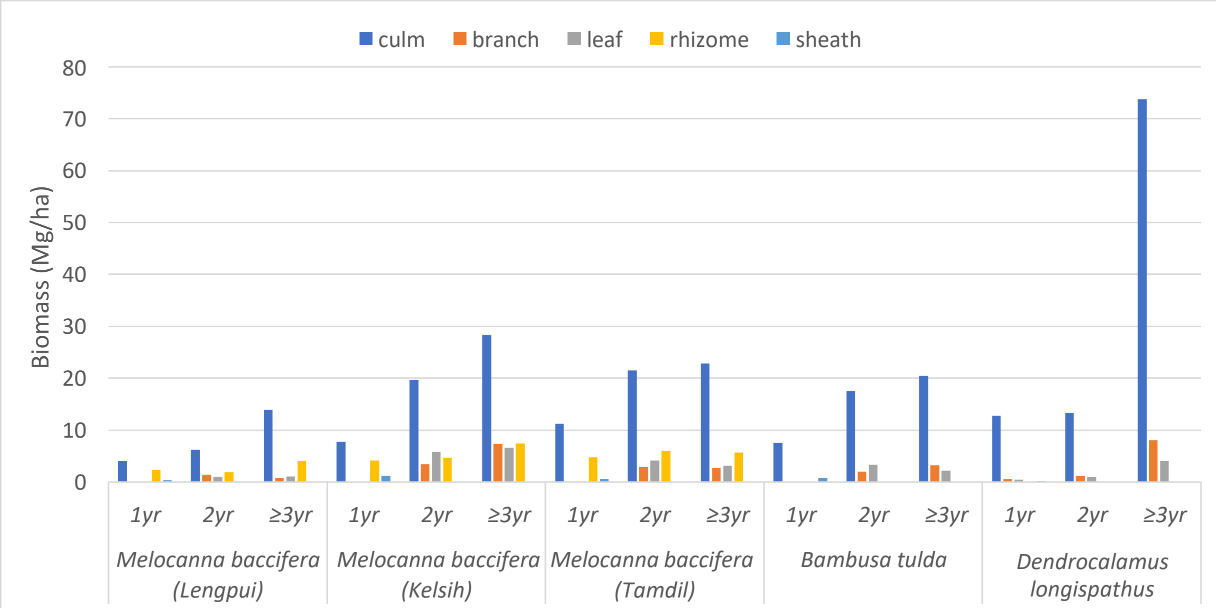

Figure 10: Biomass (Mg/ha) of different components in different bamboo species in 2015

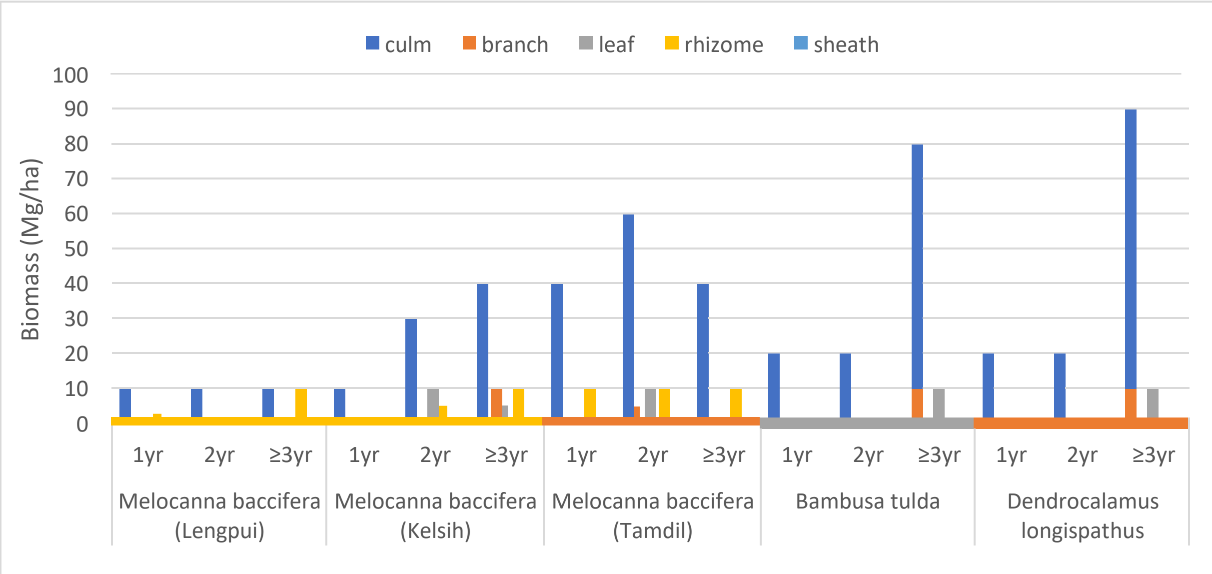

Figure 11: Biomass (Mg/ha) of different components in different bamboo species in 2016

Table 22: Aboveground biomass (Mg/ha) of *Bambusa tulda* and *Dendrocalamus longispathus* during 2015 and 2016

Bamboo	Site	Age class	2015					2016				
			Culm	Branch	Leaf	Sheath	Total	Culm	Branch	Leaf	Sheath	Total
Bambusa tulda	Lengpui	1yr	7.55 ±0.22	-	-	0.71 ±0.02	**8.26**	15.89±0.62	-	-	0.84 ±0.03	**16.73**
		2yr	17.52 ±0.23	2.04 ±0.06	3.33 ±0.26	-	**22.89**	18.50±0.57	1.4 ±0.06	2.05 ±0.13	-	**21.95**
		≥3yr	20.44 ±0.55	3.25 ±0.11	2.18 ±0.10	-	**25.87**	75.32±1.44	7.65 ±0.11	5.38 ±0.43	-	**88.35**
		Total	**45.51**	**5.29**	**5.51**	**0.71**	**57.02**	**109.71**	**9.05**	**7.43**	**0.84**	**127.03**
Dendrocalamus longispathus	Tuirial	1yr	12.78 ±0.55	0.53 ±0.12	0.41 ±0.02	0.14 ±0.02	**13.86**	20.48±0.51	0.78 ±0.05	0.67 ±0.05	0.20 ±0.02	**22.13**
		2yr	13.25 ±0.49	1.12 ±0.05	0.98 ±0.06	-	**15.35**	20.01±0.77	2.01 ±0.07	1.04 ±0.06	-	**23.06**
		≥3yr	73.78 ±1.07	8.01 ±0.09	4.08 ±0.09	-	**85.87**	90.52±1.30	8.96 ±0.26	5.33 ±0.29	-	**104.81**
		Total	**99.81**	**9.66**	**5.47**	**0.14**	**115.08**	**131.01**	**11.75**	**7.04**	**0.2**	**150**

Bambusa tulda

In 2015, the aboveground biomass was found 57.02Mg/ha. 1year old age class contributed 8.26Mg/ha, 2year and ≥3year old age classes contributed 22.89Mg/ha and 25.87Mg/ha respectively. In 2016, the aboveground biomass was found 127.03Mg/ha; 1year, 2year and ≥3year old age classes contributed 16.73Mg/ha, 21.95Mg/ha and 88.35Mg/ha respectively. The ≥3year old age class had the maximum and the 1year old age class had minimum aboveground biomass during both study years (Table 22).

By comparing among different components, biomass content was highest in the culm component (45.51Mg/ha) followed by leaf (5.51Mg/ha), branch (5.29Mg/ha) and sheath (0.71Mg/ha) during 2015. Whereas in 2016, the culm (109.71Mg/ha) followed by branch (9.05Mg/ha), leaf (7.43Mg/ha) and sheath (0.84Mg/ha).

Aboveground biomass in *Bambusa tulda* was found to have significant variations among the different age classes, during 2015 ($F_{2,4}$=221.44; P< 0.01) and 2016 ($F_{2,4}$=745.44; P< 0.01) and within the two years ($F_{2,10}$=9.28; P< 0.01). Details are provided in appendix XVII.

Dendrocalamus longispathus

In 2015, the total aboveground biomass was found 115.08Mg/ha. 1year age class contributed 13.86Mg/ha, 2year and ≥3year old age classes contributed 15.35Mg/ha and 85.87Mg/ha respectively. In 2016, the aboveground biomass was recorded 150Mg/ha; 1year, 2year and ≥3year old age classes contributed 22.13Mg/ha, 23.06Mg/ha and 104.81Mg/ha respectively. The ≥3year old age class had maximum and the 1year old age class had minimum aboveground biomass during both studied years (Table 22).

By comparing between different components, the culm component (99.81Mg/ha) recorded the maximum biomass followed by branch (9.66Mg/ha), leaf (5.47Mg/ha) and the sheath (0.14Mg/ha) during 2015. Also, in 2016 the culm component (131.01Mg/ha) had the highest aboveground biomass followed by branch (11.75Mg/ha), leaf (7.04Mg/ha) and sheath (0.2Mg/ha) (Table 22).

Aboveground biomass in *Dendrocalamus longispathus* was found to have significant variations among the different age classes, during 2015 ($F_{2,4}$=10115.55; P< 0.01) and 2016 ($F_{2,4}$=2162.71; P< 0.01) and within the two years ($F_{2,10}$=874.88; P< 0.01). Details are provided in appendix XVIII.

Melocalamus compactiflorus

In 2015, the total aboveground biomass was found 34.28 Mg/ha. 1year age class contributed 3 Mg/ha, 2year and ≥3year old age classes contributed 10.81 Mg/ha and 20.47 Mg/ha respectively. In 2016, the aboveground biomass was recorded 89.18 Mg/ha; 1year, 2year and ≥3year old age classes contributed 4.89 Mg/ha, 25.57 Mg/ha and 58.72 Mg/ha respectively (Table 23).

By comparing between different age classes, maximum aboveground biomass was recorded in ≥3year old age class in both years with 20.47 Mg/ha and 58.72 Mg/ha during 2015 and 2016 respectively. The minimum was recorded in 1year old age class with 3Mg/ha and 4.89 Mg/ha respectively during 2015 and 2016. In all the three age classes, the maximum biomass was found in culm+ branch component for both study years (Table 23).

Aboveground biomass in *Melocalamus compactiflorus* was found to have significant variations among the different age classes, during 2015 ($F_{6,12}$=561.42; P< 0.01) and 2016 ($F_{6,12}$=1727.52; P< 0.01) and within the two years ($F_{6,30}$=29.12; P< 0.01). Details are provided in appendix XIX.

Table 23: Aboveground biomass (Mg/ha) of *Melocalamus compactiflorus* during 2015 and 2016

Age class	2015				2016			
	Culm+ Branch	**Leaf**	**Sheath**	**Total**	**Culm+ Branch**	**Leaf**	**Sheath**	**Total**
1yr	2.59 ±0.29	0.06 ±0.01	0.35 ±0.02	**3**	3.02 ±0.12	1.42 ±0.18	0.45 ±0.03	**4.89**
2yr	9.55 ±0.48	1.26 ±0.07	0	**10.81**	16.67 ±0.51	8.9 ±0.27	0	**25.57**
≥3yr	18.9 ±0.41	1.57 ±0.24	0	**20.47**	44.44 ±0.66	14.28 ±0.16	0	**58.72**
Total	**31.04**	**2.89**	**0.35**	**34.28**	**64.13**	**24.6**	**0.45**	**89.18**

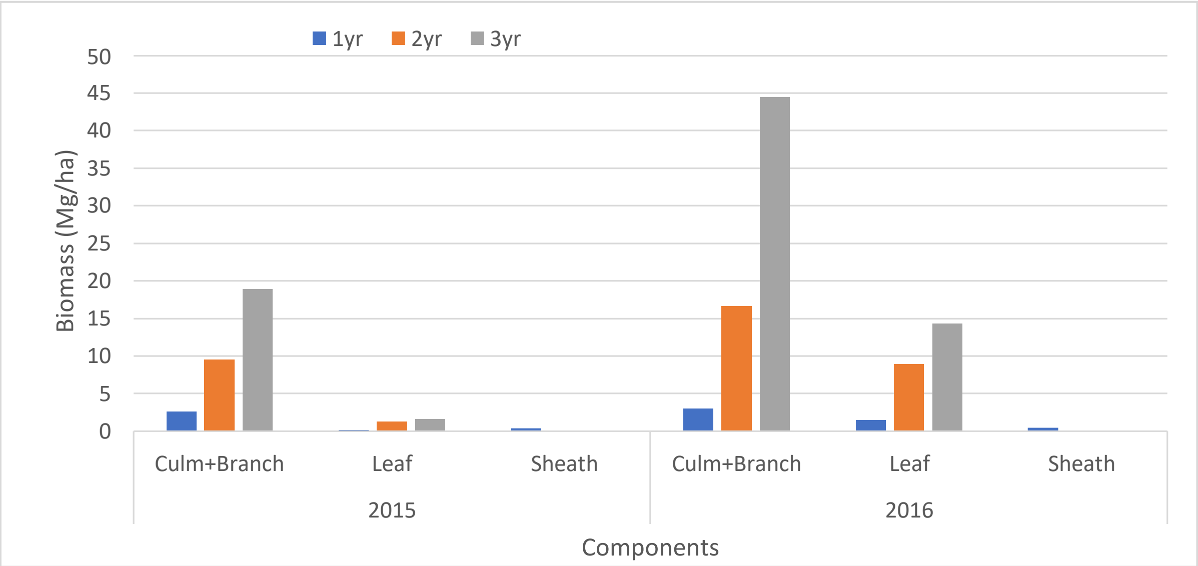

Figure 12: Biomass (Mg/ha) of different components in *Melocalamus compactiflorus* during 2015 and 2016

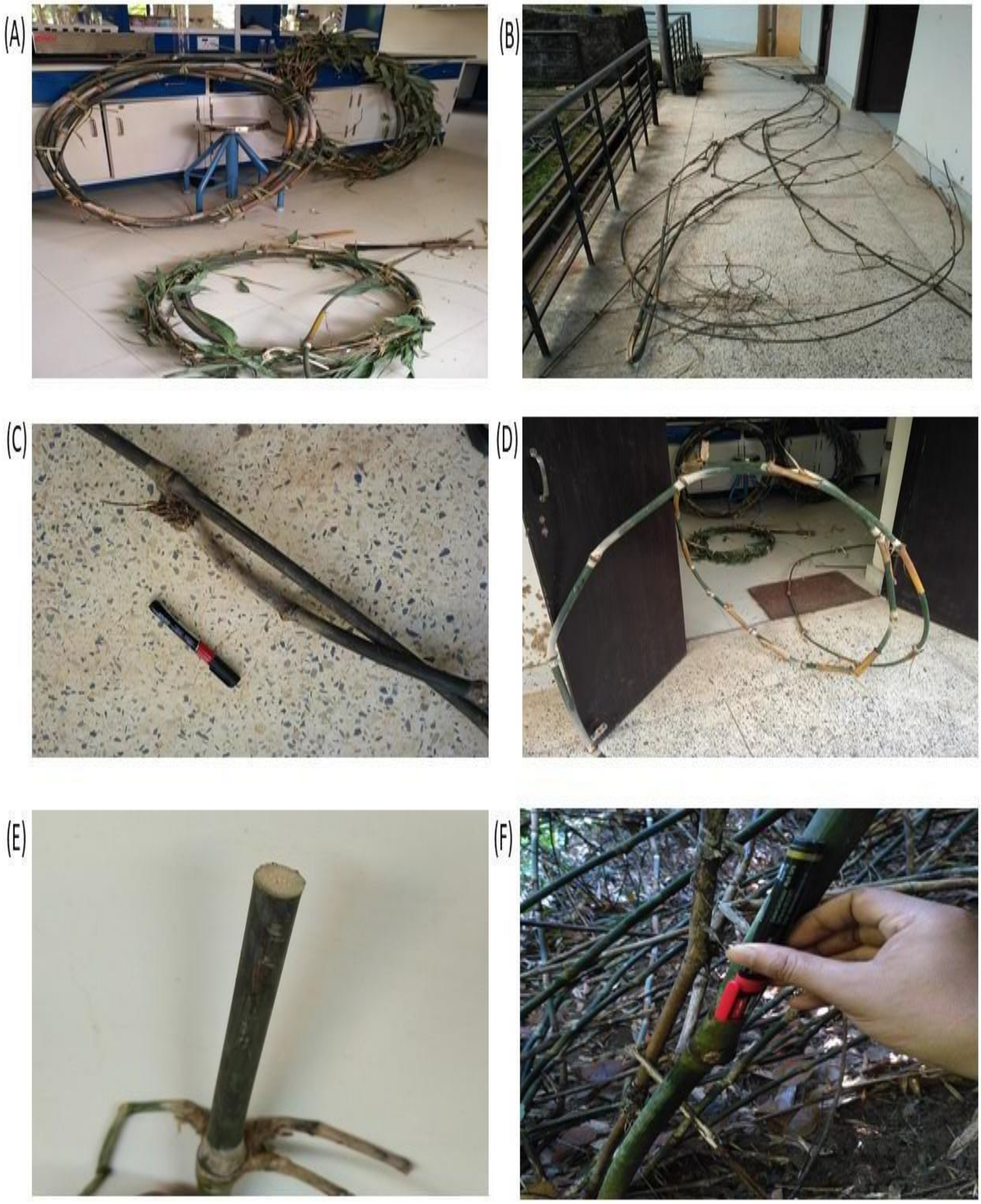

Photo plate 5: *Melocalamus compactiflorus,* (A) Samples in the laboratory, (B) A single culm (≥3year age class), (C) Junction between culm and branch, (D) 1year age class culm, (E) Cross-section of culm and (F) A matured culm in the field

4.2.5 C-stock

Melocanna baccifera

Lengpui:

In Lengpui the total C-stock of *Melocanna baccifera* was 15.15 MgC/ha during 2015. The maximum C-stock was found in ≥3year old age class (8.64 MgC/ha) followed by 2year old age class (4 MgC/ha) and minimum in 1year age class (2.51 MgC/ha) during 2015. In 2016, the total C-stock was 19.33 MgC/ha. The ≥3year old age class had maximum C-stock (8.22 MgC/ha) followed by 2year old age class (7.01 MgC/ha) and minimum in 1year old age class (4.1 MgC/ha).

By comparing between different components, during 2015 the culm (9.5 MgC/ha) had maximum C-stock followed by rhizome (3.56 MgC/ha), branch (1.08 MgC/ha), leaf (0.9 MgC/ha) and sheath (0.11 MgC/ha); during2016, maximum was recorded in culm (12.06 MgC/ha) followed by rhizome (4.82 MgC/ha), leaf (1.17 MgC/ha), branch (1.16 MgC/ha) and sheath (0.12 MgC/ha) (Table 24).

Kelsih:

In Kelsih, the total C-stock of *Melocanna baccifera* during 2015 was 38.98 MgC/ha. The maximum C-stock was found in ≥3year old age class (21.01 MgC/ha) followed by 2year old age class (13.11 MgC/ha) and minimum in 1year age class (4.86 MgC/ha). In 2016 the total C-stock was 48.8 MgC/ha. The ≥3year old age class had maximum C-stock (24.97 MgC/ha) followed by 2year old age class (17.51 MgC/ha) and minimum in 1year age class (6.32 MgC/ha) (Table 24).

By comparing among different components, during 2015 the culm (21.91MgC/ha) had maximum C-stock followed by rhizome (6.89 MgC/ha), leaf (5.33 MgC/ha), branch (4.52 MgC/ha), and sheath (0.33 MgC/ha) in 2015. In 2016, maximum was culm (31.33MgC/ha) followed by rhizome (8.12 MgC/ha), leaf (4.53 MgC/ha), branch (4.31 MgC/ha) and sheath (0.51 MgC/ha) (Table 24).

Tamdil:

In Tamdil, the total C-stock of *Melocanna baccifera* during 2015 was 35.49 MgC/ha. The maximum C-stock was found in ≥3year old age class (15.06 MgC/ha) followed by 2year old age class (13.91 MgC/ha) and minimum in 1year age class (6.52 MgC/ha). In 2016, the total C-stock was 71.82 MgC/ha. The 2year old age class had maximum C-stock (32.1 MgC/ha) followed by ≥3year old age class (22.58 MgC/ha) and minimum in 1year age class (17.14 MgC/ha) (Table24).

By comparing among different components, the culm (22.88 MgC/ha) had maximum C-stock followed by rhizome (7.12 MgC/ha), leaf (2.94 MgC/ha), branch (2.38 MgC/ha), and sheath (0.17 MgC/ha) in 2015. In 2016 maximum was culm (56.25 MgC/ha) followed by rhizome (8.65 MgC/ha), leaf (3.48 MgC/ha), branch (2.98 MgC/ha) and sheath (0.46 MgC/ha) (Table 24).

Table 24: C-stock (MgC/ha) in different components of different bamboo species during 2015 and 2016

Bamboo	Site	Age class	2015						2016					
			Culm	**Branch**	**Leaf**	**Rhizome**	**Sheath**	**Total**	**Culm**	**Branch**	**Leaf**	**Rhizome**	**Sheath**	**Total**
Melocanna baccifera	Lengpui	1yr	1.46	-	-	0.94	0.11	**2.51**	2.84	-	-	1.14	0.12	4.1
		2yr	2.06	0.7	0.4	0.84	-	**4**	4.4	0.66	0.86	1.09	-	7.01
		≥3yr	5.98	0.38	0.5	1.78	-	**8.64**	4.82	0.5	0.31	2.59	-	8.22
		Total	**9.5**	**1.08**	**0.9**	**3.56**	**0.11**	**15.15**	**12.06**	**1.16**	**1.17**	**4.82**	**0.12**	**19.33**
Melocanna baccifera	Kelsih	1yr	2.84	-	-	1.69	0.33	**4.86**	4.4	-	-	1.41	0.51	6.32
		2yr	7.47	1.33	2.31	2	-	**13.11**	11.83	1.16	2.32	2.2	-	17.51
		≥3yr	11.6	3.19	3.02	3.2	-	**21.01**	15.1	3.15	2.21	4.51	-	24.97
		Total	**21.91**	**4.52**	**5.33**	**6.89**	**0.33**	**38.98**	**31.33**	**4.31**	**4.53**	**8.12**	**0.51**	**48.8**
Melocanna baccifera	Tamdil	1yr	4.31	-	-	2.04	0.17	**6.52**	14.2	-	-	2.48	0.46	17.14
		2yr	8.53	1.15	1.6	2.63	-	**13.91**	23.9	1.96	2.94	3.3	-	32.1
		≥3yr	10.04	1.23	1.34	2.45	-	**15.06**	18.15	1.02	0.54	2.87	-	22.58
		Total	**22.88**	**2.38**	**2.94**	**7.12**	**0.17**	**35.49**	**56.25**	**2.98**	**3.48**	**8.65**	**0.46**	**71.82**
Bambusa tulda	Lengpui	1yr	3.69	-	-	-	0.21	**3.9**	7.6	-	-	-	0.25	7.85
		2yr	8.05	1.15	1.5	-	-	**10.7**	9.27	0.65	0.95	-	-	10.87
		≥3yr	10.7	1.65	0.75	-	-	**13.1**	39	3.85	2.42	-	-	45.27
		Total	**22.44**	**2.8**	**2.25**		**0.21**	**27.7**	**55.87**	**4.5**	**3.37**	**-**	**0.25**	**63.99**
Dendrocalamus longispathus	Tuirial	1yr	5.68	0.23	0.17	-	0.04	**6.12**	9.11	0.33	0.27	-	0.06	9.77
		2yr	5.24	0.45	0.42	-	-	**6.11**	7.91	0.82	0.44	-	-	9.17
		≥3yr	32.72	3.53	1.63	-	-	**37.88**	40.14	3.95	2.13	-	-	46.22
		Total	**43.64**	**4.21**	**2.22**	**-**	**0.04**	**50.11**	**57.16**	**5.1**	**2.84**	**-**	**0.06**	**65.16**

Bambusa tulda

The aboveground C-stock of *Bambusa tulda* in 2015 was 27.7 MgC/ha. The maximum C-stock was found in ≥3year old age class (13.1 MgC/ha) followed by 2year old age class (10.7 MgC/ha) and minimum in 1year age class (3.9 MgC/ha). In 2016, the total C-stock was 63.99 MgC/ha. The ≥3year old age class had maximum C-stock (45.27 MgC/ha) followed by 2year old age class (10.87 MgC/ha) and minimum in 1year age class (7.85 MgC/ha) (Table 24).

