Carbon Stock and Sequestration in Bamboo Forests of Mokokchung district, Nagaland

By

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Department of Botany

Nagaland University, Lumami-798627

Nagaland, India

2023

DEDICATION

This thesis is dedicated to my parents and my supervisor

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This is to certify that the work embodied in this thesis entitled **"Carbon stock and sequestration in Bamboo forest of Mokokchung district, Nagaland"** submitted by Ms. **Maongkala Walling bearing registration No. Ph.D./BOT/00048**, with effect from **26/8/2017** for the award of Degree of Doctor of Philosophy, Nagaland University, has been carried out under my supervision and guidance, that the work embodied has not been submitted elsewhere for the award of any other degree or diploma and it is up to the mark both in its academic contents and the quality of presentation.

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Declaration

I, Ms. **Maongkala Walling**, bearing Ph.D. registration number **Ph.D./BOT/00048**, with effect from **26/8/2017**, hereby state that the present work entitled **"Carbon stock and sequestration in Bamboo forest of Mokokchung district, Nagaland"** being submitted to Nagaland University is an original work carried out by me under the supervision of Dr. Neizo Puro, Department of Botany, Nagaland University, Lumami.

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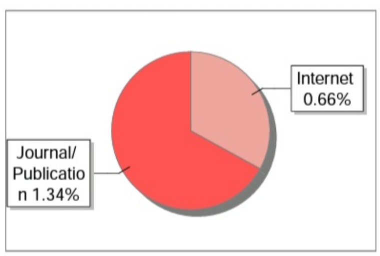

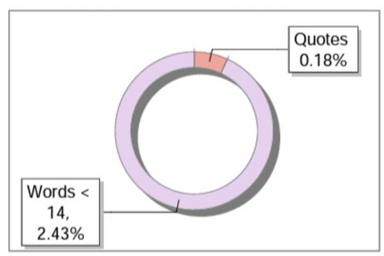

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Chapter 1

Introduction

In the tropical and subtropical parts of the world, bamboos are one of the most significant species of trees (Scurlock *et al.*, 2000). All bamboo species can be divided into three groups based on their morphology: monopodial, sympodial, and amphipod. Each group contains species cultivated for industrial, agricultural, ornamental, and ecological reasons (Maoyi and Banik, 1996). Bamboos have distinct growth patterns that differ from those of timber species, as well as rapid growth, high biomass output, and quick maturation from shoot to culm (Lu, 2001).

Bamboos are significant for national and international trade in Asia-Pacific and contribute significantly to local economies worldwide. One of the world's greatest bamboo reserves is thought to be in India. 15.69 million hectares are thought to represent the country's total bamboo bearing area, with 5.41 million hectares (mha) in the northeastern states and 0.06, 4.05, and 9.14 mha in pure, dense, and scattered bamboo stands, respectively (FSI, 2017).

"Bamboo is an essential component of many natural and agricultural ecosystems, supplying consumers in both developing and developed nations with food and raw materials (provisioning services), regulating water flows, reducing water erosion on slopes and along riverbanks, treating wastewater, and acting as a windbreak in shelterbelts, protecting against storms"- Yiping *et al.*, 2010 (pp.47).

There have been numerous international conversations and agreements due to the pervasive and growing concern over global climate change. Reduced emissions of greenhouse gases, particularly carbon dioxide, and measurements of the carbon absorbed by and stored in soils and forests have been the primary responses to this problem. As averted deforestation is a very inexpensive carbon abatement option, there is rising interest in decreased deforestation to combat climate change (Gullison *et al*., 2007). More atmospheric CO2 could be stored in terrestrial ecosystems by transforming land with low levels of carbon into forested land, which has more carbon in the flora and soil. Such land includes shrub and pasture areas, agricultural fields, and degraded forests (Yiping *et al*., 2010). Since bamboo forests are crucial for the production and are not as at risk from deforestation as primary tropical forests are, this is the field of research that is more pertinent to bamboo.

Only a few features of bamboo phenology are covered in the research that is now accessible, including leafing pattern, bud break, and periodicity of culm emergence (Banik, 1999). Plant phenologies are the outcome of biotic and climatic component interactions that, through natural selection, establish the best time for growth and reproduction. Therefore, recording bamboo's phenological behavior is necessary to comprehend the speciesspecific leaves and sheaths' dynamics and their ecological significance in terms of plants' ability to adapt to the same climatic regimes. Janzen (1976) and Franklin (2004) are the only authors who have attempted to explain the bamboo species' flowering patterns; nevertheless, their explanations do not apply to all bamboo species.