By comparing among different components, the culm (22.44 MgC/ha) had maximum C-stock followed by branch (2.8 MgC/ha), leaf (2.25 MgC/ha) and sheath (0.21MgC/ha) during 2015. In 2016, maximum was recorded in culm (55.87MgC/ha) followed by branch (4.5 MgC/ha), leaf (3.37 MgC/ha) and sheath (0.25MgC/ha) (Table 24).

Dendrocalamus longispathus

The aboveground C-stock of *Dendrocalamus longispathus* in 2015 was 50.11 MgC/ha. The maximum C-stock was found in ≥3year old age class (37.88 MgC/ha) followed by 1year age class (6.12 MgC/ha) and minimum was recorded in 2year old age class (6.11 MgC/ha) during 2015. In 2016, the C-stock was recorded 65.16 MgC/ha. The ≥3year old age class had maximum C-stock (46.22 MgC/ha) followed by followed by 1year age class (9.77 MgC/ha) and minimum in 2year old age class (9.17 MgC/ha) (Table 24).

By comparing between different components, the culm (43.64 MgC/ha) had maximum C-stock followed by branch (4.21 MgC/ha), leaf (2.22MgC/ha) and sheath (0.04 MgC/ha) in 2015. In 2016 maximum was culm (57.16 MgC/ha) followed by branch (5.1 MgC/ha), leaf (2.84 MgC/ha) and sheath (0.06MgC/ha) (Table 24).

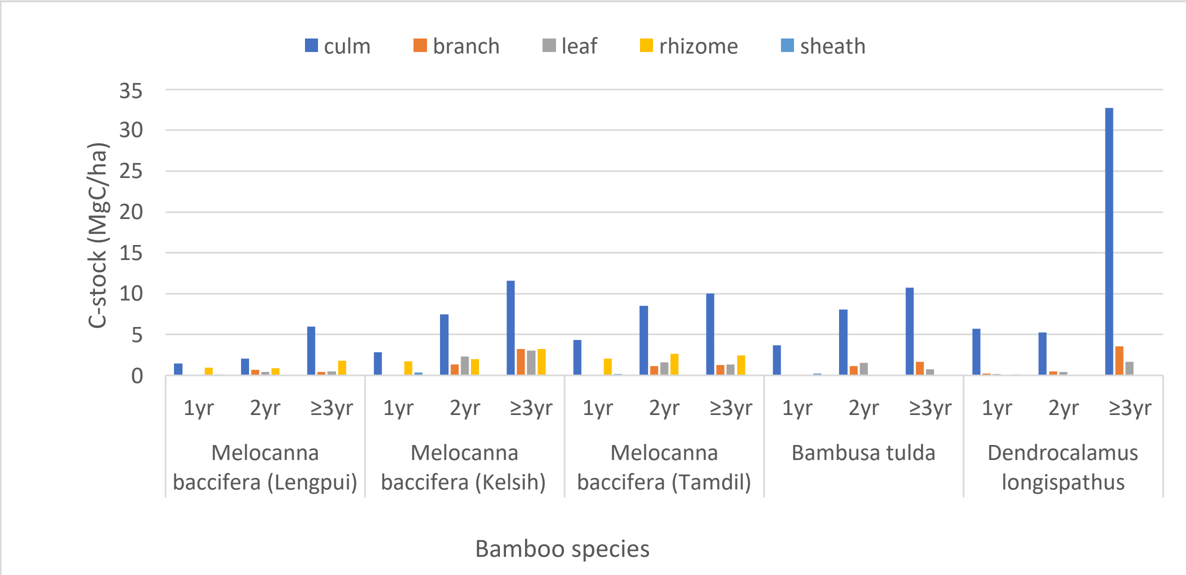

Figure 13: C-stock (MgC/ha) of different components of selected bamboo species during 2015

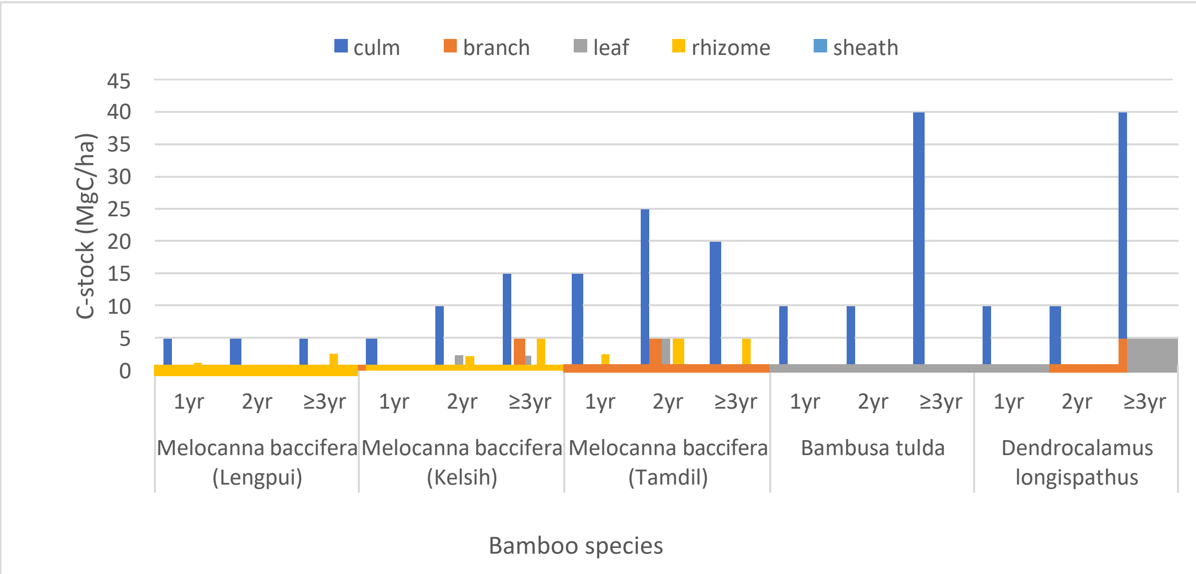

Figure 14: C-stock (MgC/ha) of different components of selected bamboo species during 2016

Melocalamus compactiflorus

In *Melocalamus compactiflorus* the sizes and morphological structures of culm and branch were difficult to separate. Thus, this bamboo species is presented in a separate table.

The total aboveground C-stock of *Melocalamus compactiflorus* during 2015 was 17.13 MgC/ha. The maximum C-stock was found in ≥3year old age class (10.23 MgC/ha) followed by 2year age class (5.4 MgC/ha) and minimum was recorded in 1year age class (1.5 MgC/ha) during 2015. In 2016, the total C-stock was recorded 44.66 MgC/ha. The ≥3year old age class had maximum C-stock (29.36 MgC/ha) followed by followed by 2year old age class (12.85 MgC/ha) and minimum in 1year age class (2.45 MgC/ha) (Table 25).

By comparing between different components, the culm+branch (15.52 MgC/ha) had maximum C-stock followed by leaf (1.44 MgC/ha) and sheath (0.17 MgC/ha) during 2015. In 2016, the maximum was recorded in culm+branch (32.13 MgC/ha) followed by leaf (12.3 MgC/ha) and sheath (0.23 MgC/ha) (Table 25).

Table 25: Aboveground C-stock (MgC/ha) in different components of *Melocalamus compactiflorus* during 2015 and 2016

Age class	**2015**				**2016**			
	Culm+ Branch	**Leaf**	**Sheat h**	**Total**	**Culm+ Branch**	**Leaf**	**Sheat h**	**Total**
1yr	1.3	0.03	0.17	**1.5**	1.51	0.71	0.23	**2.45**
2yr	4.77	0.63	0	**5.4**	8.4	4.45	0	**12.85**
≥3yr	9.45	0.78	0	**10.23**	22.22	7.14	0	**29.36**
total	15.52	1.44	0.17	**17.13**	32.13	12.3	0.23	**44.66**

4.2.6 Litterfall and their C-stock

Melocanna baccifera

Lengpui:

The total litterfalls were recorded 0.19Mg/ha and 0.21Mg/ha during 2015 and 2016 respectively. By comparing between different litter components, leaf litters (0.08 Mg/ha in 2015 and 0.09Mg/ha in 2016) were recorded maximum followed by sheath litters (0.06Mg/ha in 2015 and 0.07Mg/ha in 2016) and branch litters (0.05Mg/ha each in 2015 and 2016) (Table 26).

The total C-stocks of litterfall were 0.068 MgC/ha and 0.071MgC/ha respectively in 2015 and 2016. In both the study years C-stock of litterfall was maximum with leaf litter (0.03 MgC/ha each in 2015 and 2016) and the least with sheath litter (0.018MgC/ha) in 2015 and branch litter (0.02MgC/ha) in 2016 (Table 26).

Kelsih:

The total litterfalls were 0.2 Mg/ha and 0.22 Mg/ha during 2015 and 2016 respectively, the sheath litter (0.08 Mg/ha) was maximum in 2015 followed by leaf litter (0.07 Mg/ha) whereas in 2016, the sheath and leaf litters were 0.08 Mg/ha each followed by branch litter (0.06 Mg/ha) (Table 26).

The total C-stocks were 0.11 MgC/ha and 0.07 MgC/ha respectively in 2015 and 2016. The maximum C-stock of litterfall were leaf litters respectively 0.07 MgC/ha and 0.03 MgC/ha in 2015 and 2016 (Table 26).

Tamdil:

The total litterfalls were 0.28Mg/ha and 0.3Mg/ha during 2015 and 2016 respectively, the sheath litter was maximum in both years with 0.11Mg/ha and 0.12Mg/ha respectively in 2015 and 2016 followed by leaf litter with 0.09Mg/ha in 2015 and 0.1Mg/ha in 2016. The total C-stocks of litterfall were 0.09MgC/ha and 0.10MgC/ha in 2015 and 2016 respectively (Table 26).

Bambusa tulda

The total litterfalls were 0.2Mg/ha and 0.27Mg/ha in 2015 and 2016 respectively. Among the litter components, leaf and sheath litters contributed 0.07Mg/ha each and branch litter was 0.06Mg/ha in 2015 whereas in 2016, leaf litter was 0.11Mg/ha, sheath litter was 0.09Mg/ha and branch litter were 0.07Mg/ha (Table 26).

The total C-stock of litterfall was 0.08 MgC/ha and 0.11 MgC/ha in 2015 and 2016 respectively. Component wise contribution in C-stock of litterfall were 0.032MgC/ha by leaf litter, 0.027MgC/ha by branch litter and 0.021MgC/ha by sheath litter during 2015; whereas in 2016, 0.05MgC/ha by leaf litter, 0.036MgC/ha by branch litter and 0.027MgC/ha by sheath litter (Table 26). Details are provided in appendix XX.

Table 26: Litterfall (Mg/ha) and C-stock (MgC/ha) of different components of different bamboo species during 2015 and 2016

Bamboo	Site	Parameter	2015				2016			
			Leaf	**Branch**	**Sheath**	**Total**	**Leaf**	**Branch**	**Sheath**	**Total**
Melocanna baccifera	Lengpui	Litterfall (Mg/ha)	0.08 ±0.01	0.05 ±0.02	0.06 ±0.01	0.19	0.09 ±0.01	0.05 ±0.01	0.07 ±0.02	0.21
		C-stock (MgC/ha)	0.03	0.02	0.018	0.068	0.03	0.02	0.021	0.071
Melocanna baccifera	Kelsih	Litterfall (Mg/ha)	0.07 ±0.01	0.05 ±0.01	0.08 ±0.01	0.2	0.08 ±0.02	0.06 ±0.02	0.08 ±0.01	0.22
		C-stock (MgC/ha)	0.07	0.02	0.02	0.11	0.03	0.02	0.02	0.07
Melocanna baccifera	Tamdil	Litterfall (Mg/ha)	0.09 ±0.01	0.08 ±0.01	0.11 ±0.01	0.28	0.1 ±0.02	0.08 ±0.01	0.12 ±0.01	0.3
		C-stock (MgC/ha)	0.03	0.03	0.03	0.09	0.04	0.03	0.03	0.10
Bambusa tulda	Lengpui	Litterfall (Mg/ha)	0.07 ±0.01	0.06 ±0.01	0.07 ±0.01	0.2	0.11 ±0.02	0.07 ±0.01	0.09 ±0.01	0.27
		C-stock (MgC/ha)	0.032	0.027	0.021	0.08	0.050	0.036	0.027	0.113
Dendrocalamus longispathus	Tuirial	Litterfall (Mg/ha)	0.09 ±0.01	0.07 ±0.01	0.1 ±0.02	0.26	0.12 ±0.01	0.07 ±0.01	0.09 ±0.01	0.28
		C-stock (MgC/ha)	0.04	0.03	0.03	0.10	0.05	0.03	0.03	0.11
Melocalamus compactiflorus	Darlawn	Litterfall (Mg/ha)	0.05	0.06	0.01	0.12	0.045	0.075	0.015	0.135
		C-stock (MgC/ha)	0.025	0.03	0.005	0.06	0.022	0.037	0.007	0.066

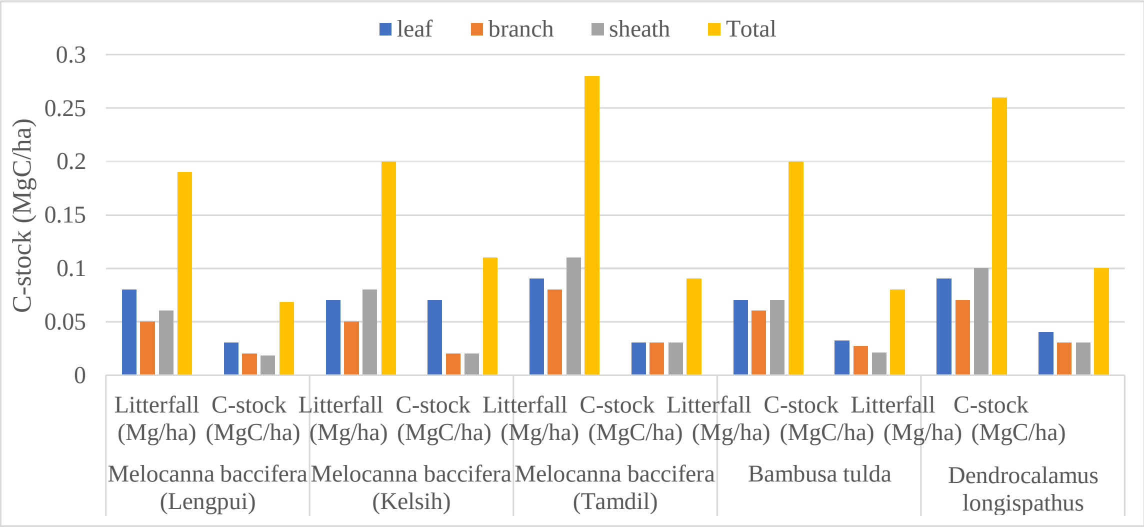

Figure 15: Litterfall (Mg/ha) and C-stock (MgC/ha) in different components of different bamboo species in different sites for 2015

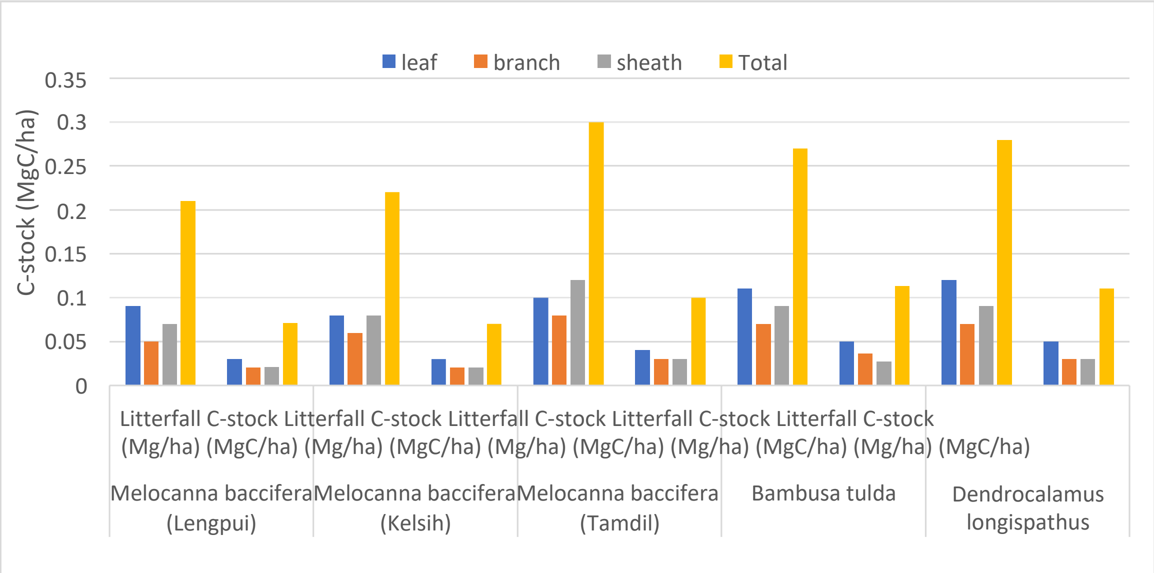

Figure 16: Litterfall (Mg/ha) and their C-stock (MgC/ha) of different components of different bamboo species in different sites for 2016

Dendrocalamus longispathus

The total litterfalls were 0.26 Mg/ha and 0.28 Mg/ha during 2015 and 2016 respectively. Among the litter components, sheath litters contributed 0.1Mg/ha, leaf litters contributed 0.09MgC/ha and the branch litter contributed 0.07Mg/ha during 2015 whereas in 2016, leaf litter was maximum (0.12Mg/ha) followed by sheath litter (0.09 Mg/ha) and branch litter (0.07Mg/ha) (Table 26).

The total C-stock of litterfalls were 0.10MgC/ha and 0.11MgC/ha in 2015 and 2016 respectively. Component wise contribution in C-stock of litterfall were leaf litter (0.04MgC/ha) and 0.03MgC/ha each by branch and the leaf litters during 2015; whereas in 2016, leaf litter (0.05MgC/ha) and 0.03MgC/ha each by branch and sheath litters (Table 26). Details are provided in appendix XX.

Melocalamus compactiflorus

The total litterfalls were 0.12Mg/ha and 0.135Mg/ha during 2015 and 2016 respectively. Among the litter components, branch litter contributed 0.06Mg/ha, leaf litter contributed 0.05MgC/ha and the sheath litter were 0.01Mg/ha in 2015. In 2016, branch litter was 0.075Mg/ha, leaf litter was 0.045Mg/ha and the sheath litter were 0.015Mg/ha (Table 26).

The total C-stock of litterfall were 0.06MgC/ha and 0.066MgC/ha in 2015 and 2016 respectively. Component wise contribution in C-stock of litterfall were 0.03MgC/ha by branch litter, 0.025MgC/ha by leaf litters and 0.005Mg/ha by sheath litter during 2015. In 2016, 0.037MgC/ha by branch litter, 0.022MgC/ha by leaf litter and 0.007MgC/ha by sheath litters (Table 26). Details are provided in appendix XX.

4.2.7 Correlation

The Pearson"s coefficient of correlation (r) was calculated for finding relationship between the different characteristics of biomass in different bamboo species.

4.2.7.1 Melocanna baccifera

Lengpui:

In 2015, DBH was found to have significant inverse correlation with culm density (r= -0.72). Total aboveground biomass was found to have significant positive correlation with culm density (r=0.97) whereas found significantly negative correlation with DBH (r= -0.87). C-stock was found to have significant positive correlation with culm density (r=0.98) and total biomass (r=1) whereas significantly inverse correlation with DBH (r= -0.84) (Table 27).

In 2016, DBH was found to have significantly inverse correlation with culm density (r= -0.92). Total biomass was found to have significant positive correlation with culm density (r=0.73) whereas found significantly negative correlation with DBH (r= -0.94). C-stock was found to have significant positive correlation with culm density (r=0.77) and total biomass (r=1) whereas significantly inverse correlation with DBH (r= -0.96) (Table 27).

Table 27: Correlation between bamboo characteristics in Lengpui for *Melocanna baccifera* (n=27)

	2015				**2016**			
	Density	**DBH**	**Biomass**	**C-stock**	**Density**	**DBH**	**Biomass**	**C-stock**
Density	1.00	-0.72*	0.97*	0.98*	1.00	-0.92*	0.73*	0.77*
DBH		1.00	-0.87	-0.84*		1.00	-0.94*	-0.96*
Biomass			1.00	1.00*			1.00	1.00*
C-stock				1.00				1.00

*: indicates significance at $p<0.05$

Kelsih:

In 2015, Total biomass was found to have significant positive correlation with culm density (r=0.81). C-stock was found to have significant positive correlation with culm density (r=0.0.84) and total biomass (r=1). Whereas in 2016, DBH was found to have significantly positive correlation with culm density (r=0.73). Total biomass was also found to have positive correlation with culm density (r=0.70) and DBH (R=1); and C-stock with culm density (r=0.73), DBH (r=1) and with total biomass (r=1) (Table 28).

Table 28. Correlation between bamboo characteristics in Kelsih for *Melocanna baccifera* (n=27).

	2015				2016			
	Density	**DBH**	**Biomass**	**C-stock**	**Density**	**DBH**	**Biomass**	**C-stock**
Density	1.00	-0.22	0.81*	0.84*	1.00	0.73*	0.70*	0.73*
DBH		1.00	0.40	0.34		1.00	1.00*	1.00*
Biomass			1.00	1.00*			1.00	1.00*
C-stock				1.00				1.00

*: indicates significance at $p<0.05$

Tamdil:

In 2015, DBH was found to have significantly inverse correlation with culm density (r= -0.99). Total biomass was found to have significant positive correlation with culm density (r=0.71). C-stock was found to have significant positive correlation with culm density (r=0.80) and total biomass (r=0.99) whereas significantly inverse correlation with DBH (r= -0.69). In 2016, DBH was significantly inverse correlation with culm density (r= -0.94) and C-stock had significant positive correlation with total biomass (r=0.98) (Table 29).

4.2.7.2 Bambusa tulda

In 2015, culm density was found to have significant positive correlation with total aboveground biomass (r=0.89) and C-stock (r=0.93) also between total aboveground biomass and C-stock (r= 1). During 2016 also, culm density was found significant positive correlations with total aboveground biomass (r= 1) and C-stock (r= 1); between total aboveground biomass and C-stock (r= 1) (Table 30).

Table 29: Correlation between bamboo characteristics in Tamdil for *Melocanna baccifera* (n=27)

	2015				2016			
	Density	**DBH**	**Biomass**	**C-stock**	**Density**	**DBH**	**Biomass**	**C-stock**
Density	1.00	-0.99*	0.71*	0.80*	1.00	-0.94*	0.40	0.56
DBH		1.00	-0.58	-0.69*		1.00	-0.07	-0.25
Biomass			1.00	0.99*			1.00	0.98*
C-stock				1.00				1.00

*: indicates significance at p<0.05

Table 30: Correlation between bamboo characteristics in Lengpui for *Bambusa tulda* (n=27)

	2015				**2016**			
	Density	**DBH**	**Biomass**	**C-stock**	**Density**	**DBH**	**Biomass**	**C-stock**
Density	1.00	-0.04	0.89*	0.93*	1.00	0.54	1.00*	1.00*
DBH		1.00	-0.50	-0.41		1.00	0.57	0.57
Biomass			1.00	1.00*			1.00	1.00*
C-stock				1.00				1.00

*: indicates significance at p<0.05

4.2.7.3 Dendrocalamus longispathus

In 2015, culm density was found to have significant positive correlation with total aboveground biomass (r=0.99) and C-stock (r=0.99) also between total aboveground biomass and C-stock (r= 1). During 2016 also, culm density was found significant positive correlations with total aboveground biomass (r= 0.99) and C-stock (r= 0.99); between total aboveground biomass and C-stock (r= 1) (Table 31).

Table 31: Correlation between bamboo characteristics in Tuirial for *Dendrocalamus longispathus* (n=27)

	2015				2016			
	Density	**DBH**	**Biomass**	**C-stock**	**Density**	**DBH**	**Biomass**	**C-stock**
Density	1.00	-0.38	0.99*	0.99*	1.00	-0.07	0.99*	0.99*
DBH		1.00	-0.52	-0.50		1.00	-0.20	-0.18
Biomass			1.00	1.00*			1.00	1.00*
C-stock				1.00				1.00

*: indicates significance at p<0.05

4.2.7.4 Melocalamus compactiflorus

In 2015, culm density was found to have significant inverse correlations with DBH (r= -0.99), whereas significant positive correlations with total aboveground biomass (r=0.96) and C-stock (r=0.96). DBH was found to have significant inverse correlations with total aboveground biomass (r= -0.89) and C-stock (r= -0.90). It was found significant positive correlation between total aboveground biomass and C-stock (r=1) (Table 32).

In 2016 also, culm density was found to have significant inverse correlations with DBH (r= -0.88), whereas significant positive correlations with total aboveground biomass (r=0.92) and C-stock (r=0.91). DBH was found to have significant inverse correlations with total aboveground biomass (r= -0.61) and C-stock (r= -0.61). It was found significant positive correlation between total aboveground biomass and C-stock (r=1) (Table 32).

Table 32: Correlation between bamboo characteristics in Darlawn for *Melocalamus compactiflorus* (n=27)

	2015				2016			
	Density	**DBH**	**Biomass**	**C-stock**	**Density**	**DBH**	**Biomass**	**C-stock**
Density	1.00	-0.99*	0.96*	0.96*	1.00	-0.88*	0.92*	0.91*
DBH		1.00	-0.89*	-0.90*		1.00	-0.61*	-0.61*
Biomass			1.00	1.00*			1.00	1.00*
C-stock				1.00				1.00

*: indicates significance at p<0.05

4.2.8. C-sequestration

The rate of total C-sequestration in *Melocanna baccifera* stands during the two study years in Lengpui, Kelsih and Tamdil were respectively 4.31 MgC/ha/yr, 10 MgC/ha/yr and 36.52 MgC/ha/yr (Table 33).

By comparing among the three sites, Tamdil was found to have maximum rate of C-sequestration followed by Kelsih and minimum was observed in Lengpui.

The rate of aboveground C-sequestration in *Bambusa tulda*, *Dendrocalamus longispathus* and *Melocalamus compactiflorus* were recorded 36.48 MgC/ha/yr, 15.26 MgC/ha/yr and 27.65 MgC/ha/yr respectively during the study years (Table 33).

4.2.9 Elemental content in bamboo vinegar

Elemental content in pyrolyzed bamboo liquid (vinegar) of *Melocanna baccifera* and *Bambusa tulda* were determined.

Melocanna baccifera

Trace elements:

Five important trace elements were determined in the vinegar of different components of *Melocanna baccifera.* By comparing between different components, the concentration of Cr was found highest in leaf (0.015ppm) and lowest in bamboo shoot (0.005ppm); the concentration of Fe was highest in ≥3year old culm (0.194 ppm) and lowest in shoot (0.105ppm). The concentration of Zn was highest in 1year age class culms (0.098ppm) and lowest in shoot (0.083ppm) whereas concentration of Mo was found higher in culm components of 1year age class and ≥3year old age classes with 176.3ppm and 556.42 ppm respectively as compare to shoot (76.06ppm) and leaf (23.35ppm). The concentration of Pb was found highest in 1year age culm (0.012ppm) (Table 34).

Table 33: C-sequestration (MgC/ha/yr) of different bamboo species during 2015 and 2016

Bamboo	Site	Biomass C-stock 2015	Biomass C-stock 2016	C-sequestration (bamboo)	Litterfall c-stock 2015	Litterfall c-stock 2016	Total C-stock (litterfall)	Total C-sequestration
Melocanna baccifera	Lengpui	15.15	19.33	4.18	0.068	0.071	0.139	4.319
Melocanna baccifera	Kelsih	38.98	48.8	9.82	0.11	0.07	0.18	10
Melocanna baccifera	Tamdil	35.49	71.82	36.33	0.09	0.1	0.19	36.52
Bambusa tulda	Lengpui	27.7	63.99	36.29	0.08	0.113	0.193	36.483
Dendrocalamus longispathus	Tuirial	50.11	65.16	15.05	0.1	0.11	0.21	15.26
Melocalamus compactiflorus	Darlawn	17.13	44.66	27.53	0.06	0.066	0.126	27.656

Table 34: Trace elements (ppm) in *Melocanna baccifera*

Components	**Age class**	**Cr**	**Fe**	**Zn**	**Mo**	**Pb**
Culm	1yr	0.006	0.156	0.098	176.300	0.012
	≥3yr	0.007	0.194	0.096	556.423	0.010
Shoot	1yr	0.005	0.105	0.083	76.060	0.010
Leaf	3yr	0.015	0.149	0.088	23.355	0.011

By comparing between 1year and ≥3year old age classes in the culm component, Cr, Fe and Mo were found to be higher in ≥3year old age class. Among the observed five trace elements, the amount of Mo was found to be maximum and the lowest was Cr in different components of *Melocanna baccifera* (Table 34).

Macro elements:

Presence of four important macro-elements were observed in different components of *Melocanna baccifera.* By comparison between different components, the concentration of Na was found highest in bamboo shoot (1.011ppm) and lowest in leaf (0.465ppm); the concentration of Mg was highest in ≥3year old culm (0.242ppm) followed by leaf (0.157ppm) and lowest in 1year old culm (0.127ppm). The concentration of Ca was found highest in shoot (3.476ppm) and lowest in 1year old culm (1.855ppm) (Table 35).

Table 35: Macro elements (ppm) in *Melocanna baccifera*

Components	**Age class**	**Na**	**Mg**	**K**	**Ca**
Culm	1yr	0.602	0.127	0.117	1.855
	≥3yr	0.806	0.242	0.149	2.585
Shoot	1yr	1.011	0.128	0.155	3.476
Leaf	≥3yr	0.465	0.157	0.127	3.404

Photo plate 6: Extraction of pyrolyzed bamboo liquid (vinegar), (A) Pieces of bamboo culm, (B) Improvised pyrolysis units, (C) Bamboo biochar after the pyrolysis and (D) Extracted vinegar

By comparing between 1year and ≥3year old age classes Na, Mg, K and Ca were found to be higher in ≥3year old age class in the culm component. Among the four determined macro elements, concentration of Ca was found to have maximum in all the components (Table 35).

Bambusa tulda

Trace elements:

Five important trace elements were determined in the vinegar of leaf and culm components of *Bambusa tulda.* By comparing between different age classes of culm, 2year old age class was found to have highest concentration of Cr (0.009ppm), Fe (1.464ppm) and Mo (13.58ppm); the concentration of Fe and Zn were found lowest in 1year age class with 0.073ppm and 0.045ppm respectively (Table 36).

Leaf component was found to have concentration of Cr (0.007ppm), Fe (0.180ppm), Zn (0.035ppm), Mo (8.07ppm) and Pb (0.01ppm). Among the observed five trace elements, the amount of Mo was found to be maximum and the lowest was Cr in different components of *Bambusa tulda* (Table 36).

Table 36: Trace elements (ppm) in *Bambusa tulda*

Component	**Age class**	**Cr**	**Fe**	**Zn**	**Mo**	**Pb**
Culm	1yr	0.005	0.073	0.045	10.580	0.009
	2yr	0.009	1.464	0.116	13.580	0.009
	≥3yr	0.007	0.103	0.141	6.690	0.009
Leaf	≥3yr	0.007	0.180	0.035	8.070	0.010

Macro elements:

Presence of four important macro-elements were observed in culm and leaf components of *Bambusa tulda.* By comparing between culms of different age classes, the concentration of Na was found to be highest in ≥3year old age class (0.641ppm) followed by 2year age class (0.603ppm) whereas the highest concentration of Mg and K were found in 2year old age class with (0.206ppm) and

(0.278ppm) respectively. The highest concentration of Ca was found in ≥3year old age class (2.107ppm) (Table 37).

The leaf component was found to have concentration of Na (0.479ppm), Mg (0.116ppm), K (0.142ppm) and Ca (3.444ppm). Among the four determined macro elements, concentration of Ca was found to have maximum in all the components (Table 37).

Table 37: Macro elements (ppm) in *Bambusa tulda*

Component	**Age class**	**Na**	**Mg**	**K**	**Ca**
Culm	1yr	0.530	0.109	0.091	1.349
	2yr	0.603	0.206	0.278	1.712
	≥3yr	0.641	0.097	0.155	2.107
Leaf	≥3yr	0.479	0.116	0.142	3.444

Chemical characteristics of bamboo vinegar

pH:

The pH of bamboo shoot was found 2.55 and that of culms ranged from 2.46 to 2.63 in *Melocanna baccifera.* In Bambusa tulda it ranged from 2.59 to 2.67 (Table 38).

Table 38: pH of bamboo vinegar

Components	**Age class**	***Melocanna baccifera***	***Bambusa tulda***
Culm	1yr	2.46	2.67
	≥3yr	2.63	2.59
Bamboo shoot	-	2.55	-

Bioactive compounds:

Six compounds with bioactive properties such as Furfural, D-Fructose, Guaiacol, Creosol, Catechol and 2-Propenyl were found in vinegar of *Melocanna baccifera*

(Table 39) and three bioactive compounds such as Malezitose, Catechol and Syringol were found in vinegar of Bambusa tulda (Table 40).

Table 39: Bioactive compounds in *Melocanna baccifera* vinegar

Sl.no.	**Compound**	**Types**	**Retention time (RT)**	**Probability**	**Molecular weight**
1	Furfural	Aldehyde	6.04	62.87	96.08
2	D-Fructose	Carbohydrate	6.4	32.79	180.16
3	Phenol, 2-methoxy- *(Guaiacol)*	Benzene	15.24	63.61	124.14
4	2-Methoxy-4-methylphenol *(Creosol)*	Benzene	18.58	55.8	138.16
5	Catechol *(1,2-benzenediol)*	Benzene	19.7	26.7	110.11
6	2- Propenyl	Allyl compound	31.16	59.39	41.07

Table 40: Bioactive compounds in *Bambusa tulda* vinegar

Sl.no.	**Compound**	**Types**	**RT**	**Probability**	**Molecular weight**
1	Malezitose	Carbohydrate	16.45	24.68	504.4
2	Catechol *(1,2-benzenediol)*	Benzene	19.26	12.35	110.11
3	2,6-Dimethoxyphenol *(Syringol)*	Polyphenol	29.97	73.27	154.16

5. DISCUSSION

5.1 Physicochemical characteristics of soil

Soil moisture (SM)

The average soil moisture content in the present study ranged from 18.19 to 25.62%; similar range of soil moisture content (17 - 24%) was reported by Manpoong & Tripathi, (2019) from different land use systems in Mizoram. The average (2015 and 2016) soil moisture content of Lengpui (21.90%) was lower than that of Kelsih (23.64%) in the present study as a result of differences in environmental factors like slope, elevation and soil texture, which was in accordance to the study of Pachepsky *et al.*, 2003. Other contributing factor can be temperature which attributed that due to warmer temperature in Lengpui with moderate slope which uplift the rate of evaporation through transpiration of vegetations. Moisture content compared from two slope site *i.e.* a tea garden and bamboo forest by Liao *et al*. (2017) have also shown that bamboo forest hillslopes retains higher moisture (10.8–31.0%) than in tea garden (7.3–19.4%). Such high soil moisture in forest hillslope were credited to the extensive rhizome system which retained moisture in the soil and thick litter layer which give bamboo forests a high capacity for soil water conservation.

The annual average rainfall data of Aizawl district shows that the year 2015 recorded higher rainfall as compared to 2016 whereas in both the study sites, the average soil moisture content was found to be higher during 2016 as compared with 2015. The reason being the topographical variations has effect on distribution of rainfall within Aizawl district. This pattern was consistent with a previously report that the topography is the main factor affecting the distribution of rainfall (Patil & Toradmal, 2020). Thus, due to differences in topographical and environmental factors, these study sites had variations in soil moisture content despite being in the same climatic zone.

Soil pH

The seasonal variation of soil pH of bamboo forests in both the study sites ranged from 5.20 to 6.06 which indicates acidic nature of soil. The soil pH in the present study was slightly higher than the range (3.9-5) reported by Wapongnungsang &

Tripathi, (2019) in different land use systems of Mizoram whereas broadly similar to a previously reported range in *bambusetums* with soil pH of 5.52 in *Bambusa bambos;* 5.44 in *Dendrocalamus asper* in Jorhat, Assam (Gogoi & Bhuyan, 2016) and 3.85- 6.02 in bamboo forest of different terrains in Jian‟ou City, China (Zhang *et al*. 2015). In the present study, soil pH was found to have negative significant correlations with soil temperature, soil moisture and soil respiration which indicates that during warm rainy seasons the soil had higher rate of decomposition of litterfall and other organic matters on the forest floor which releases the organic acids in the soil and further leaching process makes the forest soil acidic. This result was in support to Zhao *et al*., (2018) reported that decomposition of plant litters, roots and the shed root cap cells released enzymes and organic acids into the soil which neutralizes OH-ions in the soil, thereby promotes the forest soil more acidic.

Soil Bulk density (BD)

The soil BD ranged from 0.621 to 0.737 g cm^{-3} in the present study, the similar range of BD 0.40 to 0.71 g cm^{-3} was reported by Kenye *et al*., (2019) in different land use types of Mizoram. However, lower than 0.76 g cm^{-3} to 1.19 g cm^{-3} in bamboo forest of different terrains in Jian‟ou City, China (Zhang *et al*. 2015). Average BD was found higher in Lengpui as compare to Kelsih site, reason being the slop gradient which the selected site in Kelsih was steep slope and that of Lengpui in a moderately gentle slope where the soil was more compact. Other factors can be litterfall and soil texture, in Kelsih there was higher amount of litterfall thus enhanced higher organic matter content in soil. Similar conclusion was reported by Gogoi & Bhuyan,(2016) that, less BD of soil may be attributed to soil texture and amount of organic matter present in the soil. Xiangsheng *et al*., (2016) also reported that organic matter content has a significant influence on soil BD.

Soil BD and the SR had significantly negative correlations in this study which indicates that the microbial activities are higher in lesser dense forest soil. The seasonal changes in soil BD was minimal. By comparing between different seasons, BD was lower during the rainy season which can enhanced the SOC accumulation. Similar statement was reported by Zhao *et al*., (2020).

Soil temperature (ST)

In the present study, ST was higher during 2015 in both the study sites. Lengpui had higher mean ST as compared to Kelsih, reason being the difference in altitudes. Lengpui has an altitude of 400-500 a.s.l thus had warmer temperature and humid atmosphere. Other factors could be slope gradient and orientations towards the sun, the study site in Lengpui had moderate slopes facing towards north, therefore the duration of exposure to the sun was longer as compared to the site in Kelsih (650-750 a.s.l) orienting towards north-west with steep slope having lesser duration of exposure to the sun.

Soil organic carbon (SOC), C-storage and C-sequestration

In the present study, soil organic carbon (SOC) ranged from 1.64% - 3.15% in Lengpui and in Kelsih it ranged from 1.96% - 4.06%. The SOC was lower than the above ground biomass C storage. In tropical forest the C in soil is nearly equivalent to or less than the above ground C pool (Bundestag, 1990). Average SOC was recorded more in Kelsih with 2.68% and 3.14% during 2015 and 2016 respectively as compared to 2.34% and 2.47% in Lengpui. Higher SOC in Kelsih can be attributed to the higher amount of litterfall as compared to Lengpui. SOC was higher than previously reported SOC across land use patterns of Mizoram such as large home garden (2.07%), medium home garden (1.77%), young shifting cultivation fallow (1.42%) and old shifting cultivation fallow (2.12%) (Singh & Sahoo, 2021). It was also higher than 1.81% and 1.45% up to the soil depth of 0-10 cm and10-20cm respectively in bamboo forest within Aizawl district (Vanlalfakawma *et al*., 2014); teak plantation (1.08%) and natural forest (2.42%) in different parts of Mizoram (Manpoong & Tripathi, 2021). However, the current range was comparable with 0.42% to 6.48% of SOC in bamboo forest of different terrains in Jian‟ou City, China (Zhang *et al*. (2015). Various studies have shown that bamboo provides advantages over other land uses in terms of maintaining and increasing SOC, soil conservation and restoration of degraded land and other ecological services which also sequestered substantial amount of carbon under bamboo plantation (Ly *et al*., 2012).

In the present study, soil C storage up to the depth of 30 cm was 43.96 MgC/ha and 51.31 MgC/ha during 2015 and 2016 respectively in Lengpui; 52.14 MgC/ha and

56.81 MgC/ha during 2015 and 2016 respectively in Kelsih. Analysis of variance shows significant variation of C-storage within the two study sites ($P<0.05$). The observed mean was within the range of 50 -120 MgC/ha in the tropical forests of Asia (Palm *et al*., 1986), however lower than the average C-storage in a closed forest (72 MgC/ha) (Bolin, 1986) and also lower than soil C-stock in home garden soil upto top 1m (109.73 MgC/ha) in Mizoram (Singh & Sahoo, 2015).

On comparison of the two study years there was a progressive increase of C-storage as well as soil respiration in both the study sites. The positive correlation between soil C-storage and soil respiration in both years also indicates that the forest soil under the present study sites were stable. The rate of C-sequestration after deducting the rate of soil respiration from C-storage was still high. The present range of soil C-sequestration of 4.67 and 7.35 MgC/ha/yr in Kelsih and Lengpui respectively were higher than 0.59 MgC/ha/yr in *Bambusa.* based agroforestry system (Singnar *et al.*, 2015). The present range was also higher than stands of *Gmelina arborea* from Chhatisgarh, India which reported a range of 0.42 to 2.16 MgC/ha/yr (Swamy & Puri, 2005); 0.16 to 1.08 MgC/ha/yr in silvipastoral system in North Western India (Kaur *et al.*, 2002); 0.8 to 4.0 MgC/ha/yr from secondary forest succession in Puerto Rico, (Lugo *et al*., 1986) and 1.02 MgC/ha/yr from tropical forest reported by Parrotta, (1992). Whereas it was lower than 8.9Mg/ha/yr recorded from a secondary tropical forest in Costa Rica (Fonseca *et al.*, 2011).

By comparing between the two study sites, Kelsih was found to have higher amount in C-storage and soil respiration whereas the rate of C-sequestration was higher in Lengpui. The reason could be attributed to difference in slope gradient and altitude of the two sites. Lengpui being the gentle slope and low altitude landscape has greater capability to retain higher amount of carbon.

Total Nitrogen (TN)

In the present study, TN up to 30cm depth of soil ranged from 0.58% to 0.73%. Mishra *et al.*, (2017) reported that N content in soil are predominant in the top surface layer (0-30cm). There were significant positive correlations of TN with SOC and SR. By comparing between the two study sites, Kelsih recorded higher amount of TN content in soil which attributes that the bamboo forest in Kelsih had higher amount of organic matters and decomposition rate was higher. Organic matter and SOC have great influence on TN and many different available nutrients in soil which provide scope for the microorganisms to feed on and to release nutrients in soil (Wapongnungsang *et al*., 2017). Percentage of TN in the present study was higher than 0.19% to 0.39% in different land use types of Mizoram such as woody forest, secondary forest and jhumland reported by Manpoong & Tripathi (2019). The current finding indicates that bamboo forest soil has higher TN content over woody forest, secondary forests and jhumlands.

Available Phosphorus (AP) and available Potassium (AK)

In the present study, AP ranged from 0.024% to 0.11% in Lengpui and that of 0.05% to 0.08% in Kelsih. As comparing between different seasons, post-monsoon season was found to have higher AP in the soil in both study sites. The present finding was consistent with 0.075 to 0.077% in *Schizostachyum pergracile* stands (Thokchom & Yadava, 2017) whereas greater than 4.20 mg/Kg reported by Yinga *et al*., (2022) and also greater than 4.99 mg/Kg in mixed forest (Mishra et al., 2019). However, lower than 2.1 mg/g to 5.6 mg/g in bamboo forest of Mizoram reported by Manpoong, C. (2019).

The AK ranged from 32 ppm to 62.77 ppm in Lengpui and in Kelsih, it ranged from 55 ppm to 79.33 ppm. The present finding was greater than 26.70 ppm in a mixed forest (Mishra et al., 2019) and 8.58 ppm to 14.43 ppm in a bamboo forest reported by Manpoong, C. (2019).

Soil respiration (SR)

In the present study, SR ranged from 9.56 Mg/ha/yr to 22.14 Mg/ha/yr in Lenpui and in Kelsih it ranged from 11.18 Mg/ha/yr to 25.00 Mg/ha/yr which were higher than annual SR rate 7.22 to 10.70 Mg/ha/yr of bamboo plantation in subtropical China (Zhang *et al*., 2020); 6.47Mg/ha/yr in temperate deciduous forest and 6.95Mg/ha/yr in coniferous forest reported by Raich & Schlesinger, (1992); 3.26Mg/ha/yr in teak forest and 3.13 Mg/ha/yr in mixed deciduous forest in Thailand (Wangluk *et al*., 2013). Current finding was also higher than 7.22 to 10.70 Mg/ha/yr of bamboo plantation in subtropical China reported by Zhou *et al*., (2013). However, it was lower than 31.1Mg/ha/yr in *Phyllostachys bambusoides* stands from temperate zones in Japan (Isagi, 1994). These differences are expected to dependence of SR on different and environmental conditions like temperature, rainfall and the amount of organic matters in different forest types within the same climatic zones.

Correlation analysis shows that SR had significant positive correlations with ST and SOC in this study. The result was in accordance with the results reported by Tu *et al*., (2013) and Sheng *et al*., (2010) which suggested that the ST affects the pattern of the SR rates primarily by regulating the microbial activities and plant metabolisms related to soil carbon cycling.

5.2 Bamboo

Melocanna baccifera (MB)

Culm density

In MB, average culm densities were 11772 culm/ha in Lengpui, 11914 culm/ha in Kelsih and 8813 culm/ha in Tamdil. The result was consistent with 11,022 culm/ha of *Melocanna baccifera* in Mizoram (Lalnunmawia, 2008); whereas the present culm densities were higher than 3400–4220 culms/ha in moso bamboo in China (Xu *et al*., 2018); however, lower than 39,075 culms/ha of *Melocanna baccifera and* 43,000 culm/ha *Pseudostachyum polymorphum* in Assam (Singnar *et al*., 2017); 20,784 culms/ha of *Yushania alpina* in West Amhara, Ethiopia (Nigatu *et al*., 2020). The culm density in Tamdil was lower as compared to Lengpui and Kelsih.

By comparison between different age classes, the culm density was found highest in the ≥3-year-old age class followed by 2-year-old age class and the least was found in 1-year age class in Lengpui and Tamdil, however in Kelsih the culm density of 2-year-old age class was higher than 1-year age class. Higher culm density of older age class than younger culms in the present study was contradictory to Singnar *et al*., (2017); Thokchom & Yadav (2015) who reported younger culm densities are greater than older culms. In Mizoram, young shoots of *Melocanna baccifera* is a favourite seasonal food. Therefore, the present trend was observed due to the frequent harvesting of young shoots by the local people.

DBH

The DBH of *Melocanna baccifera* in the present study ranged from 2.07-6.24 cm. In lengpui, DBH was ranged from 2.07-4.64 cm, 2.80-4.40 cm in Kelsih and 4.00-6.24 cm in Tamdil. The culm sizes were comparatively bigger in Tamdil as compare to Lengpui and Kelsih. The reason could be environmental factor like water availability in Tamdil as the study site is at the periphery of a large lake called Tamdil. The current range of DBH was in the range reported by Platt *et al*., (2010) of *Melocanna baccifera* from western Myanmar. It was also comparable with the previously reported DBH range of 3-5 cm by Signar *et al*., (2015). Significant negative correlation was found between DBH and culm density within the three sites. Lesser culm density in the site Tamdil compared to Lengpui and Kelsih can be attributed to the bigger size of culms, similar pattern of negative correlations between DBH and culm density in moso bamboo was reported by Yen & Lee, (2011).

***Bambusa tulda* (BT), *Dendrocalamus longispathus* (DL), and *Melocalamus compactiflorus* (MC)**

Culm density

The average culm density of BT, DL and MC were observed to be 4255 culms/ha, 5746 culms/ha and 3819 culms/ha respectively. The current culm density was higher than 1088 culms/ha of *Bambusa tulda* in Tripura Northeast India (Majumdar *et al*., 2016); 1860 culms/ha of *Bambusa tulda* and 1364 culms/ha of *Dendrocalamus strictus* in Northern India (Pathak *et al*., 2015); and 2933 culms/ha of *Bambusa vulgaris* in Bangladesh (Sohel *et al*., 2015). However, the present range was lower than 7365 culms/ha of village bamboo grove in Assam (Nath and Das, 2012); 7171culms/ha of *Bambusa vulgaris* in Ghana (Amoah *et al*., 2020), and 32,376 culm/ha in *Schizostachyum dullooa* (Singnar *et al*., 2017). The net change in culm density was 5267 culm/ha and 6960 culm/ha in BT and DL respectively. There was a decrease in culm density of 1year age class (-334 culm/ha) and 2-year age class (-66 culm/ha) in BT during the second year of study which indicates that number of young shoots were comparatively lesser in the later year and younger bamboo culms were harvested without proper planning. In DL, there was a net increase of 6960 culm/ha in the second year with 1year age class (1670 culm/ha), 2year age class (1450 culm/ha) and (3840 culm/ha). Similar pattern of net change was also observed in MC; which attributed that DL and MC forest sites were undisturbed by human activities.

In the present study, culm density of older age class was higher as compared to the younger age class. The distribution pattern was 1:1:3 for 1, 2 and ≥ 3-year-old in all three sympodial bamboos. The recommendation of Yuming *et al*., (2001) which reported that maintenance of age class structure of 3:3:3:1 for 1 to 4-year-old bamboo stands for the optimum culm production was not observed in the present study. The reason for lower younger culms could be attributed to lack of harvesting of the mature culms as the study sites Lengpui (for BT) was a protected site and the study sites in Tuirial (for DL) and Darlawn (MC) were in deep natural forests with remote terrains which were difficult for the extraction of matured culms. Similar pattern of higher density of older age culms was also observed from Masha bamboo forest in Ethiopia reported by Embaye *et al*., (2005). Nath and Das (2012) reported a stand population structure of 4:3:2:1 in 1 to 4-year-old culms in a bamboo grove in Barak valley of Assam in Northeast India. Yuming *et al*., (2001) further suggested that, in a bamboo forest more prevalence of older culms with high lifferfall biomass than the new shoots produced are the indicators of forest degradation. Whereas, in the present study the litterfall biomass was very low which indicates that the level of forest degradation was not very high in the selected study sites. However, for protection and to preserved these natural forests from possible threat of forest degradations, the mature culms should be harvested with proper planning for its utilization and to maintain the stands.

The correlation analysis indicated that culm density plays an important role in the level of aboveground biomass, the increase in culm density especially in the older age class in the second year can be the determining factor for the amount of aboveground biomass.

DBH

BDH in BT, DL and MC in the present study ranged from 4.3-5.5 cm, 5.5-6.1cm and 1.9-2.3 cm respectively. Among the studied bamboo species, DL was observed to have the largest culm size followed by BT and MC with the smallest culm sizes. The present range of DBH was greater than 3.67 cm in BT reported by Getachew *et al*., (2021); whereas in the range of 3.38-6.84 Xayalath *et al*., (2020) and 4.52-5.75cm (Banik, 2015). In DL, the current result was greater than 4.1-5.3 cm reported by Banik, (2015). As MC being an uncommon bamboo species, the previous data for its comparison on DBH was not found.

The positive correlation between aboveground biomass and DBH in BT was also a significant factor for the abrupt increase in aboveground biomass in the second-year of study period. There was an increase of 0.45, 0.60 and 0.68 cm in the average DBH of BT in the 1, 2 and ≥ 3-year-old age class respectively, indicating a maximum increase in the older age class. Whereas in DL, MC increase in DBH was observed only in 1-year old age class and 2-year-old age class respectively in the second year. The specific reason for this variation in growth pattern between studied bamboo species was unclear. Whereas, Banik, (2015) had reported that culm DBH may increase or decrease depending on the site conditions and primarily determined by the health and size of bud present in the underground rhizome from where it develops. Xu *et al*., (2020) also reported that particular growth pattern was followed in moso bamboo by transferring nutrients and carbonates from mature to young culms through interconnected rhizome.

5.3 Biomass, C-storage and C-sequestration

***Malocanna baccifera* (MB)**

Between the three age classes the ≥3-year-old contributes maximum above ground biomass (AGB) of culm component. The total biomass (above and below ground) ranged from 36.92 to 47.99 Mg/ha, 96.24 to 117.31 and 85.64 to 178.72 Mg/ha in Lengpui, Kelsih and Tamdil respectively. Out of the total AGB, culm component shared the highest proportion (73.03%) followed by leave (15.81%) and branch (11.16%) in MB). In the current study, biomass of leaf component in 2-year-old age class was higher than branch biomass which was not found in majority of other studies (Shanmughavel & Francis, 1996; Singh & Singh,1999; Nath *et al*., 2009; Yen *et al*., 2010). By comparing between the three selected sites Tamdil had the highest amount of biomass accumulation followed by Kelsih and the least with Lengpui. The reason for higher amount of biomass in Tamdil was attributed by greater culm sizes in all the analysed age classes of bamboo than culm sizes in Lengpui and Kelsih.

The contribution of the ≥ 3-year-old age class (average of the two study years) to total biomass (above and below ground) was maximum with Lengpui (47.26%), Kelsih (50.53%) and Tamdil (42.35%). The present finding was comparable with previously reported biomass range in *Melocanna baccifera* bamboo forest concluding around 50% was contributed by ≥ 3-year-old age class (Nath *et al*., 2009); also, in in *Phyllostachys makinoi* (Yen *et al*., 2010). In all the three sites the ≥3-year-old culms contributes maximum biomass and least was in 1-year old culms. The amount of biomass accumulation in different components followed the pattern culm>rhizome>leaf >branch> sheath.

By comparing between different components, percentage of C-content was highest in rhizome (28.48%) followed by culm component (26.51%), branch (19.29%), leaf component (19.08%) and sheath component (6.61%). The present range is consistent with 83.67%, 8.94% and 7.39% contribution by culm, branch and leave components respectively in Schizostachyum *pergacile* bamboo form Northeast India (Thokchom & Yadav, 2015); with mixed bamboo forest from Ghana which had 90.3%, 5.7% and 4.0% contribution of culm, branch and leave components, respectively (Amoh *et al*., 2020). As the compared reports did not separated culm and rhizome components, the C-content in culm components were greater than the present finding.

The C-storage ranged from 15.15 to 19.33 Mg/ha, 38.98 to 48.8 Mg/ha and 35.49 to 71.82 Mg/ha respectively in Lengpui, Kelsih and Tamdil. C-storage corresponds according to the level of aboveground biomass. The current findings of C-storage in *Melocanna baccifera* was higher than 20.92 Mg/ha of *Bambusa tulda* (Majumdar *et al*., 2016); 6.47 Mg/ha of *Dendrocalamus strictus* (Pathak *et al.*, 2015) and 13.96 Mg/ha of moso bamboo (Xu *et al*., 2018). The rate of C-sequestration was 4.31 Mg/ha/year, 9.93 Mg/ha/year and 36.52 Mg/ha/yr in Lengpui, Kelsih and Tamdil respectively. The current finding was consistent with 8.98 Mg/ha/yr and 22.07 Mg/ha/yr of C-sequestration in bamboo forests of Kolasib and Lunglei district respectively (Vanlalfakawma, D. C. (2014); 18.93–23.55 Mg/ha/year reported by Embaye *et al.* (2005) and 21.36 Mg/ha/year (Nath and Das, 2009). By comparing between three selected sites, rate of C-sequestration was maximum in Tamdil despite lower culm density. In MB, culm size can be a significant factor effecting the C-sequestration; another factor was the sharp increase in culm density of 1year age class in the second year of this study at Tamdil.

***Bambusa tulda* (BT), *Dendrocalamus longispathus* (DL), and *Melocalamus compactiflorus* (MC)**

The aboveground biomass was much higher in DL with a total of 115.08 Mg/ha and 150.0 Mg/ha in the first and the second year of study respectively whereas, in BT it was 57.02 Mg/ha and 127.03 Mg/ha in the first and the second year respectively and in MC it was 34.28 Mg/ha and 89.18 Mg/ha respectively. There was a wide gap in aboveground biomass of BT between the 2 years of this study period especially in the ≥ 3-year-old age group with as much as 70.01 Mg/ha. As mentioned above, the high increment in culm density of ≥ 3-year-old culms in BT during the second-year study period was the main reason for such a result. The reason could be higher culm density in the 2-year-old age class in BT during the first-year study period which ultimately comes under ≥ 3-year-old age class in the second year. The culm density of DL and MC were lower in the 2-year-old age class in both the study period thereby a wider gap between the 2 years was not observed in biomass. A difference of only 18.94 Mg/ha in biomass in the ≥ 3-year-old age class between the 2 years was recorded in DL. The positive correlation between the biomass and DBH in BT was also a significant factor for the abrupt increase in biomass in the second-year study period. There was an increase of 0.5, 0.6 and 0.7 cm in the average DBH of BT in the 1, 2 and ≥ 3-year-old age class respectively, indicating a maximum increase in the older age class. Whereas in DL, increase in DBH was observed only in 1-year old age class (0.3cm) in the second year of study and in MC there was increase only in 2-year old age class (0.1cm).

The contribution of the ≥ 3-year-old age class to aboveground biomass was maximum in all the three selected bamboo species with 57.46%, 72.24% and 62.77% respectively in BT, DL and MC (average of the two study years). Xu *et al*., (2018) have also reported a similar trend of a maximum contribution of 50% by the 3-year-old age group from a moso bamboo forest from Zhejiang province, China. Increase in culm biomass with increase in age was also observed in *Melocanna baccifera* bamboo forest (Nath *et al*., 2009); *Phyllostachys makinoi* (Yen *et al*., 2010) and in *Dendrocalamus latiflorus* (Wang, 2004). The younger culms have more moisture content, as age progresses the level of moisture content declines leading to higher contribution in the aboveground biomass. The present range of aboveground biomass was comparable with Pathak *et al.* (2015) which reported 104.7 Mg/ha from a *Bambusa balcooa* and 70.4 Mg/ha from *Bambusa tulda* forest in Utter Pradesh, Northern India; 162.2 Mg/ha of *Schizostachyum pergacile* from Manipur Northeast India (Thokchom and Yadava, 2015) and 114.6 Mg/ha of moso bamboo from Taiwan (Wang *et al*., 2009). The culm density was much lower in their studies compared to the present study. The present range is also comparable to 105.33 Mg/ha of *Phyllostachys makinoi* from Taiwan (Yen *et al*., 2010) which have almost the same range of culm density with the present work. However, it was lower than Quiroga *et al*., (2013) which reported aboveground biomass of 200 Mg/ha from *Guadua angustifolia* bamboo forest in Bolivia. In their study the DBH of the bamboo was very high with 16.8 cm and a low culm density of 4500 culms/ha.

By comparing between different components, percentage of C-content was maximum in culm component (39.58%) followed by branch (28.35%), leaf component (24.01%) and sheath component (8.04%) in BT. In DL, highest C-content was in culm component (31.30%) followed by branch component (31.29%), leaf component (30.29%) and the least C-content with sheath component (7.10%). The pattern of C-content was consistent with Thokchom & Yadav, (2015); Amoh *et al*., (2020) which reported maximum C-content in culm component followed by branch, leaf and sheath components in Schizostachyum *pergacile* bamboo form Northeast India and in mixed bamboo forest from Ghana.

The C-storage ranged from 27.7 to 63.99 Mg/ha, 50.11 to 65.16 Mg/ha and 17.13 to 44.66 Mg/ha respectively in BT, DL and MC. The results correspond according to the level of aboveground biomass. The present observation of C-storage in aboveground biomass was higher than 20.92 Mg/ha of *Bambusa tulda* (Majumdar *et al*., 2016); 6.47 Mg/ha of *Dendrocalamus strictus* (Pathak *et al.*, 2015) and 13.96 Mg/ha of moso bamboo (Xu *et al*., 2018). The rate of C-sequestration was respectively 36.48 Mg/ha/year, 15.26 Mg/ha/year and 27.65 Mg/ha/yr in BT, DL and MC which were comparable with 18.93–23.55 Mg/ha/year reported by Embaye *et al.*(2005) and 21.36 Mg/ha/year reported by Nath and Das (2009) but higher than other previous reports in evergreen broadleaved forest (8.35Mg/ha/yr) and coniferous and broadleaved mixed forest (6.59 Mg/ha/yr) in Zhejiang Province (Zhang *et al*. 2007). The culm density was very high in the present study, leading to the high rate of C-sequestration in the aboveground biomass. By comparing between these selected clumping bamboo species, BT (36.48 Mg/ha/yr) has maximum capability to sequester C in the aboveground biomass followed by MC (27.65 Mg/ha/yr) and DL (15.26 Mg/ha/yr). However, it can be suggested that estimation of rate of C-sequestration in aboveground biomass should be carried for a longer duration of years so that large differences in level of C-storage between the successive years can be normalized. From the present findings it can be concluded that density of the culms is an important factor in the study of aboveground biomass of bamboos. In order to maintain a stable ecosystem of bamboo forest, harvesting of old culms is an important factor as concentration of older culms would hamper sprouting of new shoots. Moreover, the study also showed that aboveground biomass in the stands of *Bambusa tulda*, *Dendrocalamus longispathus* and *Melocalamus compactiflorus* have high potential for sequestration of C. As also suggested by Nath and Das (2009) C-sequestration by bamboo forest can be considered for CDM projects under Kyoto Protocol. It will eliminate poverty and environmental degradation. Therefore, initiatives can be taken up by policymakers to utilize the barren lands for plantation of bamboo.

5.4 Elemental analysis

The vinegar was smoky dark brown liquid with specific odour. The pH was ranged from 2.46 to 2.63 in MB; 2.59 to 2.67 in BT (Table 27) in the present study which was similar with the earlier report of 2.5 to 2.8 (Akakabe *et al*., 2006). The chemical characteristics of bamboo vinegar through GC-MS analysis shows the presence of aldehydes, benzene, allyl compounds, polyphenols and carbohydrates; Akakabe *et al*., (2006) had reported that the organic compounds in bamboo vinegar were mainly ketones, aldehydes, phenols and carboxylic acids out of which acetic acid comprised of about 80%. Different studies have reported that vinegar could be used as anti-bacteria on vegetables and fresh fruits (Wu *et al*., 2000; Rhee *et al*., 2003; Sengun & Karapinar, 2004; Chang & Fang, 2007) it also had therapeutic effect on burns due to antibacterial properties (Krystynowicz *et al*., 2000).

In the present study, polyphenols such as furfural, D-fructose, Phenol-2-methoxy (Guiacol), 2-Methoxy-4-methylphenol (Creosol), Catechol and 2-Propenyl were found in pyrolyzed liquid of MB (Table 28); Malezitose, Catechol and 2,6-Dimethoxyphenol in BT. The present finding was comparable with previous report of phenolic content in different bamboo species *Dendrocalamus latiflorus* (612.24 mg/100g, fresh weight), *Dendrocalamus hamiltonii* (586.36 mg/100g, fresh weight), *Bambusa nutans* (489.83 mg/100g, fresh weight) and *D endrocalamus giganteus* (336.56 mg/100g, fresh weight) Nirmala *et al*., (2018). Theapparrat *et al*., (2015) also reported that many phenol derivatives were found in pyroligneous acids of *Dendrocalamus asper* and *Hevea brasiliensis* such as 4-propyl-2-methylphenol, 2-methylphenol, 2-furfuraldehyde, methyl-2-furoate and 2-methylfuran which were basically resulted from thermal degradation of lignin.

Phenolic compounds such as, chlorogenic acid, caffeic acid, and luteolin-7-glucoside were present in leaf extract of *Phyllostachys nigra* having radical scavenging and antioxidant activities Hu *et al*. (2000). The dominant phenols in the pyrolyzed plant biomass were obtained from cleavage of β-O-4 linkage in lignin; according to characteristics of functional groups, pyrolyzed bamboo liquid products are primarily classified into eight groups which were acids, phenols, furans, aldehydes, ketones, alcohols, hydrocarbons and esters (Sun *et al*., 2020). Nirmala *et al*., (2018) also reported that Several compounds with antioxidative properties have been isolated from the leaves and shoots of many bamboo species. Bamboo shoot is rich in vitamin C and vitamin E, it is also a good multivitamin food that can act as a foundation for good health. Consumption of natural antioxidants like polyphenols can reduce the formation of oxidized low-density lipoproteins (LDL) in the bloodstream (Sugiyama *et al*., 2003). Results showed that *D. latiflorus* (612.24 mg/100g, fresh weight) has highest phenolic content, followed by *D. hamiltonii* (586.36 mg/100g, fresh weight), *B. nutans* (489.83 mg/100g, fresh weight), and *D. giganteus* (336.56 mg/100g, fresh weight). Similarly, Nemenyi *et al*. (2015), analyzed the total phenolic content of shoots of 14 *Phyllostachys* species (*P. aureosulcata, P. aureosulcata f. aureocaulis, P. aureosulcata f. spectabilis, P. bissetii, P. flexuosa, P. humilis, P. nigra* var. *nigra, P. nigra* var. *henonis, P. mannii, P. sulphurea* var. *sulphurea, P. viridiglaucescens, P. vivax f. aureocaulis*), harvested at different time duration. The highest value of total phenolic content was measured in the shoots of *P. aureosulcata* (1,321.95 µg

GA/ml) and lowest was reported in the shoots of *P. vivax f. aureocaulis* (826.22 µg GA/ml). It was also reported that, the highest total phenolic content was measured in taxa harvested on the first collection date and the values consequently decreased in taxa collected at later harvest dates.

The trace elements such as Cr, Fe, Zn, Mo and Pb and four macro elements (Na, Mg, K, and Ca) were observed in the pyrolyzed liquids of MB and BT with different concentrations. Bamboo shoots are gifted with rich quantities of useful minerals; trace elements in bamboo shoots associated with antioxidant defense system are zinc, iron, selenium, copper and manganese (Nirmala *et al*., 2018). Soetan & Oyewole, (2009) high lightened the role of trace minerals in enzyme functions and in nutrition and biochemistry. Iron content in shoots of different bamboo species as reported by Christian *et al*. (2015) ranges from 10.3 µg/g to 43.2 µg/g. Zinc, copper, and manganese content in *Phyllostachys* species ranges from 11.5 µg to 54.6 µg/g, 0.6 µg to 35.0 µg/g, and 11.5 µg to 176.7 µg/g respectively (Mainka, Zhao, & Li, 1989; Tabet, Oftedal, & Allen, 2004; Christian *et al*., 2015). Iron is the most abundant trace element in the body, and almost all iron occurs bound to proteins; in the dry weight of bamboo it ranged from 8.0 to 8.2 mg/100g; Zn ranged from 6.8 to 10.0 mg/100g, Mg ranged from 2.5 to 3.6 mg/100g and Cu ranged from 2.5 to 2.6 mg/100g (Nirmala *et al*., 2018) Thus, bamboo was found to have potential as a source of dietary minerals with great importance.

6. SUMMARY AND CONCLUSION

Attention towards the changing pattern of earth"s climatic condition is one of the most challenging concerns of this century. It is evident from geological time scale that climate of the planet earth has been changing subsequently on its own pace, but the global temperature has been increasing in an alarming rate since the end of 18^{th} century and majority of the scientific communities believe that this alarming change is a result of anthropogenic activities. Increased in greenhouse gas (GHG) emissions and overloading amounts of these gases, mainly the CO2 in atmosphere is the primary causes of global warming and frequent occurrence of extreme weather events worldwide in recent decades.

Human induced activities such as land use change and extensive use of fossil fuel have already affected the composition of Earth's atmosphere and experienced tremendous changes in biological diversity of the planet earth. The third conference of parties of The United Nations Framework Convention on Climate Change (UNFCCC) in Kyoto, 1997 had a unanimous agreement on incorporation of forestry activities as a sustainable way for the carbon emission reduction (Ramachandran *et al*., 2007). and to adopt the Clean Development Mechanism (CDM) a strategy for the mitigation of global warming by reducing CO2 from the atmosphere, encouraging Global Environmental Facility (GEF), and Reduced Emission from Deforestation and Forest Degradation (REDD) to provide financial supports to the developing countries to promote forestry and reduction emission of CO_2 which is a green way for mitigation of CO_2 from the atmosphere. Basically, plants convert carbon dioxide (CO_2) into organic compounds as biomass through photosynthesis, and these biomasses are the primary source of energy in the food web of ecosystems, known as gross primary product (GPP).

Different plant species have different potentials for capturing and sequestration of carbon. In recent years, the carbon sequestration (CS) capacity of various forests has become increasingly important worldwide because of global warming. Bamboo forest is an important forest type with high potential CS, and this forest type is abundant in Taiwan. Further research on bamboo could provide valuable information on the CS potential of various bamboo species in relation to their stand characteristics (Liu & Yen, 2021). Thus, the present study was conducted to investigate the CS potential of five main bamboo species naturally found in Mizoram.

Bamboo is a unique group of tall grasses with woody interconnected stems which belongs to the subfamily *Bambusoideae* of grass family *Poaceae* (Graminaceae) which is recognized for its fast-growing potential and its versatile nature among the plant‟s kingdom on earth. There are about 1,500 species in 90 genera worldwide (Desalegn & Tadesse, 2014). The North-eastern hill States of India harbour nearly 90 species of bamboos, 41 of which are endemic to the region. There are 3 large genera of bamboo in India i.e *Bambusa*, *Dendrocalamus*, and *Ochlandra stridula* with more than 10 species each; together these three genera represent about 45% of the total bamboo species found in the country (Sharma & Nirmala, 2015). Role of bamboo in C storage and sequestration has not been studied adequately in northeast India (Nath *et al*., 2009; Nath & Das, 2011).

The present work was carried out on three main sections such as analyses on soil physico-chemical characteristics of bamboo forest, biomass estimation and CS potential of selected bamboo species and the estimation of elemental content and bioactive compounds in pyrolyzed bamboo liquid (vinegar).

Soil physico-chemical characteristics

The average soil moisture content in the present study ranged from 18.19 to 25.62%; similar range of soil moisture content (17 - 24%) was reported by Manpoong & Tripathi, (2019) from different land use systems in Mizoram. The seasonal variation of soil pH of bamboo forests in both the study sites ranged from 5.20 to 6.06 which indicates acidic nature of soil (Table 2). The soil BD was ranged from 0.621 to 0.737 g cm^{-3} in the present study (Table 4); the similar range of BD 0.40 to 0.71 g cm^{-3} was reported by Alice *et al*., (2019) in different land use types of Mizoram. ST was higher during 2015 in both the study sites (Table 3) and Lengpui site had higher mean ST as compare to Kelsih site. Soil organic carbon (SOC) up to the depth of 30cm ranged from 1.64% - 3.15% in Lengpui and in Kelsih it ranged from 1.96% - 4.06% (Table 5). SOC content in the study were higher than previously reported SOC across different land use patterns of Mizoram such as large home garden

(2.07%), medium home garden (1.77%), young shifting cultivation fallow (1.42%) and old shifting cultivation fallow (2.12%) (Singh & Sahoo, 2021). Soil C storage up to the depth of 30 cm were 43.96 MgC/ha and 51.31 MgC/ha during 2015 and 2016 respectively in Lengpui; 52.14 MgC/ha and 56.81 MgC/ha during 2015 and 2016 respectively in Kelsih (Table10). The SR ranged from 9.56 Mg/ha/yr to 22.14 Mg/ha/yr in Lenpui and in Kelsih it ranged from 11.18 Mg/ha/yr to 25.00 Mg/ha/yr (Table 9) which were higher than annual SR rate 7.22 to 10.70 Mg/ha/yr of bamboo plantation in subtropical China (Zhang *et al*.,2020).

Biomass estimation and C-sequestration potential

The total biomass (above and below ground) in *Melocanna baccifera* was ranged from 36.92 to 47.99 Mg/ha, 96.24 to 117.31 and 85.64 to 178.72 Mg/ha in Lengpui, Kelsih and Tamdil respectively (Table 16). By comparing between different components, culm component had maximum biomass (73.03%) followed by leave (15.81%) and branch (11.16%). The C-storage in biomass were ranged from 15.15 to 19.33 Mg/ha, 38.98 to 48.8 Mg/ha and 35.49 to 71.82 Mg/ha respectively in Lengpui, Kelsih and Tamdil (Table 19). The rate of C-sequestration was 4.31 Mg/ha/year, 9.93 Mg/ha/year and 36.52 Mg/ha/yr in Lengpui, Kelsih and Tamdil respectively. The current finding was consistent with 8.98 Mg/ha/yr and 22.07 Mg/ha/yr of C-sequestration in bamboo forests of Kolasib and Lunglei district respectively (Vanlalfakawma, D. C. (2014); 18.93–23.55 Mg/ha/year reported by Embaye *et al.*, (2005) and 21.36 Mg/ha/year (Nath & Das, 2009).

The aboveground biomass was highest in DL which ranged from 115.08 Mg/ha to 150.0 Mg/ha in 2015 and 2016 respectively, in BT it was ranged from 57.02 Mg/ha to 127.03 Mg/ and in MC it was ranged from 34.28 Mg/ha to 89.18 Mg/ha respectively (Table 17 and 18). The C-storage in AGB during the studied years were ranged from 27.7 to 63.99 Mg/ha, 50.11 to 65.16 Mg/ha and 17.13 to 44.66 Mg/ha respectively in BT, DL and MC.

Elemental content and chemical compound in pyrolyzed bamboo liquid (vinegar)

Bamboo vinegar is a brown-red transparent liquid with a special smoky odour and is composed of nearly 90% water and more than 200 kinds of chemical components (Mu *et al*., 2006); it has been widely used in agriculture and daily life in different parts of the world.

In the present study, the trace elements such as Cr, Fe, Zn, Mo and Pb and four macro elements (Na, Mg, K, and Ca) were observed in the pyrolyzed liquids of MB and BT with different concentrations (Tables 23-26). Bamboo vinegar contains organic compounds such as phenolic compounds, organic acids, alkanes, alcohol, aldehydes and many more (Ikimoto & Ikeshima , 2000). pH of bamboo vinegar was ranged from 2.46 to 2.63 in MB; 2.59 to 2.67 in BT (Table 27) which was consistent with 2.5 to 2.8 (Akakabe *et al*., 2006). Polyphenols such as furfural, D-fructose, Phenol-2-methoxy (Guiacol), 2-Methoxy-4-methylphenol (Creosol), Catechol and 2-Propenyl were found in pyrolyzed liquid of MB (Table 28); Malezitose, Catechol and 2,6-Dimethoxyphenol in BT (Table 29). The present finding was parallel with previous report of phenolic content in different bamboo species *Dendrocalamus latiflorus* (612.24 mg/100g, fresh weight), *Dendrocalamus hamiltonii* (586.36 mg/100g, fresh weight), *Bambusa nutans* (489.83 mg/100g, fresh weight) and *Dendrocalamus giganteus* (336.56 mg/100g, fresh weight) (Nirmala *et al*., (2018).

From the above findings it can be concluded that biomass in the stands of *Melocanna baccifera*, *Bambusa tulda*, *Dendrocalamus longispathus* and *Melocalamus compactiflorus* have high potential for C-sequestration. To maintain a stable ecosystem of bamboo forest, harvesting of matured culms is important as the concentration of older culms would hamper sprouting of new shoots. Moreover, as suggested by Nath & Das (2009) C-sequestration by bamboo forest can be considered for CDM projects under Kyoto Protocol. Organized plantation of bamboo will improve the economic condition of the local people as well as reducing environmental deprivation. Therefore, initiatives can be taken up by policymakers to utilize the degraded lands for plantation of bamboo and to mitigate CO_2 from atmosphere thus reduce the impact of climate change.

APPENDICES

Appendix I: Quadrate-wise soil moisture content (%) in Lengpui and Kelsih during 2015 and 2016

Site	Month	2015			2016		
		Q1	Q2	Q3	Q1	Q2	Q3
Lengpui	March	8.43	8.87	8.59	8.56	8.79	8.81
	April	19.66	19.94	19.86	20.62	20.74	20.65
	May	20.21	20.39	20.66	25.1	25.31	25.79
	June	19.51	19.36	19.54	27.72	27.43	27.86
	July	19.14	18.95	19.21	26.66	26.81	26.93
	August	22.12	22.67	23.07	33.21	33.55	33.53
	September	23.26	23.47	23.17	35.14	35.1	35.18
	October	19.86	19.47	20.01	33.14	33.46	33.48
	November	15.66	15.48	16.02	26.56	26.25	26.96
	December	13	12.89	13.41	18.41	18.54	18.31
Kelsih	March	8.48	8.59	8.64	12.04	12.14	12.12
	April	19.86	20.06	20.08	21.87	21.67	22.37
	May	21.21	21.34	21.38	21.78	21.8	21.91
	June	24.29	24.16	24.39	32.21	32.34	32.53
	July	29.06	28.75	29.46	28.1	28.24	28.14
	August	32.48	32.55	32.65	31.66	31.85	31.89
	September	31	31.08	31.34	30.34	30.51	30.35
	October	28.41	28.65	28.44	27	26.94	27.24
	November	18.31	18.4	18.43	23.21	23.25	23.26
	December	13.64	13.56	13.66	16.54	16.62	16.67

Appendix II: Quadrate wise variation of seasonal soil pH of Lengpui and Kelsih during 2015 and 2016

Site	Season	2015			2016		
		Q1	Q2	Q3	Q1	Q2	Q3
Lengpui	Summer	5.61	5.68	5.66	5.81	5.89	5.85
	Rainy	5.14	5.26	5.2	5.24	5.26	5.19
	Winter	5.34	5.38	5.3	5.51	5.57	5.54
Kelsih	Summer	6.02	6.09	6.07	5.7	5.66	5.59
	Rainy	5.79	5.84	5.95	5.31	5.4	5.34
	Winter	6.08	5.96	6.02	5.94	6.03	5.73

Appendix III: Quadrate wise seasonal variation of soil temperature (^{0}C) of Lengpui and Kelsih during 2015 and 2016

Site	Season	2015			2016		
		Q1	Q2	Q3	Q1	Q2	Q3
Lengpui	Summer	32.87	32.89	32.91	22.44	22.45	22.34
	Rainy	26.64	26.63	26.62	25.42	25.34	25.41
	Winter	20.52	20.52	20.52	20	20.07	20.02
Kelsih	Summer	23.28	23.34	23.31	22.28	22.27	22.26
	Rainy	26.41	26.45	26.43	24.86	24.87	24.82
	Winter	20.42	20.42	20.39	19.9	19.94	19.89

Appendix IV: Quadrate wise seasonal variation of soil bulk density (g/cm^3) of Lengpui and Kelsih during 2015 and 2016

Site	Season	2015			2016		
		Q1	Q2	Q3	Q1	Q2	Q3
Lengpui	Summer	0.739	0.737	0.735	0.662	0.663	0.661
	Rainy	0.723	0.726	0.72	0.653	0.652	0.648
	Winter	0.732	0.731	0.733	0.664	0.663	0.665
Kelsih	Summer	0.638	0.638	0.641	0.631	0.634	0.628
	Rainy	0.631	0.635	0.63	0.626	0.621	0.616
	Winter	0.709	0.708	0.707	0.643	0.643	0.64

Appendix V: Quadrate-wise monthly variation of SOC (%) in Lengpui and Kelsih during 2015 and 2016

Site	Month	2015			2016		
		Q1	Q2	Q3	Q1	Q2	Q3
Lengpui	March	2.05	2	2.01	1.96	2.02	2.02
	April	2.41	2.32	2.29	2.48	2.46	2.41
	May	1.84	1.93	1.84	2.28	2.31	2.25
	June	2.49	2.38	2.45	3.18	3.11	3.1
	July	2.79	2.88	2.88	2.77	2.84	2.97
	August	2.86	2.8	2.8	2.26	2.31	2.3
	September	2.72	2.64	2.47	3.09	3.16	3.2
	October	2.49	2.58	2.58	2.51	2.49	2.62
	November	1.91	1.94	2.03	2.38	2.31	2.39
	December	1.95	1.99	1.97	1.58	1.67	1.67
Kelsih	March	1.95	2.03	1.9	2.04	1.87	2.09
	April	2.06	2.19	2.02	2.12	2.34	2.17
	May	2.15	2.17	2.1	2.19	2.25	2.25
	June	3.13	3.22	3.07	3.46	3.64	3.43
	July	3	3.04	3.05	3.89	4.1	4.19
	August	2.74	2.81	2.64	3.9	3.79	4.34
	September	2.81	2.97	2.74	3.46	3.71	3.63
	October	3.34	3.17	3.45	3.55	3.76	3.58
	November	3.08	3.24	3.19	3.14	3.32	3.41
	December	2.14	2.67	2.6	2.72	2.99	3.11

Appendix VI: Quadrate wise seasonal variation of Total Nitrogen (%) in Lengpui and Kelsih during 2015 and 2016

Site	Season	2015			2016		
		Q1	Q2	Q3	Q1	Q2	Q3
Lengpui	Summer	0.57	0.59	0.58	0.61	0.62	0.6
	Rainy	0.61	0.61	0.61	0.64	0.64	0.67
	Winter	0.57	0.58	0.59	0.69	0.7	0.71
Kelsih	Summer	0.65	0.65	0.65	0.66	0.65	0.64
	Rainy	0.66	0.68	0.67	0.73	0.74	0.75
	Winter	0.69	0.7	0.71	0.66	0.66	0.66

Appendix VII: Quadrate wise seasonal variation of Available Phosphorus (%) in Lengpui and Kelsih during 2015 and 2016

Site	Season	2015			2016		
		Q1	Q2	Q3	Q1	Q2	Q3
Lengpui	Summer	0.06	0.063	0.057	0.082	0.079	0.079
	Rainy	0.064	0.061	0.055	0.051	0.049	0.05
	Winter	0.021	0.024	0.027	0.11	0.114	0.106
Kelsih	Summer	0.049	0.05	0.051	0.051	0.05	0.049
	Rainy	0.08	0.081	0.079	0.082	0.08	0.078
	Winter	0.079	0.079	0.082	0.07	0.07	0.07

Appendix VIII: Quadrate wise seasonal variation of Available Potassium (ppm) in Lengpui and Kelsih during 2015 and 2016

Site	Season	2015			2016		
		Q1	Q2	Q3	Q1	Q2	Q3
Lengpui	Summer	50.71	50.71	50.38	62.68	62.8	62.83
	Rainy	32.1	32.14	31.76	56.23	56.09	56.01
	Winter	47.25	47.27	47.08	44.08	43.98	43.94
Kelsih	Summer	75.68	75.66	75.64	55.02	55	54.98
	Rainy	79.34	79.34	79.31	63.34	63.29	63.36
	Winter	70.01	69.88	69.75	63.81	63.68	63.82

Appendix IX: Quadrate-wise monthly variations of Soil respiration (mg/kg/d) in Lengpui and Kelsih during 2015 and 2016

Site	Month	2015			2016		
		Q1	Q2	Q3	Q1	Q2	Q3
Lengpui	March	9.24	9.86	9.58	11.04	11.43	11.19
	April	11.97	12.73	13.13	15.42	15.44	15.85
	May	12.21	12.87	13.32	22.12	22.16	22.14
	June	14.8	15.56	15.48	18.52	18.94	18.73
	July	18.49	18.76	18.91	19.43	20.14	20.1
	August	14.81	14.76	15.07	14.2	14.12	14.37
	September	15.71	15.7	15.51	19.84	20.16	20.48
	October	15.02	15.41	15.44	20.58	20.58	20.64
	November	12.4	12.08	12.54	17.04	16.91	16.99
	December	11	10.81	11.28	14.12	14.36	14.69
Kelsih	March	11.17	11.17	11.2	14.34	14.3	14.35
	April	13.67	13.6	13.89	19.21	19.18	18.94
	May	15.88	15.91	16.03	20.04	19.82	20.14
	June	20.34	20.4	20.37	24.88	25.04	25.08
	July	21.57	21.59	21.64	24.5	24.84	24.79
	August	21.4	21.47	21.72	24.06	24.01	23.87
	September	20.75	21.02	20.63	24.39	24.41	24.88
	October	19.08	19.12	19.28	20.94	21.06	21.12
	November	17.24	17.31	17.74	19.7	19.81	19.35
	December	14.49	14.53	14.57	15.04	15.74	15.66

Appendix X: Number of *Melocanna baccifera* culms of different age classes in different quadrates during 2015 and 2016

Site	Age class	2015			2016		
		Q1	Q2	Q3	Q1	Q2	Q3
Lengpui	1yr	62	75	66	71	68	60
	2yr	84	71	59	89	79	76
	≥3yr	136	126	184	204	285	322
Kelsih	1yr	78	65	68	121	139	136
	2yr	74	79	49	112	129	138
	≥3yr	164	127	151	186	179	146
Tamdil	1yr	55	60	47	76	61	75
	2yr	71	79	54	108	99	117
	≥3yr	98	109	105	124	117	131

Appendix XI: Number of culms of *Bambusa tulda, Dendrocalamus longispathus* and *Melocalamus compactiflorus* of different age classes in different quadrates during 2015 and 2016

Species	Age class	2015			2016		
		Q1	Q2	Q3	Q1	Q2	Q3
Bambusa tulda	1yr	21	26	31	19	24	25
	2yr	34	30	34	31	34	31
	≥3yr	42	48	38	94	105	99
Dendrocalamus longispathus	1yr	27	30	34	50	50	41
	2yr	20	27	17	29	38	41
	≥3yr	76	81	99	104	116	152
Melocalamus compactiflorus	1yr	12	15	15	33	40	30
	2yr	21	18	19	27	33	39
	≥3yr	39	46	50	81	95	71

Appendix XII: DBH (cm) of different bamboo species of different age classes in different quadrates during 2015 and 2016

Species	Site	Age class	2015			2016		
			Q1	Q2	Q3	Q1	Q2	Q3
Melocanna baccifera	Lengpui	1yr	2.71	2.24	2.49	3.7	4.2	3.8
		2yr	2.41	2.52	2.15	3	3.5	3.4
		≥3yr	1.9	3.2	1.86	2.4	2.1	3.3
	Kelsih	1yr	3.4	3	3.2	2.9	3.2	3.2
		2yr	3.1	3.4	4	3	3.6	3.6
		≥3yr	2.9	3.6	3.4	3.8	3.4	3.6
	Tamdil	1yr	5.7	5.4	4.8	5.4	6	5.7
		2yr	4.8	5.2	5.6	4.9	5.8	5.2
		≥3yr	4.8	4.2	4.5	5	4.5	4.6
Bambusa tulda	Lengpui	1yr	4.3	5.2	5.2	5	5.2	6
		2yr	4.5	4.6	3.8	4.9	5.3	4.5
		≥3yr	4.3	5.1	5	5.7	5.4	5.4
Dendrocalamus longispathus	Tuirial	1yr	5.6	6.1	5.7	6	5.8	6.5
		2yr	6	5.6	5.5	5.8	5.7	5
		≥3yr	5.7	5.9	5.5	5.4	6.1	5.6
Melocalamus compactiflorus	Darlawn	1yr	2.2	2.3	2.1	2.3	2.1	1.9
		2yr	2.1	2	2.5	2.3	2.4	2.2
		≥3yr	2	2	1.7	1.8	2	1.9

Appendix XIII: Component-wise, total and average C-content (%) of different age classes of studied bamboo species

Bamboo species	Site	Age class	Culm	Branch	Leaf	Rhizome	Sheath	Total	Average
Melocanna baccifera	Lengpui	1yr	36.71	-	-	41.37	29.72	107.8	35.93
		2yr	36.63	46.56	43.08	42.36	-	168.63	42.15
		≥3yr	43	45.4	45.9	41.8	-	176.1	44.02
		Total (1yr+2yr+3yr)	**116.34**	**91.96**	**88.98**	**125.53**	**29.72**	**452.53**	-
		%	**25.70**	**20.32**	**19.66**	**27.73**	**6.56**	**100**	-
	Kelsih	1yr	38.35	-	-	41.38	29.46	109.19	36.39
		2yr	39.5	39.25	39.3	43.02	-	161.07	40.26
		≥3yr	42.05	43.35	44.8	43	-	173.2	43.3
		Total (1yr+2yr+3yr)	**119.9**	**82.6**	**84.1**	**127.4**	**29.46**	**443.46**	-
		%	**27.03**	**18.62**	**18.96**	**28.72**	**6.64**	**100**	-
	Tamdil	1yr	36.35	-	-	43.5	29.65	109.5	36.5
		2yr	39.8	39.75	39.75	44.5	-	163.8	40.95
		≥3yr	43.5	44.9	43.5	41.5	-	173.4	43.35
		Total (1yr+2yr+3yr)	**119.65**	**84.65**	**83.25**	**129.5**	**29.65**	**446.7**	-
		%	**26.78**	**18.95**	**18.63**	**28.99**	**6.63**	**100**	-
Bambusa tulda	Lengpui	1yr	48.5	-	-	-	30.14	78.64	39.32
		2yr	47.82	54.75	45.75	-	-	148.32	49.44
		≥3yr	52	51.5	44.25	-	-	147.75	49.25
		Total (1yr+2yr+3yr)	**148.32**	**106.25**	**90**	**-**	**30.14**	**374.71**	-
		%	**39.58**	**28.35**	**24.01**	**-**	**8.043**	**100**	-
Dendrocalamus longispathus	Tuirial	1yr	44.5	43.56	41.6	-	29.14	158.8	39.7
		2yr	39.58	40.72	42.6	-	-	122.9	40.96
		≥3yr	44.35	44.11	40.11	-	-	128.57	42.85
		Total (1yr+2yr+3yr)	**128.43**	**128.39**	**124.31**	**-**	**29.14**	**410.27**	-
		%	**31.30**	**31.29**	**30.29**	**-**	**7.10**	**100**	-

Appendix XIV: Component-wise total biomass (Mg/ha) of *Melocanna baccifera* in Lengpui during 2015 and 2016

Age class	Components	2015			2016		
		Q1	Q2	Q3	Q1	Q2	Q3
1yr	Culm	3.41	4.67	3.92	6.74	7.46	9.08
	Sheath	0.3	0.41	0.4	0.29	0.41	0.32
	Rhizome	2.17	2.5	2.11	2.14	2.97	3.26
2yr	Culm	5.41	6.72	6.47	10.15	11.1	11.81
	Branch	1.04	1.89	1.27	1.25	1.47	2.14
	Leaf	1.07	1.1	0.71	2.07	2.19	2.55
	Rhizome	2.34	1.27	2.09	2	2.71	3.09
≥3yr	Culm	12.87	13.89	14.94	10.87	11.5	11.32
	Branch	0.75	0.95	0.73	1.05	1.14	1.32
	Leaf	0.94	1.08	1.1	0.67	0.74	0.69
	Rhizome	3.9	4.15	4.19	5.12	7.42	6.93

Appendix XV: Component-wise total biomass (Mg/ha) of *Melocanna baccifera* in Kelsih during 2015 and 2016

Age class	Components	2015			2016		
		Q1	Q2	Q3	Q1	Q2	Q3
1yr	**Culm**	**7.12**	**7.9**	**8.2**	**10.8**	**11.6**	**11.44**
	Sheath	**1.05**	**1.27**	**1.04**	**1.24**	**2.06**	**1.83**
	Rhizome	**3.71**	**4.58**	**4.16**	**3.01**	**3.46**	**3.61**
2yr	**Culm**	**18.74**	**19.9**	**20.37**	**27.4**	**29.71**	**29.5**
	Branch	**2.97**	**3.5**	**3.94**	**2.31**	**3.1**	**3.32**
	Leaf	**4.8**	**5.72**	**6.97**	**5.24**	**5.86**	**6.75**
	Rhizome	**4.14**	**4.54**	**5.27**	**5.31**	**5.04**	**5.01**
≥3yr	**Culm**	**29.7**	**28.1**	**26.92**	**34.6**	**35.89**	**35.23**
	Branch	**7.7**	**7.18**	**7.02**	**7.2**	**7.84**	**6.98**
	Leaf	**6.14**	**6.9**	**6.85**	**5.14**	**5.4**	**4.55**
	Rhizome	**7.25**	**8.14**	**6.93**	**9.83**	**10.3**	**11.37**

Appendix XVI: Component-wise total biomass (Mg/ha) of *Melocanna baccifera* in Tamdil during 2015 and 2016

Age class	Component	2015			2016		
		Q1	Q2	Q3	Q1	Q2	Q3
1yr	Culm	10.78	11.4	11.66	38.31	39.76	40.31
	Sheath	0.54	0.71	0.55	1.24	1.68	1.73
	Rhizome	4.14	4.97	5.14	5.27	5.71	5.97
2yr	Culm	21.07	21.74	21.84	58.14	60.21	60.96
	Branch	2.48	3.02	3.26	4.13	4.91	5.36
	Leaf	4.11	4.31	4.12	7.01	7.25	7.28
	Rhizome	5.8	6.14	6.06	7.14	7.29	7.59
≥3yr	Culm	22.12	23.09	23.25	42.3	42.97	41.39
	Branch	2.14	2.86	3.1	2.28	2.68	2
	Leaf	3.04	3.17	3.15	1.21	1.46	1.05
	Rhizome	5.51	5.77	5.88	7.24	7.18	7.15

Appendix XVII: Component-wise AGB (Mg/ha) of *Bambusa tulda* during 2015 and 2016

Age class	Component	2015			2016		
		Q1	Q2	Q3	Q1	Q2	Q3
1year	Culm	7.12	7.84	7.69	14.8	15.91	16.96
	Sheath	0.69	0.74	0.7	0.78	0.87	0.87
2year	Culm	17.12	17.9	17.54	18.2	17.7	19.6
	Branch	2.12	2.08	1.92	1.41	1.3	1.49
	Leaf	3.15	3.84	3	1.8	2.1	2.25
3year	Culm	21.35	19.46	20.51	76.4	77.1	72.46
	Branch	3.46	3.09	3.2	7.69	7.82	7.44
	Leaf	2.38	2.08	2.08	5.17	6.21	4.76

Appendix XVIII: Component-wise AGB (Mg/ha) of *Dendrocalamus longispathus* during 2015 and 2016

Age class	Component	2015			2016		
		Q1	Q2	Q3	Q1	Q2	Q3
1year	Culm	11.68	13.45	13.21	19.62	21.4	20.42
	Branch	0.29	0.64	0.66	0.69	0.84	0.81
	Leaf	0.38	0.42	0.43	0.58	0.72	0.71
	Sheath	0.12	0.17	0.13	0.17	0.28	0.15
2year	Culm	12.45	14.14	13.16	18.94	21.51	19.58
	Branch	1.08	1.21	1.07	1.97	2.14	1.92
	Leaf	0.86	1.08	1	0.92	1.13	1.07
3year	Culm	71.65	74.89	74.8	88.41	90.27	92.88
	Branch	7.83	8.14	8.06	8.44	9.15	9.29
	Leaf	3.95	4.24	4.05	4.86	5.27	5.86

Appendix XIX: Component-wise AGB (Mg/ha) of *Melocalamus compactiflorus* during 2015 and 2016

Age class	Component	2015			2016		
		Q1	Q2	Q3	Q1	Q2	Q3
1yr	Culm+Branch	2.46	3.14	2.17	2.89	2.91	3.26
	Sheath	0.38	0.34	0.33	0.51	0.42	0.42
	Leaf	0.05	0.08	0.05	1.74	1.41	1.11
2yr	Culm+Branch	10.41	9.48	8.76	17.53	16.7	15.78
	Leaf	1.15	1.24	1.39	8.42	8.94	9.34
3yr	Culm+Branch	18.13	19.05	19.52	43.15	44.86	45.31
	Leaf	1.13	1.64	1.94	14.36	13.98	14.5

Appendix XX: Litterfall (Mg/ha) of different components of bamboo during 2015 and 2016

Species	Site	Component	2015			2016		
			Q1	Q2	Q3	Q1	Q2	Q3
Melocanna baccifera	Lengpui	Leaf	0.06	0.08	0.1	0.08	0.1	0.09
		Branch	0.04	0.03	0.08	0.05	0.03	0.07
		Sheath	0.06	0.04	0.08	0.1	0.05	0.06
	Kelsih	Leaf	0.08	0.05	0.08	0.06	0.06	0.12
		Branch	0.06	0.05	0.04	0.05	0.04	0.09
		Sheath	0.07	0.1	0.07	0.09	0.09	0.06
	Tamdil	Leaf	0.08	0.09	0.1	0.09	0.08	0.13
		Branch	0.07	0.08	0.09	0.06	0.08	0.1
		Sheath	0.1	0.12	0.11	0.13	0.1	0.13
Bambusa tulda	Lengpui	Leaf	0.08	0.08	0.05	0.1	0.09	0.14
		Branch	0.06	0.07	0.05	0.08	0.07	0.06
		Sheath	0.08	0.07	0.06	0.1	0.09	0.08
Dendrocalamus longispathus	Tuirial	Leaf	0.07	0.11	0.09	0.1	0.12	0.14
		Branch	0.06	0.08	0.07	0.06	0.07	0.08
		Sheath	0.12	0.07	0.11	0.09	0.08	0.1
Melocalamus compactiflorus	Darlawn	Leaf	0.05	0.05	0.08	0.071	0.078	0.076
		Branch	0.01	0.012	0.008	0.016	0.018	0.011
		Sheath	0.041	0.049	0.06	0.048	0.051	0.036

Appendix XXI: Two-way Anova table of soil moisture in Lengpui (A) Within months and quadrates during 2015, (B) Within months and quadrates during 2016 and (C) Between 2015 and 2016

(A)

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	545.2909	9	60.58788	1264.501	2.46E-23	3.597074
Columns	0.39494	2	0.19747	4.121304	0.033604	6.012905
Error	0.86246	18	0.047914			
Total	546.5483	29				

(B)

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	1740.212	9	193.3569	6130.531	1.69E-29	3.597074
Columns	0.29048	2	0.14524	4.604946	0.024261	6.012905
Error	0.56772	18	0.03154			
Total	1741.07	29				

(C)

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	2002.272	9	222.4747	35.169401	1.8074E-17	2.830129
Columns	827.4221	5	165.4844	26.160222	2.7604E-12	3.454416
Error	284.6611	45	6.325803			
Total	3114.356	59				

Appendix XXII: Two-way Anova tables of soil moisture in Kelsih (A) Within months and quadrates during 2015, (B) Within months and quadrates during 2016 and (C) Between 2015 and 2016

(A)

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	1666.168	9	185.1298	11102.6	8.08E-32	3.597074
Columns	0.16406	2	0.08203	4.919504	0.01975	6.012905
Error	0.30014	18	0.016674			
Total	1666.632	29				

(B)

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	1202.791	9	133.6434	8226.459	1.2E-30	3.597074
Columns	0.15398	2	0.07699	4.739142	0.02221	6.012905
Error	0.29242	18	0.016246			
Total	1203.237	29				

(C)

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	2740.208	9	304.4676	105.9283	2.86E-27	2.830129
Columns	49.351	5	9.8702	3.433973	0.010319	3.454416
Error	129.3426	45	2.87428			
Total	2918.902	59				

Appendix XXIII: Two-way Anova tables of soil pH in Lengpui (A) Within seasons and quadrates during 2015, (B) Within seasons and quadrates during 2016 and (C) Between 2015 and 2016

(A)

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.3182	2	0.1591	170.4642857	0.000134	18
Columns	0.009266667	2	0.004633333	4.964285714	0.082472	18
Error	0.003733333	4	0.000933333			
Total	0.3312	8				

(B)

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.5766	2	0.2883	455.2105263	1.91E-05	18
Columns	0.005066667	2	0.002533333	4	0.111111	18
Error	0.002533333	4	0.000633333			
Total	0.5842	8				

(C)

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.8659	2	0.43295	123.1137	9.055E-08	7.55943216
Columns	0.106783	5	0.021357	6.072986	0.0077441	5.63632619
Error	0.035167	10	0.003517			
Total	1.00785	17				

Appendix XXIV: Two-way Anova tables of soil pH in Kelsih (A) Between seasons and quadrates during 2016, (B) Between 2015 and 2016

(A)

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.455	2	0.2275	35.3626943	0.002865389	18
Columns	0.032067	2	0.016033	2.492227979	0.198214953	18
Error	0.025733	4	0.006433			
Total	0.5128	8				

(B)

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.3991	2	0.19955	11.94672	0.0022357	7.55943216
Columns	0.577867	5	0.115573	6.919178	0.004879	5.63632619
Error	0.167033	10	0.016703			
Total	1.144	17				

Appendix XXV: Two-way Anova tables of soil temperature in Lengpui (A) Between seasons and quadrates during 2015, (B) Between seasons and quadrates during 2016 and (C) Between 2015 and 2016

(A)

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	229.5366	2	114.7683	491864.1428	1.65336E-11	18
Columns	6.67E-05	2	3.33E-05	0.142857143	0.871111111	18
Error	0.000933	4	0.000233			
Total	229.5376	8				

(B)

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	43.2744	2	21.6372	7212.4	7.68528E-08	18
Columns	0.0018	2	0.0009	0.3	0.756143667	18
Error	0.012	4	0.003			
Total	43.2882	8				

(C)

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	179.9409	2	89.97045	9.686425	0.0045737	7.55943216
Columns	74.54392	5	14.90878	1.605114	0.2449162	5.63632619
Error	92.88303	10	9.288303			
Total	347.3679	17				

Appendix XXVI: Two-way Anova tables of soil temperature in Kelsih (A) Between seasons and quadrates during 2015, (B) Between seasons and quadrates during 2016 and (C) Between 2015 and 2016

(A)

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	54.3848	2	27.1924	81577.2	6.01037E-10	18
Columns	0.001867	2	0.000933	2.8	0.173611111	18
Error	0.001333	4	0.000333			
Total	54.388	8				

(B)

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	36.6296	2	18.3148	78492	6.49213E-10	18
Columns	0.002067	2	0.001033	4.428571429	0.096790123	18
Error	0.000933	4	0.000233			
Total	36.6326	8				

(C)

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	90.1396	2	45.0698	513.8697	8.309E-11	7.55943216
Columns	4.871133	5	0.974227	11.10778	0.0007913	5.63632619
Error	0.877067	10	0.087707			
Total	95.8878	17				

Appendix XXVII: Two-way Anova tables of soil bulk density in Lengpui (A) Between seasons and quadrates during 2015, (B) Between seasons and quadrates during 2016 and (C) Between 2015 and 2016

(A)

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	0.000302	2	0.000151	30.2	0.003857876	18
Columns	8E-06	2	4E-06	0.8	0.510204082	18
Error	2E-05	4	5E-06			
Total	0.00033	8				

(B)

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.000294	2	0.000147	44.1	0.001882167	18
Columns	4.67E-06	2	2.33E-06	0.7	0.548696845	18
Error	1.33E-05	4	3.33E-06			
Total	0.000312	8				

(C)

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.000559	2	0.00028	39.73934	1.743E-05	7.55943216
Columns	0.023125	5	0.004625	657.5877	2.995E-12	5.63632619
Error	7.03E-05	10	7.03E-06			
Total	0.023755	17				

Appendix XXVIII: Two-way Anova tables of soil bulk density in Kelsih (A) Between seasons and quadrates during 2015, (B) Between seasons and quadrates during 2016 and (C) Between 2015 and 2016

(A)

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.010586	2	0.005293	1058.6	3.55596E-06	18
Columns	2E-06	2	1E-06	0.2	0.826446281	18
Error	2E-05	4	5E-06			
Total	0.010608	8				

(B)

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	0.000662	2	0.000331	56.74285714	0.001159177	18
Columns	5.07E-05	2	2.53E-05	4.342857143	0.099423748	18
Error	2.33E-05	4	5.83E-06			
Total	0.000736	8				

(C)

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	0.008049	2	0.004025	12.41236	0.0019524	7.55943216
Columns	0.003665	5	0.000733	2.26082	0.1275362	5.63632619
Error	0.003242	10	0.000324			
Total	0.014957	17				

Appendix XX IX: Anova tables of SOC in Lengpui (A) Between months and quadrates during 2015, (B) Between months and quadrates during 2016 and (C) Between 2015 and 2016

(A)

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	3.66603	9	0.407337	100.0827	1.62E-13	3.597074
Columns	0.00194	2	0.00097	0.238329	0.79039	6.012905
Error	0.07326	18	0.00407			
Total	3.74123	29				

(B)

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	6.1374	9	0.681933	255.4057	4.08E-17	3.597074
Columns	0.00974	2	0.00487	1.82397	0.189978	6.012905
Error	0.04806	18	0.00267			
Total	6.1952	29				

(C)

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	7.797915	9	0.866435	18.3322	2.569E-12	2.83012899
Columns	0.253615	5	0.050723	1.073207	0.3879101	3.45441621
Error	2.126835	45	0.047263			
Total	10.17837	59				

Appendix XXX: Two-way Anova tables of SOC in Kelsih (A) Between months and quadrates during 2015, (B) Between months and quadrates during 2016 and (C) Between 2015 and 2016

(A)

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	6.63987	9	0.737763	56.01847634	2.49467E-11	3.597074
Columns	0.06414	2	0.03207	2.435079727	0.11588569	6.012905
Error	0.23706	18	0.01317			
Total	6.94107	29				

(B)

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	15.73908	9	1.748787	100.9109444	1.5067E-13	3.597074
Columns	0.16226	2	0.08113	4.681477207	0.02306671	6.012905
Error	0.31194	18	0.01733			
Total	16.21328	29				

(C)

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	19.88522	9	2.209468	32.67655	7.404E-17	2.83012899
Columns	3.386615	5	0.677323	10.01715	1.724E-06	3.45441621
Error	3.042735	45	0.067616			
Total	26.31457	59				

Appendix XXXI: Two-way Anova table of TN in Lengpui between different seasons and quadrates during 2016

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.0122	2	0.0061	33.27272727	0.003215	18
Columns	0.000266667	2	0.000133333	0.727272727	0.537778	18
Error	0.000733333	4	0.000183333			
Total	0.0132	8				

Appendix XXXII: Two-way Anova tables of TN in Kelsih (A) Between different seasons and quadrates during 2015, (B) Between different seasons and quadrates during 2016

(A)

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.0038	2	0.0019	38	0.0025	18
Columns	0.0002	2	0.0001	2	0.25	18
Error	0.0002	4	5E-05			
Total	0.0042	8				

(B)

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.0146	2	0.0073	73	0.000711	18
Columns	-3.46945E-18	2	-1.73472E-18	-1.73472E-14	#NUM!	18
Error	0.0004	4	0.0001			
Total	0.015	8				

Appendix XXXIII: Two-way Anova tables of AP in Lengpui (A) Between different seasons and quadrates during 2015, (B) Between different seasons and quadrates during 2016

(A)

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.0146	2	0.0073	73	0.000711	18
Columns	-3.46945E-18	2	-1.73472E-18	-1.73472E-14	#NUM!	18
Error	0.0004	4	0.0001			
Total	0.015	8				

(B)

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.0054	2	0.0027	395.1219512	2.54E-05	18
Columns	1.26667E-05	2	6.33333E-06	0.926829268	0.466944	18
Error	2.73333E-05	4	6.83333E-06			
Total	0.00544	8				

Appendix XXXIV: Two-way Anova tables of AP in Kelsihi (A) Between different seasons and quadrates during 2015, (B) Between different seasons and quadrates during 2016 and (C) Between 2015 and 2016

(A)

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.0018	2	0.0009	490.9090909	1.65E-05	18
Columns	2.66667E-06	2	1.33333E-06	0.727272727	0.537778	18
Error	7.33333E-06	4	1.83333E-06			
Total	0.00181	8				

(B)

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	0.0014	2	0.0007	700	8.12E-06	18
Columns	6E-06	2	3E-06	3	0.16	18
Error	4E-06	4	1E-06			
Total	0.00141	8				

(C)

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	0.0031	2	0.00155	139.2216	5.008E-08	7.55943216
Columns	5.87E-05	5	1.17E-05	1.053892	0.4391316	5.63632619
Error	0.000111	10	1.11E-05			
Total	0.00327	17				

Appendix XXXV: Two-way Anova tables of AK in Lengpui (A) Between different seasons and quadrates during 2015, (B) Between different seasons and quadrates during 2016

(A)

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	588.56	2	294.28	91962.5	4.73E-10	18
Columns	0.1688	2	0.0844	26.375	0.004968	18
Error	0.0128	4	0.0032			
Total	588.7416	8				

(B)

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	543.3206	2	271.6603	26897.05941	5.53E-09	18
Columns	0.0074	2	0.0037	0.366336634	0.714343	18
Error	0.0404	4	0.0101			
Total	543.3684	8				

Appendix XXXVI: Two-way Anova tables of AK in Kelsih (A) Between different seasons and quadrates during 2015, (B) Between different seasons and quadrates during 2016

(A)

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	136.1798	2	68.0899	16021.15294	1.56E-08	18
Columns	0.0182	2	0.0091	2.141176471	0.233245	18
Error	0.017	4	0.00425			
Total	136.215	8				

(B)

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	146.4954	2	73.2477	41073.47664	2.37E-09	18
Columns	0.008466667	2	0.004233333	2.373831776	0.209091	18
Error	0.007133333	4	0.001783333			
Total	146.511	8				

Appendix XXXVII: Two-way Anova tables of SR in Lengpui (A) Between different months and quadrates during 2015, (B) Between different months and quadrates during 2016 (C) Between 2015 and 2016

(A)

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	190.0946	9	21.12162	297.4457	1.049E-17	3.59707391
Columns	1.08542	2	0.54271	7.642726	0.0039551	6.01290483
Error	1.27818	18	0.07101			
Total	192.4582	29				

(B)

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	327.3603	9	36.37336	1116.470345	7.53231E-23	3.597074
Columns	0.42818	2	0.21409	6.571433444	0.007198222	6.012905
Error	0.58642	18	0.032579			
Total	328.3749	29				

(C)

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	418.4329	9	46.49254	20.73779	3.07E-13	2.830129
Columns	193.3302	5	38.66605	17.24682	1.67E-09	3.454416
Error	100.8866	45	2.241924			
Total	712.6497	59				

Appendix XXXVIII: Two-way Anova tables of SR in Kelsih (A) Between different months and quadrates during 2015, (B) Between different months and quadrates during 2016 (C) Between 2015 and 2016

(A)

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	360.7945	9	40.08828	2780.261	2.072E-26	3.59707391
Columns	0.11246	2	0.05623	3.899746	0.0391699	6.01290483
Error	0.25954	18	0.014419			
Total	361.1665	29				

(B)

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	396.8538	9	44.09487	1121.658037	7.22524E-23	3.597074
Columns	0.07998	2	0.03999	1.017240892	0.381460458	6.012905
Error	0.70762	18	0.039312			
Total	397.6414	29				

(C)

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	733.2376	9	81.47085	144.464	3.64E-30	2.830129
Columns	149.6922	5	29.93844	53.08678	9.34E-18	3.454416
Error	25.37787	45	0.563953			
Total	908.3077	59				

Appendix XXXIX: Two-way Anova table for culm density of *Melocanna baccifera* within different age classes and quadrates in Lengpui (A) during 2015, (B) during 2016 and (C) Between 2015 and 2016

(A)

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	12554.89	2	6277.444	12.0733	0.020196	18
Columns	244.2222	2	122.1111	0.234854	0.800869	18
Error	2079.778	4	519.9444			
Total	14878.89	8				

(B)

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	77562	2	38781	26.42057	0.004952	18
Columns	1570.667	2	785.3333	0.535029	0.622435	18
Error	5871.333	4	1467.833			
Total	85004	8				

(C)

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	76253.44	2	38126.72	17.47765	0.000545	7.559432
Columns	10308.28	5	2061.656	0.945083	0.493081	5.636326
Error	21814.56	10	2181.456			
Total	108376.3	17				

Appendix XL: Two-way Anova table for culm density of *Melocanna baccifera* within different age classes and quadrates in Kelsih (A) during 2015, (B) between 2015 and 2016

(A)

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	12338	2	6169	29.65865	0.003991	18
Columns	465.5	2	232.75	1.11899	0.41118	18
Error	832	4	208			
Total	13635.5	8				

(B)

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	14412.72	2	7206.36	20.69289	0.000279	7.559432
Columns	10964.06	5	2192.811	6.296607	0.006826	5.636326
Error	3482.529	10	348.2529			
Total	28859.3	17				

Appendix XLI: Two-way Anova table for culm density of *Melocanna baccifera* within different age classes and quadrates in Tamdil (A) during 2015, (B) during 2016 and (C) between 2015 and 2016

(A)

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	3987.62	2	1993.81	45.92974	0.001741	18
Columns	292.02	2	146.01	3.363511	0.139047	18
Error	173.64	4	43.41			
Total	4453.28	8				

(B)

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	4493.618	2	2246.809	266.4548	5.55E-05	18
Columns	367.0245	2	183.5122	21.76318	0.007084	18
Error	33.72893	4	8.432233			
Total	4894.371	8				

(C)

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	8007.872	2	4003.936	58.81785	2.95E-06	7.559432
Columns	3590.527	5	718.1054	10.54897	0.000974	5.636326
Error	680.7348	10	68.07348			
Total	12279.13	17				

Appendix XLII: Two-way Anova table for culm density of *Bambusa tulda* within different age classes and quadrates (A) during 2016, (B) between 2015 and 2016

(A)

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	10498.67	2	5249.333	787.4	6.42E-06	18
Columns	60.66667	2	30.33333	4.55	0.093235	18
Error	26.66667	4	6.666667			
Total	10586	8				

(B)

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	7473.778	2	3736.889	10.45121	0.003548	7.559432
Columns	1457.111	5	291.4222	0.81504	0.565309	5.636326
Error	3575.556	10	357.5556			
Total	12506.44	17				

Appendix XLIII: Two-way Anova table for culm density of *Dendrocalamus longispathus* within different age classes and quadrates (A) during 2015, (B) during 2016 and (C) between 2015 and 2016

(A)

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	7225.82	2	3612.91	56.97698	0.00115	18
Columns	138.32	2	69.16	1.09068	0.418747	18
Error	253.64	4	63.41			
Total	7617.78	8				

(B)

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	13767.68	2	6883.84	29.79501	0.003957	18
Columns	448.88	2	224.44	0.971434	0.453031	18
Error	924.16	4	231.04			
Total	15140.72	8				

(C)

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	20470.03	2	10235.02	60.16103	2.66E-06	7.559432
Columns	3009.28	5	601.856	3.537687	0.04221	5.636326
Error	1701.27	10	170.127			
Total	25180.58	17				

Appendix XLIV: Two-way Anova table for culm density of *Melocalamus compactiflorus* within different age classes and quadrates (A) during 2015, (B) during 2016 and (C) between 2015 and 2016

(A)

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	1641.5	2	820.75	70.85612	0.000754	18
Columns	26.16667	2	13.08333	1.129496	0.408424	18
Error	46.33333	4	11.58333			
Total	1714	8				

(B)

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	4739.218	2	2369.609	38.32836	0.002459	18
Columns	151.145	2	75.5725	1.222383	0.385217	18
Error	247.2956	4	61.8239			
Total	5137.658	8				

(C)

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	5928.959	2	2964.479	39.77097	1.74E-05	7.559432
Columns	2780.123	5	556.0246	7.459534	0.003707	5.636326
Error	745.3878	10	74.53878			
Total	9454.47	17				

Appendix XLV: Two-way Anova table for DBH of *Melocanna baccifera* within three age classes (A) between 2015 and 2016 in Tamdil, (B) between the four studied bamboo species during 2015 (C) between the four studied bamboo species during 2016

(A)

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	2.59	2	1.295	8.652561	0.006588	7.559432
Columns	0.478333	5	0.095667	0.639198	0.675569	5.636326
Error	1.496667	10	0.149667			
Total	4.565	17				

(B)

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	101.1846	17	5.952035	44.04096	3.15E-18	2.544672
Columns	0.310178	2	0.155089	1.147551	0.329401	5.289277
Error	4.595022	34	0.135148			
Total	106.0898	53				

(C)

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	101.52	17	5.971765	52.37489	1.96E-19	2.544672
Columns	0.263333	za2	0.131667	1.154772	0.327181	5.289277
Error	3.876667	34	0.11402			
Total	105.66	53				

Appendix XLVI: Two-way Anova table for DBH of *Melocalamus compactiflorus* between the two years and respective quadrates

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Rows	0.39	2	0.195	6.030928	0.019133	7.559432
Columns	0.046667	5	0.009333	0.28866	0.908662	5.636326
Error	0.323333	10	0.032333			
Total	0.76	17				

REFERENCES

Abebe, S., Minale, A. S., & Teketay, D. (2021). Socio-economic importance of the bamboo resources in the Lower Beles River Basin, north-western Ethiopia. Environment, Development and Sustainability, 1-20.

Akakabe, Y., Tamura, Y., Iwamoto, S., Takabayashi, M., & Nyuugaku, T. (2006). Volatile organic compounds with characteristic odor in bamboo vinegar. Bioscience, biotechnology, and biochemistry, 70(11), 2797-2799.

Akoto, D. S., Denich, M., Partey, S. T., Frith, O., Kwaku, M., Mensah, A. A., & Borgemeister, C. (2018). Socioeconomic indicators of bamboo use for agroforestry development in the dry semi-deciduous forest zone of Ghana. Sustainability, 10(7), 2324.

Amoah, M., Assan, F., & Dadzie, P. K. (2020). Aboveground biomass, carbon storage and fuel values of Bambusa vulgaris, Oxynanteria abbyssinica and Bambusa vulgaris var. vitata plantations in the Bobiri forest reserve of Ghana. Journal of Sustainable Forestry, 39(2), 113-136.

Arnell, N. W., Lowe, J. A., Challinor, A. J., & Osborn, T. J. (2019). Global and regional impacts of climate change at different levels of global temperature increase. Climatic Change, 155(3), 377-391.

Banik, R. L. (2015). Growth, behaviour and silviculture of bamboos. Bamboos in India. Dehradun, ENVIS Centre on Forestry.

Basumatary, A., Middha, S. K., Usha, T., Basumatary, A. K., Brahma, B. K., & Goyal, A. K. (2017). Bamboo shoots as a nutritive boon for Northeast India: an overview. 3 Biotech, 7(3), 1-6.

Beer, C., Reichstein, M., Tomelleri, E., Ciais, P., Jung, M., Carvalhais, N., ... & Papale, D. (2010). Terrestrial gross carbon dioxide uptake: global distribution and covariation with climate. Science, 329(5993), 834-838.

Besar, N. A., Suardi, H., Phua, M. H., James, D., Mokhtar, M. B., & Ahmed, M. F. (2020). Carbon stock and sequestration potential of an agroforestry system in Sabah, Malaysia. Forests, 11(2), 210.

Bhatt, B. P., Singh, K., & Singh, A. (2005). Nutritional values of some commercial edible bamboo species of the North Eastern Himalayan region, India. Journal of Bamboo and Rattan, 4(2), 111-124.

Bolin, B. (1986). The greenhouse effect, climate change, and ecosystems. SCOPE 29, 541.

Bosetti, V., Carraro, C., Galeotti, M., Massetti, E., & Tavoni, M. (2006). A world induced technical change hybrid model. The Energy Journal, (Special Issue# 2).

Bundestag, G. (1990). Protecting the tropical forest, a high priority task. Second report of the Enquête-Commission: Preventive Measures to Protect the Earth's Atmosphere.)

Chandel, S. S., Shrivastva, R., Sharma, V., & Ramasamy, P. (2016). Overview of the initiatives in renewable energy sector under the national action plan on climate change in India. Renewable and Sustainable Energy Reviews, 54, 866-873.

Chang, J. M., & Fang, T. J. (2007). Survival of Escherichia coli O157: H7 and Salmonella enterica serovars Typhimurium in iceberg lettuce and the antimicrobial effect of rice vinegar against E. coli O157: H7. Food Microbiology, 24(7-8), 745-751.

Chen, X., Zhang, J., Zhang, B., Dong, S., Guo, X., Mu, X., & Fei, B. (2017). A novel hierarchical porous nitrogen-doped carbon derived from bamboo shoot for high performance supercapacitor. Scientific reports, 7(1), 1-11.

Chongtham, N., Bisht, M. S., & Haorongbam, S. (2011). Nutritional properties of bamboo shoots: potential and prospects for utilization as a health food. Comprehensive Reviews in Food Science and Food Safety, 10(3), 153-168.

Choudhury, D., Sahu, J. K., & Sharma, G. D. (2012). Value addition to bamboo shoots: a review. Journal of Food Science and Technology, 49(4), 407-414.

Christian, A. L., Knott, K. K., Vance, C. K., Falcone, J. F., Bauer, L. L., Fahey Jr, G. C., ... & Kouba, A. J. (2015). Nutrient and mineral composition during shoot growth in seven species of P hyllostachys and P seudosasa bamboo consumed by giant panda. Journal of Animal Physiology and Animal Nutrition, 99(6), 1172-1183.

Collatz, G. J., Berry, J. A., & Clark, J. S. (1998). Effects of climate and atmospheric CO2 partial pressure on the global distribution of C4 grasses: present, past, and future. Oecologia, 114(4), 441-454.

Collin, B., Doelsch, E., Keller, C., Cazevieille, P., Tella, M., Chaurand, P., ... & Meunier, J. D. (2014). Evidence of sulfur-bound reduced copper in bamboo exposed to high silicon and copper concentrations. Environmental Pollution, 187, 22-30.

Collin, B., Doelsch, E., Keller, C., Panfili, F., & Meunier, J. D. (2012). Distribution and variability of silicon, copper and zinc in different bamboo species. Plant and soil, 351(1), 377-387.

Deng, X., Yin, J., Xu, L., Shi, Y., Zhou, G., Li, Y., ... & Xiong, Y. (2020). Effects of abandonment management on soil C and N pools in Moso bamboo forests. Science of the Total Environment, 729, 138949.

Desalegn, G., & Tadesse, W. (2014). Resource potential of bamboo, challenges and future directions towards sustainable management and utilization in Ethiopia. Forest Systems, 23(2), 294-299.

Dev, I., Ram, A., Ahlawat, S. P., Palsaniya, D. R., Singh, R., Dhyani, S. K., ... & Prasad, J. (2020). Bamboo-based agroforestry system (Dendrocalamus strictus+ sesame–chickpea) for enhancing productivity in semi-arid tropics of central India. Agroforestry Systems, 94(5), 1725-1739.

Dixon, R. K., Solomon, A. M., Brown, S., Houghton, R. A., Trexier, M. C., & Wisniewski, J. (1994). Carbon pools and flux of global forest ecosystems. Science, 263(5144), 185-190.

Doelsch, E., Masion, A., Moussard, G., Chevassus-Rosset, C., & Wojciechowicz, O. (2010). Impact of pig slurry and green waste compost application on heavy metal exchangeable fractions in tropical soils. Geoderma, 155(3-4), 390-400.

Dwivedi, A. K., Kumar, A., Baredar, P., & Prakash, O. (2019). Bamboo as a complementary crop to address climate change and livelihoods–Insights from India. Forest Policy and Economics, 102, 66-74.

El-Naggar, A., Lee, S. S., Rinklebe, J., Farooq, M., Song, H., Sarmah, A. K., ... & Ok, Y. S. (2019). Biochar application to low fertility soils: A review of current status, and future prospects. Geoderma, 337, 536-554.

Emamverdian, A., Ding, Y., Ranaei, F., & Ahmad, Z. (2020). Application of bamboo plants in nine aspects. The Scientific World Journal, 2020.

Embaye, K., Weih, M., Ledin, S., & Christersson, L. (2005). Biomass and nutrient distribution in a highland bamboo forest in southwest Ethiopia: implications for management. Forest ecology and management, 204(2-3), 159-169.

Environment, Forests & Climate Change Department (mizoram.gov.in)

Ferez, A. P. C., Campoe, O. C., Mendes, J. C. T., & Stape, J. L. (2015). Silvicultural opportunities for increasing carbon stock in restoration of Atlantic forests in Brazil. Forest Ecology and Management, 350, 40-45.

Fonseca, W., Benayas, J. M. R., & Alice, F. E. (2011). Carbon accumulation in the biomass and soil of different aged secondary forests in the humid tropics of Costa Rica. Forest Ecology and Management, 262(8), 1400-1408.

Friedlingstein, P., O'sullivan, M., Jones, M. W., Andrew, R. M., Hauck, J., Olsen, A., ... & Zaehle, S. (2020). Global carbon budget 2020. Earth System Science Data, 12(4), 3269-3340.

Fu, S. G., Yoon, Y., & Bazemore, R. (2002). Aroma-active components in fermented bamboo shoots. Journal of Agricultural and Food Chemistry, 50(3), 549-554.

Getachew, G., Wudu, D., Alamire, G., Kasahun, H., Ayalew, A., Redae, T., & Wudu, M. (2021). Adaptability and Growth Performance of Introduced Bamboo Species in North East Ethiopia.

Gogoi, B., & Bhuyan, T. C. (2016). Physico-chemical properties and microbial biomass carbon of bamboo growing soils: a comparative study. Ind For, 142(8), 739-744.

Grombone-Guaratini, M. T., Gaspar, M., Oliveira, V. F., Torres, M. A. M. G., Do Nascimento, A., & Aidar, M. P. M. (2013). Atmospheric CO2 enrichment markedly increases photosynthesis and growth in a woody tropical bamboo from the Brazilian Atlantic Forest. New Zealand Journal of Botany, 51(4), 275-285.

Hansena, J., Satoa, M., Ruedyb, R., Schmidtc, G., & Lob, K. (2021). Global Temperature in 2020.

Hu, C., Zhang, Y., & Kitts, D. D. (2000). Evaluation of antioxidant and prooxidant activities of bamboo Phyllostachys nigra var. Henonis leaf extract in vitro. Journal of Agricultural and Food Chemistry, 48(8), 3170-3176.

Ikimoto, T., & Ikeshima, O. (2000). Usages of Bamboo Charcoal and Bamboo Vinegar. Nobunkyou Publication, 89-107.

IPCC, 2013 https://repository.library.noaa.gov/view/noaa/19486/noaa_19486_DS1.pdf

Isagi, Y. (1994). Carbon stock and cycling in a bamboo Phyllostachys bambusoides stand. Ecological Research, 9(1), 47-55.

Kandlikar, M., & Sagar, A. (1999). Climate change research and analysis in India: an integrated assessment of a South–North divide. Global Environmental Change, 9(2), 119-138.

Kaur, B., Gupta, S. R., & Singh, G. (2002). Carbon storage and nitrogen cycling in silvopastoral systems on a sodic in northwestern India. Agroforestry systems, 54(1), 21-29.

Kenye, A., Sahoo, U. K., Singh, S. L., & Gogoi, A. (2019). Soil organic carbon stock of different land uses of Mizoram, Northeast India. AIMS Geosciences, 5(1), 25-40.

Kittur, B. H., Sudhakara, K., Mohan Kumar, B., Kunhamu, T. K., & Sureshkumar, P. (2016). Bamboo based agroforestry systems in Kerala, India: performance of turmeric (Curcuma longa L.) in the subcanopy of differentially spaced seven year-old bamboo stand. Agroforestry Systems, 90(2), 237-250.

Korrensalo, A., Alekseychik, P., Hájek, T., Rinne, J., Vesala, T., Mehtätalo, L., ... & Tuittila, E. S. (2017). Species-specific temporal variation in photosynthesis as a moderator of peatland carbon sequestration. Biogeosciences, 14(2), 257-269.

Krystynowicz, A., Czaja, W., Pomorski, L., Kolodziejczyk, M., & Bielecki, S. (2000). The evaluation of usefulness of microbial cellulose as a wound dressing material. MEDEDELINGEN-FACULTEIT LANDBOUWKUNDIGE EN TOEGEPASTE BIOLOGISCHE WETENSCHAPPEN, 65(3; ISSU A), 213-220.

Kuehl, Y., & Yiping, L. (2012). Carbon off-setting with bamboo. INBAR working paper 71. INBAR, Beijing.

Lal, R. (2004). Soil carbon sequestration to mitigate climate change. Geoderma, 123(1-2), 1-22.

Lalhruaitluanga, H., & Prasad, M. N. V. (2009). Traditional uses, economic importance and ecological services of Meloccana baccifera Roxb. in Mizoram, India. Asian and Australasian Journal of Plant Science and Biotechnology, 3(1), 1-6.

Lalnunmawia, F. (2008). Influence of excessive biotic pressure and fire on culm diameter, density flux and seed production in Melocanna baccifera stands. Journal of Forestry Research, 19(2), 148-150.

Lead (II) adsorption from aqueous solutions by raw and activated charcoals of Melocanna baccifera Roxburgh (bamboo)--a comparative study https://doi.org/10.1016/j.jhazmat.2009.10.005

Lebrato, M., Iglesias-Rodríguez, D., Feely, R. A., Greeley, D., Jones, D. O., Suarez-Bosche, N., ... & Alker, B. (2010). Global contribution of echinoderms to the marine carbon cycle: CaCO3 budget and benthic compartments. Ecological Monographs, 80(3), 441-467.

Lehmann, J., & Joseph, S. (Eds.). (2015). Biochar for environmental management: science, technology and implementation. Routledge.

Li, C., Cai, Y., Xiao, L., Gao, X., Shi, Y., Du, H., ... & Zhou, G. (2021). Effects of different planting approaches and site conditions on aboveground carbon storage along a 10-year chronosequence after moso bamboo reforestation. Forest Ecology and Management, 482, 118867.

Li, C., Shi, Y., Zhou, G., Zhou, Y., Xu, L., Tong, L., & Liu, X. (2018). Effects of different management approaches on soil carbon dynamics in Moso bamboo forest ecosystems. Catena, 169, 59-68.

Li, G., Du, S., & Wen, Z. (2016). Mapping the climatic suitable habitat of oriental arborvitae (Platycladus orientalis) for introduction and cultivation at a global scale. Scientific Reports, 6(1), 1-9.

Li, X., Mao, F., Du, H., Zhou, G., Xing, L., Liu, T., ... & Zhang, M. (2019). Spatiotemporal evolution and impacts of climate change on bamboo distribution in China. Journal of environmental management, 248, 109265.

Li, Y., Li, Y., Chang, S. X., Xu, Q., Guo, Z., Gao, Q., ... & Liang, X. (2017). Bamboo invasion of broadleaf forests altered soil fungal community closely linked to changes in soil organic C chemical composition and mineral N production. Plant and Soil, 418(1), 507-521.

Liao, K., Lai, X., Zhou, Z., & Zhu, Q. (2017). Applying fractal analysis to detect spatio-temporal variability of soil moisture content on two contrasting land use hillslopes. Catena, 157, 163-172.

Liu, G. L., Fan, S. H., Qi, L. H., Du, M. Y., & Xiao, F. M. (2011). Soil properties of different phyllostachys pubescens forests with soil reclamation. Acta Agriculturae Universitatis Jiangxiensis, 33(1), 68-75.

Liu, W., Hui, C., Wang, F., Wang, M., & Liu, G. (2018). Review of the Resources and Utilization of Bamboo in China. Bamboo-Current and Future Prospects, 133-142.

Liu, Y. H., & Yen, T. M. (2021). Assessing aboveground carbon storage capacity in bamboo plantations with various species related to its affecting factors across Taiwan. Forest Ecology and Management, 481, 118745.

Liu, Y., Zhou, G., Du, H., Berninger, F., Mao, F., Li, X., ... & Xu, L. (2018). Response of carbon uptake to abiotic and biotic drivers in an intensively managed Lei bamboo forest. Journal of environmental management, 223, 713-722.

Lobovikov, M., Paudel, S., Ball, L., Piazza, M., Guardia, M., Ren, H., & Wu, J. (2007). World bamboo resources: a thematic study prepared in the framework of the global forest resources assessment 2005 (No. 18). Food & Agriculture Org.

Lou, R., Wu, S. B., & Lv, G. J. (2010). Fast pyrolysis of enzymatic/mild acidolysis lignin from moso bamboo. BioResources, 5(2), 827-837.

Lugo, A. E., Sanchez, M. J., & Brown, S. (1986). Land use and organic carbon content of some subtropical soils. Plant and soil, 96(2), 185-196.

Ly, P., Pillot, D., Lamballe, P., & de Neergaard, A. (2012). Evaluation of bamboo as an alternative cropping strategy in the northern central upland of Vietnam: Above-ground carbon fixing capacity, accumulation of soil organic carbon, and socio-economic aspects. Agriculture, ecosystems & environment, 149, 80-90.

Madison, J., Hamilton, A., Jay, J., & Goldman, L. (2008). Federalist Papers (Oxford world's classics). Oxford University Press.

Mainka, S. A., Guanlu, Z., & Mao, L. (1989). Utilization of a bamboo, sugar cane, and gruel diet by two juvenile giant pandas (Ailuropoda melanoleuca). Journal of Zoo and Wildlife Medicine, 39-44.

Major, J., Steiner, C., Downie, A., Lehmann, J., & Joseph, S. (2009). Biochar effects on nutrient leaching. Biochar for environmental management: Science and technology, 271.

Majumdar, K., Choudhary, B. K., & Datta, B. K. (2016). Aboveground woody biomass, carbon stocks potential in selected tropical forest patches of Tripura, Northeast India. Open Journal of Ecology, 6(10), 598.

Manpoong, C. (2019). *Influence of rhizosphere on soil fertility in different land use systems of Mizoram* (Doctoral dissertation, Mizoram University).

Manpoong, C., & Tripathi, S. K. (2019). Soil properties under different land use systems of Mizoram, North East India. Journal of Applied and Natural Science, 11(1), 121-125.

Manpoong, C., & Tripathi, S. K. (2021). Soil carbon stock in different land-use systems in the hilly terrain of Mizoram, Northeast India. Journal of Applied and Natural Science, 13(2), 723-728.

Mekonnen, Z., Worku, A., Yohannes, T., Alebachew, M., & Kassa, H. (2014). Bamboo Resources in Ethiopia: Their value chain and contribution to livelihoods. Ethnobotany Research and Applications, 12, 511-524.

Melorose J, Perroy R, Careas S (2015). Assosa Bamboo (Oxytenanthera abyssinica) as an Alternative Scaffolding Material. Statewide Agricultural Land Use Baseline 2015, 1(2), 221-248.

Mishra, G., Marzaioli, R., Giri, K., & Pandey, S. (2019). Soil quality assessment across different stands in tropical moist deciduous forests of Nagaland, India. *Journal of Forestry Research*, *30*(4), 1479-1485.

Mu, J., Yu, Z. M., Wu, W. Q., & Wu, Q. L. (2006). Preliminary study of application effect of bamboo vinegar on vegetable growth. Forestry Studies in China, 8(3), 43-47.

Nath, A. J., & Das, A. K. (2012). Carbon pool and sequestration potential of village bamboos in the agroforestry system of northeast India. Tropical Ecology, 53(3), 287-293.

Nath, A. J., Das, G., & Das, A. K. (2009). Above ground standing biomass and carbon storage in village bamboos in North East India. Biomass and bioenergy, 33(9), 1188-1196.

Nath, A. J., Sileshi, G. W., & Das, A. K. (2018). Bamboo based family forests offer opportunities for biomass production and carbon farming in North East India. Land Use Policy, 75, 191-200.

Nath, A. J., Sileshi, G. W., & Das, A. K. (2020). Bamboo: Climate Change Adaptation and Mitigation. CRC Press.

Nemenyi, A., Stefanovitsne-Banyai, E., Zoltán, P. É. K., HEGEDŰS, A., Gyuricza, C., Barocsi, Z., & Helyes, L. (2015). Total antioxidant capacity and total phenolics content of Phyllostachys taxa shoots. Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 43(1), 64-69.

Nfornkah, B. N., Rene, K., Louis, Z., Martin, T., & Cedric, C. D. (2020). Bamboo diversity and carbon stocks of dominant species in different agro-ecological zones in Cameroon. African Journal of Environmental Science and Technology, 14(10), 290-300.

Nirmala, C., & Bisht, M. S. (2017). 10 WBC Reports: Bamboo: A prospective ingredient for functional food and nutraceuticals. Bamboo journal, (30), 82-99.

Nirmala, C., Bisht, M. S., Bajwa, H. K., & Santosh, O. (2018). Bamboo: A rich source of natural antioxidants and its applications in the food and pharmaceutical industry. Trends in Food Science & Technology, 77, 91-99.

Novak, J. M., Watts, D. W., & Stone, K. C. (2004). Copper and zinc accumulation, profile distribution, and crop removal in coastal plain soils receiving long-term, intensive applications of swine manure. Transactions of the ASAE, 47(5), 1513.

Pachepsky, Y., Radcliffe, D. E., & Selim, H. M. (2003). Scaling methods in soil physics. CRC press.

Palm, C. A., Houghton, R. A., Melillo, J. M., & Skole, D. L. (1986). Atmospheric carbon dioxide from deforestation in Southeast Asia. Biotropica, 177-188.

Pan, J., Liu, Y., Yuan, X., Xie, J., Niu, J., Fang, H., ... & Zhang, L. (2020). Root litter mixing with that of Japanese cedar altered CO2 emissions from Moso Bamboo Forest soil. Forests, 11(3), 356.

Park, E. J., & Jhon, D. Y. (2009). Effects of bamboo shoot consumption on lipid profiles and bowel function in healthy young women. Nutrition, 25(7-8), 723-728.

Parrotta, J. A. (1992). The role of plantation forests in rehabilitating degraded tropical ecosystems. Agriculture, ecosystems & environment, 41(2), 115-133.

Pathak, P. K., Kumar, H., Kumari, G., & Bilyaminu, H. (2015). Biomass production potential in different species of bamboo in Central Uttar Pradesh. The Ecoscan, 10(1), 41-43.

Patil, V. V., & Toradmal, M. A. B. (2020). Digital Terrain Analysis for Watershed Characterization and Management-A Case Study of Vincharna River Basin Maharashtra, India. Journal of Information and Computational Science, 10(2), 637-647.

Pepper, W., Barbour, W., Sankovski, A., & Braatz, B. (1998). No-policy greenhouse gas emission scenarios: revisiting IPCC 1992. Environmental science & policy, 1(4), 289-311.

Pitak, L., Sirisomboon, P., Saengprachatanarug, K., Wongpichet, S., & Posom, J. (2021). Rapid elemental composition measurement of commercial pellets using line-scan hyperspectral imaging analysis. Energy, 220, 119698.

Platt, S. G., Ko, W. K., Myo, K. M., Khaing, L. L., Platt, K., Maung, A., & Rainwater, T. R. (2010). Notes on Melocanna baccifera and bamboo brakes in the Rakhine Hills of western Myanmar. Bamboo Science & Culture, 23(1).

Prasad, H. A. C., & Kochher, J. S. (2009). Climate change and India-some major issues and policy implications. Department of Economic Affairs, Ministry of Finance, Government of India, 8.

Qin, H., Niu, L., Wu, Q., Chen, J., Li, Y., Liang, C., ... & Shen, Y. (2017). Bamboo forest expansion increases soil organic carbon through its effect on soil arbuscular mycorrhizal fungal community and abundance. Plant and Soil, 420(1), 407-421.

Quiroga, R. A. R., Li, T., Lora, G., & Andersen, L. (2013). A measurement of the carbon sequestration potential of Guadua Angustifolia in the Carrasco National Park, Bolivia (No. 04/2013). Institute for Advanced Development Studies.

Rai, S. N., & Chauhan, K. V. S. (1998). Distribution and growing stock of bamboos in India. Indian forester, 124(2), 89-98.

Raich, J. W., & Schlesinger, W. H. (1992). The global carbon dioxide flux in soil respiration and its relationship to vegetation and climate. Tellus B, 44(2), 81-99.

Ramachandran Nair, P. K., Mohan Kumar, B., & Nair, V. D. (2009). Agroforestry as a strategy for carbon sequestration. Journal of plant nutrition and soil science, 172(1), 10-23.

Rana, M. P., Mukul, S. A., Sohel, M., Chowdhury, M. S. H., Akhter, S., Chowdhury, M. Q., & Koike, M. (2010). Economics and employment generation of bamboo-based enterprises: a case study from eastern Bangladesh. Small-Scale Forestry, 9(1), 41-51.

Rastogi, N. P. (2011). Winds of change: India's emerging climate strategy. The International Spectator, 46(2), 127-141.

Ray, R., Ganguly, D., Chowdhury, C., Dey, M., Das, S., Dutta, M. K., ... & Jana, T. K. (2011). Carbon sequestration and annual increase of carbon stock in a mangrove forest. Atmospheric Environment, 45(28), 5016-5024.

Reiss, C. (1993). Measuring the amount of ascorbic acid in cabbage. Tested studies for laboratory teaching, 7, 8.

Rhee, M. S., Lee, S. Y., Dougherty, R. H., & Kang, D. H. (2003). Antimicrobial effects of mustard flour and acetic acid against Escherichia coli O157: H7, Listeria monocytogenes, and Salmonella enterica serovar Typhimurium. Applied and environmental microbiology, 69(5), 2959-2963.

Saatchi, S. S., Harris, N. L., Brown, S., Lefsky, M., Mitchard, E. T., Salas, W., ... & Morel, A. (2011). Benchmark map of forest carbon stocks in tropical regions across three continents. Proceedings of the national academy of sciences, 108(24), 9899-9904.

Saikia, P., Kataki, R., Choudhury, P. K., & Konwer, D. (2007). Carbonization of eight bamboo species of northeast India. Energy Sources, Part A, 29(9), 799-805.

Sawarkar, A. D., Shrimankar, D. D., Kumar, A., Kumar, A., Singh, E., Singh, L., ... & Kumar, R. (2020). Commercial clustering of sustainable bamboo species in India. Industrial Crops and Products, 154, 112693.

Schillaci, C., Nepravishta, R., & Bellomaria, A. (2014). Antioxidants in food and pharmaceutical research. Albanian Journal of Pharmaceutical Sciences, 1(1), 9-15.

Schimel, D. S. (1995). Terrestrial ecosystems and the carbon cycle. Global change biology, 1(1), 77-91.

Schimel, D. S., House, J. I., Hibbard, K. A., Bousquet, P., Ciais, P., Peylin, P., ... & Wirth, C. (2001). Recent patterns and mechanisms of carbon exchange by terrestrial ecosystems. Nature, 414(6860), 169-172.

Sedjo, R., & Sohngen, B. (2012). Carbon sequestration in forests and soils. Annu. Rev. Resour. Econ., 4(1), 127-144.

Sengun, I. Y., & Karapinar, M. (2004). Effectiveness of lemon juice, vinegar and their mixture in the elimination of Salmonella typhimurium on carrots (Daucus carota L.). International journal of food microbiology, 96(3), 301-305.

Shanmughavel, P., & Francis, K. (1996). Above ground biomass production and nutrient distribution in growing bamboo (Bambusa bambos (L.) Voss). Biomass and Bioenergy, 10(5-6), 383-391.

Sharma, M. L., & Nirmala, C. (2015, September). Bamboo diversity of India: an update. In Proceedings of the 10th world bamboo congress, Damyang, Korea (pp. 17-22).

Sheng, H. A. O., Yang, Y., Yang, Z., Chen, G., Xie, J., Guo, J., & Zou, S. (2010). The dynamic response of soil respiration to land-use changes in subtropical China. Global Change Biology, 16(3), 1107-1121.

Shimada, M. (1972). Biochemical studies on bamboo lignin and methoxylation in hardwood and softwood lignins. Wood Research: Bulletin of the Wood Research Institute Kyoto University, 53, 19-65.

Singh, A. N., & Singh, J. S. (1999). Biomass, net primary production and impact of bamboo plantation on soil redevelopment in a dry tropical region. Forest ecology and management, 119(1-3), 195-207.

Singh, S. L., & Sahoo, U. K. (2015). Soil carbon sequestration in homegardens of different age and size in Aizawl district of Mizoram, Northeast India. NeBIO, 6(3), 12-15.

Singh, S. L., & Sahoo, U. K. (2021). Tree species composition, diversity and soil organic carbon stock in homegardens and shifting cultivation fallows of Mizoram, Northeast India. Vegetos, 34(1), 220-228.

Singnar, P., Das, M. C., Sileshi, G. W., Brahma, B., Nath, A. J., & Das, A. K. (2017). Allometric scaling, biomass accumulation and carbon stocks in different aged stands of thin-walled bamboos Schizostachyum dullooa, Pseudostachyum polymorphum and Melocanna baccifera. Forest ecology and management, 395, 81-91.

Singnar, P., Nath, A. J., & Das, A. K. (2015). Culm characteristics and volume-weight relationship of a forest bamboo (Melocanna baccifera (Roxb.) Kurz) from northeast India. Journal of Forestry Research, 26(4), 841-849.

Six, J., Conant, R. T., Paul, E. A., & Paustian, K. (2002). Stabilization mechanisms of soil organic matter: implications for C-saturation of soils. Plant and soil, 241(2), 155-176.

Soetan, K. O., & Oyewole, O. E. (2009). The need for adequate processing to reduce the anti-nutritional factors in plants used as human foods and animal feeds: A review. African Journal of food science, 3(9), 223-232.

Sohel, M. S. I., Alamgir, M., Akhter, S., & Rahman, M. (2015). Carbon storage in a bamboo (Bambusa vulgaris) plantation in the degraded tropical forests: implications for policy development. Land Use Policy, 49, 142-151.

Sohngen, B., & Mendelsohn, R. (2003). An optimal control model of forest carbon sequestration. American Journal of Agricultural Economics, 85(2), 448-457.

Song, X., Zhou, G., Jiang, H., Yu, S., Fu, J., Li, W., ... & Peng, C. (2011). Carbon sequestration by Chinese bamboo forests and their ecological benefits: assessment of potential, problems, and future challenges. Environmental Reviews, 19(NA), 418-428.

Sudhakara, K., & Jijeesh, C. M. (2015, February). Bamboos: emerging carbon sink for global climate change mitigation. In Proceedings of the Conference: National Workshop on Carbon Sequestration in Forest and Non-Forest Ecosystems.

Sugiyama, M., Tang, A. C., Wakaki, Y., & Koyama, W. (2003). Glycemic index of single and mixed meal foods among common Japanese foods with white rice as a reference food. European journal of clinical nutrition, 57(6), 743-752.

Sun, H., Hockaday, W. C., Masiello, C. A., & Zygourakis, K. (2012). Multiple controls on the chemical and physical structure of biochars. Industrial & Engineering Chemistry Research, 51(9), 3587-3597.

Sun, Y., Sun, Y., Chen, W., Wang, S., Liang, G., Li, W., ... & Zhang, W. (2020). Effect of torrefaction temperature and O2 concentration on the pyrolysis behaviour of moso bamboo. BioResources, 15(3), 6344-6370.

Swamy, S. L., & Puri, S. (2005). Biomass production and C-sequestration of Gmelina arborea in plantation and agroforestry system in India. Agroforestry systems, 64(3), 181-195.

Tabet, R. B., Oftedal, O. T., & Allen, M. E. (2004). Seasonal differences in composition of bamboo fed to giant pandas (Ailuropoda melanoleuca) at the National Zoo. In Proceedings of the Fifth Comparative Nutrition Society Symposium, Hickory Corners, MI (pp. 176-183).

Terefe, R., Jian, L., & Kunyong, Y. (2019). Role of bamboo forest for mitigation and adaptation to climate change challenges in China. reproduction, 2(3), 4.

Terefe, R., Samuel, D., Sanbato, M., & Daba, M. (2016). Adaptation and growth performance of different lowland bamboo species in Bako, West Shoa, Ethiopia. Journal of Natural Sciences Research, 6(9), 61-65.

Theapparat, Y., Chandumpai, A., Leelasuphakul, W., & Laemsak, N. (2015). Pyroligneous acids from carbonisation of wood and bamboo: their components and antifungal activity. Journal of Tropical Forest Science, 517-526.

Thokchom, A., & Yadav, P. S. (2015). Comparing aboveground carbon sequestration between bamboo forest and dipterocarpus forests of manipur, north east india. International Journal of Ecology and Environmental Sciences, 41(1-2), 33-42.

Thokchom, A., & Yadava, P. S. (2017). Biomass, carbon stock and sequestration potential of Schizostachyum pergracile bamboo forest of Manipur, north east India. Tropical Ecology, 58(1), 23-32.

Thomas, C. D., Cameron, A., Green, R. E., Bakkenes, M., Beaumont, L. J., Collingham, Y. C., ... & Williams, S. E. (2004). Extinction risk from climate change. Nature, 427(6970), 145-148.

Tiilikkala, K., Fagernäs, L., & Tiilikkala, J. (2010). History and use of wood pyrolysis liquids as biocide and plant protection product.

Tinsley, B. L. (2015). Bamboo harvesting for household income generation in the Ethiopian highlands: Current conditions and management challenges.

Tripathi, Y. C. (1998). Food and nutrition potential of bamboo. MFP News, 8(1), 10-11.

Tu, L. H., Hu, T. X., Zhang, J., Li, X. W., Hu, H. L., Liu, L., & Xiao, Y. L. (2013). Nitrogen addition stimulates different components of soil respiration in a subtropical bamboo ecosystem. Soil Biology and Biochemistry, 58, 255-264.

Vanlalfakawma, D. C., Lalnunmawia, F., & Tripathi, S. K. (2014). Soil carbon pools of bamboo forests of Mizoram, India. Sci Vision, 14, 46-50.

Viglašová, E., Galamboš, M., Danková, Z., Krivosudský, L., Lengauer, C. L., Hood-Nowotny, R., ... & Briančin, J. (2018). Production, characterization and adsorption studies of bamboo-based biochar/montmorillonite composite for nitrate removal. Waste Management, 79, 385-394.

Wang, J., Chen, T. H., Chang, H. C., Chung, H. Y., Li, T. I., & Liu, C. P. (2009). The structures, aboveground biomass, carbon storage of Phyllostachys pubescens stands in Huisun experimental forest station and Shi-Zhuo. QJ For Res, 34(4), 17-26.

Wang, M. L., Harrison, M. L., Tonnis, B. D., Pinnow, D., Davis, J., & Irish, B. M. (2018). Total leaf crude protein, amino acid composition and elemental content in the USDA-ARS bamboo germplasm collections. Plant Genetic Resources, 16(2), 185-187.

Wang, Y. C. (2004). Estimates of biomass and carbon sequestration in Dendrocalamus latiflorus culms. Forest Products Industries, 23(1), 13-22.

Wangluk, S., Boonyawat, S., Diloksumpun, S., & Tongdeenok, P. (2013). Role of soil temperature and moisture on soil respiration in a teak plantation and mixed deciduous forest in Thailand. Journal of Tropical Forest Science, 339-349.

Wapongnungsang, C. M., & Tripathi, S. K. (2018). Changes in soil fertility and rice productivity in three consecutive years cropping under different fallow phases following shifting cultivation. International Journal of Plant & Soil Science, 25(6), 1-10.

Wapongnungsang, H. R., & Tripathi, S. K. (2017). Litter decomposition Vis-a-Vis carbon and nitrogen dynamics of Tephrosia candida components in different fallow periods following shifting cultivation in Mizoram. Indian Journal of Ecology, 44(4), 791-796.

White, L., Harris, N. L., Zutta, B. R., Saatchi, S. S., Brown, S., Salas, W., ... & Morel, A. (2010). Benchmark map of forest carbon stocks in tropical regions across three continents.

Wu, F. M., Doyle, M. P., Beuchat, L. R., Wells, J. G., Mintz, E. D., & Swaminathan, B. (2000). Fate of Shigella sonnei on parsley and methods of disinfection. Journal of Food Protection, 63(5), 568-572.

Xayalath, S., Hirota, I., Tomita, S., & Nakagawa, M. (2020). Aboveground biomass and seasonal patterns of aboveground net primary productivity in five bamboo species in northern Laos. Journal of Plant Ecology, 13(2), 150-156.

Xiangsheng, Y. I., Guosheng, L. I., & Yanyu, Y. I. N. (2016). Pedotransfer functions for estimating soil bulk density: A case study in the Three-River Headwater region of Qinghai Province, China. Pedosphere, 26(3), 362-373.

Xu, L., Deng, X., Ying, J., Zhou, G., & Shi, Y. (2020). Silicate fertilizer application reduces soil greenhouse gas emissions in a Moso bamboo forest. Science of The Total Environment, 747, 141380.

Xu, L., Shi, Y., Zhou, G., Xu, X., Liu, E., Zhou, Y., ... & Chen, L. (2018). Structural development and carbon dynamics of Moso bamboo forests in Zhejiang Province, China. Forest ecology and management, 409, 479-488.

Xu, M., Ji, H., & Zhuang, S. (2018). Carbon stock of Moso bamboo (Phyllostachys pubescens) forests along a latitude gradient in the subtropical region of China. PloS one, 13(2), e0193024.

Yang, Y., Fang, J., Smith, P., Tang, Y., Chen, A., Ji, C., ... & HE, J. S. (2009). Changes in topsoil carbon stock in the Tibetan grasslands between the 1980s and 2004. Global Change Biology, 15(11), 2723-2729.

Yen, T. M., & Lee, J. S. (2011). Comparing aboveground carbon sequestration between moso bamboo (Phyllostachys heterocycla) and China fir (Cunninghamia lanceolata) forests based on the allometric model. Forest Ecology and Management, 261(6), 995-1002.

Yen, T. M., Ji, Y. J., & Lee, J. S. (2010). Estimating biomass production and carbon storage for a fast-growing makino bamboo (Phyllostachys makinoi) plant based on the diameter distribution model. Forest Ecology and Management, 260(3), 339-344.

Yinga, O. E., Kumar, K. S., Chowlani, M., Tripathi, S. K., Khanduri, V. P., & Singh, S. K. (2022). Influence of land-use pattern on soil quality in a steeply sloped tropical mountainous region, India. *Archives of Agronomy and Soil Science*, *68*(6), 852-872.

Yiping, L., Yanxia, L., Buckingham, K., Henley, G., & Guomo, Z. (2010). Bamboo and Climate Change Mitigation: a comparative analysis of carbon sequestration. International Network for Bamboo and Rattan, 30.

Yuen, J. Q., Fung, T., & Ziegler, A. D. (2017). Carbon stocks in bamboo ecosystems worldwide: Estimates and uncertainties. Forest Ecology and Management, 393, 113-138.

Yuming, Y., Chaomao, H., Jiarong, X., & Fan, D. (2001). Techniques of cultivation and integrated development of sympodial bamboo species. Sustainable Development of Bamboo and Rattan Sectors in Tropical China. Beijing: China Forestry Publishing House, 48-66.

Zhang, H., Qian, Z., & Zhuang, S. (2020). Effects of soil temperature, water content, species, and fertilization on soil respiration in bamboo forest in subtropical China. Forests, 11(1), 99.

Zhang, H., Zhuang, S., Qian, H., Wang, F., & Ji, H. (2015). Spatial variability of the topsoil organic carbon in the Moso bamboo forests of southern China in association with soil properties. PloS one, 10(3), e0119175.

Zhang, J., Ge, Y., Chang, J., Jiang, B., Jiang, H., Peng, C., ... & Yu, S. (2007). Carbon storage by ecological service forests in Zhejiang Province, subtropical China. Forest Ecology and Management, 245(1-3), 64-75.

Zhang, K., Yao, L., Meng, J., & Tao, J. (2018). Maxent modeling for predicting the potential geographical distribution of two peony species under climate change. Science of the Total Environment, 634, 1326-1334.

Zhang, S., Sheng, K., Yan, W., Liu, J., Shuang, E., Yang, M., & Zhang, X. (2021). Bamboo derived hydrochar microspheres fabricated by acid-assisted hydrothermal carbonization. Chemosphere, 263, 128093.

Zhang, X., Gao, G., Wu, Z., Wen, X., Zhong, H., Zhong, Z., ... & Gai, X. (2019). Agroforestry alters the rhizosphere soil bacterial and fungal communities of moso bamboo plantations in subtropical China. Applied Soil Ecology, 143, 192-200.

Zhao, X., Virk, A. L., Ma, S. T., Kan, Z. R., Qi, J. Y., Pu, C., ... & Zhang, H. L. (2020). Dynamics in soil organic carbon of wheat-maize dominant cropping system in the North China Plain under tillage and residue management. Journal of environmental management, 265, 110549.

Zhao, Z., Liu, G., Liu, Q., Huang, C., Li, H., & Wu, C. (2018). Distribution characteristics and seasonal variation of soil nutrients in the Mun River Basin, Thailand. International Journal of Environmental Research and Public Health, 15(9), 1818.

Zhou and Ziang, (2004) Carbon sequestration by Chinese bamboo forests and their ecological benefits: assessment of potential, problems, and future challenges. Environmental Reviews https://doi.org/10.1139/a11-015

Zhou, Z., Zhang, Z., Zha, T., Luo, Z., Zheng, J., & Sun, O. J. (2013). Predicting soil respiration using carbon stock in roots, litter and soil organic matter in forests of Loess Plateau in China. Soil Biology and Biochemistry, 57, 135-143.

BIO-DATA

Kshetrimayum Suresh Singh
PhD scholar
Department of Environmental Science,
Mizoram University.
E-mail: eisureshlamjing@gmail.com
Contact no.: +91-8787607495

---

1. ACADEMIC PROFILE

UGC-NET: Qualified for Lectureship (2014).

Master of Science: Department of Environmental Studies, University of Delhi (2011-2013).

Bachelor of Science: Zoology (Hons.), SGTB Khalsa College, University of Delhi (2006-2011).

2. RESEARCH EXPERIENCE

DST- New Delhi, funded project: ***"Sequestration of Carbon in Bamboo Forest of Aizawl District, Mizoram"*** **(February 2015 to March 2018)**

Position**: Junior Research Fellow (JRF)**

3. CONFERENCES/SEMINARS ATTENDED

C1. "International Conference on Chemistry &Environmental Sustainability (ICCES)", February 2019. (**Oral presentation)**.

C2. "12th Annual Convention of Association of Biotechnology and Pharmacy (ABAP) &International Conference on Biodiversity, Environment and Human Health Innovation and Emerging Trends (BEHIET)", November 2018. **(Poster presentation)**.

C3. "XIX Commonwealth Forestry Conference", Dehradun, April 2017 **(Poster presentation)**.

C4. UGC sponsored short term course on "**Applied statistics**" (7th -12th September 2015) at Mizoram University. **(Participant).**

C5. Second national seminar on "Climate change and socio-ecological transformation with special reference to North-east India" (5th - 6th November, 2015) at Mizoram University **(Participant)**

4. PUBLICATIONS

P1. Angom Sarjubala Devi, and Kshetrimayum Suresh Singh. "Carbon storage and sequestration potential in aboveground biomass of bamboos in North East India." *Scientific Reports* 11.1(2021):1-8.

P2. Angom Sarjubala Devi, Uttam Kumar Sahoo, Bhanu Prakash Mishra and Kshetrimayum Suresh Singh. “Carbon Stock and Carbon Sequestration In Above-Ground Biomass Of Muli Bamboo At Different Altitudes In North-East India” *IJEP* 41(5): 557-561: Vol. 41 Issue. 5 (May 2021)

P3. Angom Sarjubala Devi, and Kshetrimayum Suresh Singh. "Estimation of soil carbon sequestration and flux through soil respiration under Muli Bamboo forests in North-East India." *Ecology Environment and Conservation* 25 (2019): 129-133.

P4. Angom Sarjubala Devi, Kshetrimayum suresh Singh and H. Lalramnghinglova. "Aboveground biomass production of Melocanna baccifera and Bambusa tulda in a sub-tropical bamboo forest in Lengpui, North-East India." *Int Res J Environ Sci* 7 (2018): 23-28.

P5. Angom Sarjubala Devi, Kshetrimayum Suresh Singh and H. Lalramnghinglova. “Above Ground Biomass Production of *Melocanna baccifera* (Roxb.) Kurz. In Different Terrains” *Environment & Ecology* 35 (4D): 3523-3527 (2017).

PARTICULARS OF THE CANDIDATE

NAME OF THE CANDIDATE	: Kshetrimayum Suresh Singh
DEGREE	: Ph.D.
TITLE OF THESIS	: Element composition and carbon sequestration of selected bamboo species in Aizawl district, Mizoram
DATE OF ADMISSION	: 11.08.2016
APPROVAL OF RESEARCH APPROVAL	
1. DRC	: 27.03.2017
2. BOS	: 07.04.2017
3. SCHOOL BOARD	: 31.05.2017
MZU REGISTRATION No.	1607384
Ph.D REGISTRATION No. & DATE:	MZU/PhD/1037 of 31.05.2017

Head

Department of Environmental Science

Mizoram University

ABSTRACT

ELEMENT COMPOSITION AND CARBON SEQUESTRATION OF SELECTED BAMBOO SPECIES IN AIZAWL DISTRICT, MIZORAM

AN ABSTRACT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

KSHETRIMAYUM SURESH SINGH

MZU REGISTRATION NO: 1607384

Ph.D. REG NO: MZU/PhD/1037 of 31.05.2017

DEPARTMENT OF ENVIRONMENTAL SCIENCE

SCHOOL OF EARTH SCIENCES AND NATURAL RESOURCES MANAGEMENT

JUNE, 2022

ELEMENT COMPOSITION AND CARBON SEQUESTRATION OF SELECTED BAMBOO SPECIES IN AIZAWL DISTRICT, MIZORAM

BY

KSHETRIMAYUM SURESH SINGH
DEPARTMENT OF ENVIRONMENTAL SCIENCE

SUPERVISOR

Dr. ANGOM SARJUBALA DEVI
DEPARTMENT OF ENVIRONMENTAL SCIENCE
MIZORAM UNIVERSITY

SUBMITTED
IN PARTIAL FULFILLMENT OF THE REQUIREMENT OF THE DEGREE OF DOCTOR PHILOSOPHY IN ENVIRONMENTAL SCIENCE OF MIZORAM UNIVERSITY, AIZAWL

It is evident from geological time scale that climate of the planet earth has been changing subsequently on its own pace, but the global temperature has been increasing in an alarming rate since the end of 18^{th} century and majority of the scientific communities believe that this alarming change is a result of anthropogenic activities. Increased in greenhouse gas (GHG) emissions and overloading amounts of these gases, mainly the CO_2 in atmosphere is the primary causes of global warming and frequent occurrence of extreme weather events worldwide in recent decades. This changing pattern of earth's climatic condition is one of the most challenging concerns of this century. The third conference of parties of The United Nations Framework Convention on Climate Change (UNFCCC) in Kyoto, 1997 had a unanimous agreement on incorporation of forestry activities as a sustainable way for the carbon emission reduction. and to adopt the Clean Development Mechanism (CDM) a strategy for the mitigation of global warming by reducing CO_2 from the atmosphere, encouraging Global Environmental Facility (GEF), and Reduced Emission from Deforestation and Forest Degradation (REDD) to provide financial supports to the developing countries to promote forestry and reduction emission of CO_2 which is a green way for mitigation of CO_2 from the atmosphere.

Different plant species have different potentials for capturing and sequestration of carbon. Bamboo forest is an important forest type with high C-sequestration potential, which is abundant in different parts of the world. Bamboo is a unique group of tall grasses with woody interconnected stems which belongs to the subfamily *Bambusoideae*, family *Poaceae* (Graminaceae) which is recognized for its fast-growing potential and its versatile nature among the plant kingdom on earth. There are about 1,500 species in 90 genera worldwide. The North-eastern states of India harbour nearly 90 species of bamboo, 41 of which are endemic to the region. The present study was conducted to investigate the C- sequestration potential and elemental contents of five bamboo species naturally found in Aizawl district of Mizoram.

Aizawl district is a hilly district located in the northern part of Mizoram. The district has geographical expansion of 3576.31 km^2 which is located in between 23°43′37.59″ N and 92°43′3.5″ E. The climate is moderate and pleasant with abundant rain in the monsoon season. Within Aizawl district, five sites such as

Lengpui, Kelsih, Tamdil, Tuirial and Darlawn were selected based upon the presence of different types of bamboo forests.

For the determination of physio-chemical properties of soil, samples were collected monthly from two study sites, Lengpui and Kelsih during 2015 and 2016. Three plots were selected and earmarked for each *Melocanna baccifera* and *Bambusa tulda* stands in Lengpui. In Kelsih also three plots were earmarked for MB stand. From each plot, three replicates of soil were collected from a depth of 0-30 cm. All the physio-chemical analysis of soil was carried out by following the methods outlined in Anderson and Ingram (1993).

For the estimation of biomass and their C-storage, bamboo samples from all the five study sites were collected. Three plots for different bamboo species namely *Melocanna baccifera* (MB), *Bambusa tulda* (BT), *Dendrocalamus longispathus* (DL) and *Melocalamus compactiflorus* (MC) were earmarked in each site. In each plot, three quadrates of size (10x10) m were laid down. Laying of quadrates and analysis of biomass were done once during each year (2015 and 2016) for all the species. The study was carried out during the months of December, January and February in each study year. Within every quadrate, bamboo culms were classified into three age classes namely 1yr, 2yr and ≥3yr based upon morphological characteristics used by Wimbush (1945) and Banik (1993). Three culms of each age class were harvested from each quadrate, a total of 162 bamboo culms of the four different bamboo species were harvested annually for this study. They plant components were separated for every individual culm into culm, branch and leaf components. The fresh net weight of each component was recorded separately in the field and samples of each plant components were taken back to the laboratory for further analysis as sub-samples. In laboratory the fresh weight of each sub-samples was recorded and oven dried for 48 hours at 105^{o}C in order to found out dry weight. Biomass of the sub-samples was estimated by finding ratio of fresh to the oven dry weight method given by FAO (2012). Bamboo samples were pyrolyzed and extracted liquid (vinegar) was used for determination of elemental content.

Major findings of this study were:

Soil physio-chemical characteristics

The average soil moisture content in the present study ranged from 18.19 to 25.62%; the seasonal variation of soil pH of bamboo forests in both the study sites ranged from 5.20 to 6.06 which indicates acidic nature of soil. The soil bulk density (BD) was ranged from 0.621 to 0.737 g cm^{-3} in the present study. Soil temperature (ST) was higher during 2015 in both the study sites and Lengpui site had higher mean ST as compare to Kelsih site. Soil organic carbon (SOC) up to the depth of 30cm ranged from 1.64% - 3.15% in Lengpui and in Kelsih it ranged from 1.96% - 4.06% (Table 5). Soil C storage up to the depth of 30 cm were 43.96 MgC/ha and 51.31 MgC/ha during 2015 and 2016 respectively in Lengpui; 52.14 MgC/ha and 56.81 MgC/ha during 2015 and 2016 respectively in Kelsih. Soil respiration (SR) ranged from 9.56 Mg/ha/yr to 22.14 Mg/ha/yr in Lenpui, and in Kelsih it ranged from 11.18 Mg/ha/yr to 25.00 Mg/ha/yr.

Biomass estimation and C-sequestration potential

The total biomass (above and below ground) in MB was ranged from 36.92 to 47.99 Mg/ha, 96.24 to 117.31 and 85.64 to 178.72 Mg/ha in Lengpui, Kelsih and Tamdil respectively. By comparing between different components, culm component had maximum biomass (73.03%) followed by leave (15.81%) and branch (11.16%). The C-storage in biomass were ranged from 15.15 to 19.33 Mg/ha, 38.98 to 48.8 Mg/ha and 35.49 to 71.82 Mg/ha respectively in Lengpui, Kelsih and Tamdil. The rate of C-sequestration was 4.31 Mg/ha/year, 9.93 Mg/ha/year and 36.52 Mg/ha/yr in Lengpui, Kelsih and Tamdil respectively.

The aboveground biomass (AGB) was highest in DL which ranged from 115.08 Mg/ha to 150.0 Mg/ha in 2015 and 2016 respectively, in BT it was ranged from 57.02 Mg/ha to 127.03 Mg/ and in MC it was ranged from 34.28 Mg/ha to 89.18 Mg/ha respectively. The C-storage in AGB during the studied years were ranged from 27.7 to 63.99 Mg/ha, 50.11 to 65.16 Mg/ha and 17.13 to 44.66 Mg/ha respectively in BT, DL and MC.

Elemental content and chemical compounds in pyrolyzed bamboo liquid (vinegar)

In the present study, the trace elements such as Cr, Fe, Zn, Mo and Pb and four macro elements (Na, Mg, K, and Ca) were observed in the pyrolyzed liquids of MB and BT with different concentrations. Bamboo vinegar contains organic compounds such as phenolic compounds, organic acids, alkanes, alcohol, aldehydes and many more. pH of bamboo vinegar ranged from 2.46 to 2.63 in MB; 2.59 to 2.67 in BT. Polyphenols such as furfural, D-fructose, Phenol-2-methoxy (Guiacol), 2-Methoxy-4-methylphenol (Creosol), Catechol and 2-Propenyl were found in pyrolyzed liquid of MB; Malezitose, Catechol and 2,6-Dimethoxyphenol in BT.

From the above findings it can be concluded that biomass in the stands of *Melocanna baccifera*, *Bambusa tulda*, *Dendrocalamus longispathus* and *Melocalamus compactiflorus* have high potential for C-sequestration. To maintain a stable ecosystem of bamboo forest, harvesting of matured culms is important as the concentration of older culms would hamper sprouting of new shoots. Organized plantation of bamboo will improve the economic condition of the local people as well as reducing environmental deprivation. Therefore, initiatives can be taken up by policymakers to utilize the degraded lands for plantation of bamboo and to mitigate CO_2 from atmosphere thus reduce the impact of climate change