The productivity and sustainability of terrestrial ecosystems are significantly influenced by SOC content (Thockhom and Yadava 2017). Minor adjustments to the soil's organic carbon pool could greatly impact the amount of CO2 in the atmosphere (Nath *et al*., 2015c). Its composition is acknowledged as a crucial element of soil fertility. The soil organic carbon pool can be improved by converting degraded soils from agroecosystems, and other land uses into forests, and perennial land uses (Lal, 2004). Additionally, it can help with the growth of vegetation and the soil's ability to store organic carbon (Bhattacharyya *et al*., 2008). Plants receive the appropriate amount of nitrogen and carbon. According to Schlesinger and Andrew (2000), "soil respiration plays a significant role in the exchange of carbon dioxide between soil and atmosphere and significantly contributes to the global carbon dioxide flux. The carbon budget is regulated by soil respiration, which also speeds up carbon sequestration. Future atmospheric carbon dioxide concentrations and the land ecosystem's carbon dioxide sink robustness will likely be significantly impacted by how soil respiration responds to climate change" (pp.12). Due to several environmental parameters, including temperature, soil moisture, soil organic matter, litter, kind of vegetation, topographical features, and soil texture, soil respiration differs from one habitat to the next. Among these variables, soil moisture and temperature are crucial in boosting soil carbon dioxide outflow. Numerous studies have examined the potential for carbon sequestration in soils used for agriculture, forests (Bradley and Pregitzer 2007), and agroforestry (Lorenz and Lal 2014). The soil organic carbon stock under a bamboo forest stand composed of *Bambusa tulda*, *Bambusa pallida*, *Dendrocalamus hamiltonii*, and *Dendrocalamus asper*, however, has yet to receive much attention from published experimental research. There are presently few studies on the ability of several Indian bamboo species to sequester carbon.

Bamboo plays a significant role in rural North-East of India (Nath and Das, 2012). However, there needs to be more information available on carbon store and storage in the forest ecosystems of North-East India (Yadava, 2010; Thokchom and Yadava, 2013 and Yadava and Thokchom, 2013).

As a result, Nagaland, which has abundant forests and wild plants, used to be regarded as a state with significant natural resources. However, Nagaland now makes up around 32.4% of the world's degraded forest area due to jhum cultivation's widespread degradation of forest cover. There is considerably less carbon sequestration in places with degraded forests and abandoned agricultural land. Fast-growing bamboo plants store more carbon dioxide, produce up to 35% more oxygen, and use water twice as efficiently as comparable stands of trees, making bamboo forests more effective and efficient carbon sinks. As a result, the goal of the present study, "Carbon storage and sequestration in the bamboo forest of

Mokokchung District, Nagaland," is to encourage the employment of bamboo-based land use systems with a higher capacity to sequester carbon in unused agricultural land and degraded forest sites. Including a bamboo farming system can motivate farmers to stop clear-cutting trees and raise public awareness of the need to store carbon in soil and forests. Since there is no information on the rate of carbon sequestration and carbon pool in soil and vegetation in the bamboo forest of Nagaland, North East India, the current research aims explicitly at estimating the carbon storage and sequestration in the bamboo forest at different altitudes and its soil physiochemical characteristics under Mokokchung District. As a result, given the ecological relevance and importance as well as the paucity of research in this area, the current study is conducted with the following objectives:

1. To study the dominant bamboo species in different elevation.

2. To study the phenology of dominant bamboo species with respect to elevation gradient.

3. Development of allometric models for dominant species of Mokokchung district.

4. Estimation of biomass and carbon storage in bamboo forest with respect to elevation gradient.

5. Soil organic carbon pools in bamboo forest with respect to elevation gradient.

Chapter 2

Review of Literature

2.1. Distribution of Bamboo:

Bamboo is a natural composite whose native countries are primarily tropical (Abd. Latif *et al*.,1900). It is a perennial, enormous, woody grass of the angiosperm family, bamboo (Champan, 1990). They are all members of the same subfamily Bambusoideae (Kigomo, 1988). According to Wang and Shen (1987), there are more than 1200–1500 species of bamboo worldwide, divided into 60–70 genera. Bamboo can grow in both cold, hardy forests and hot, humid rainforests. It can withstand and even flourish in temperatures as low as 20 °C. Additionally, 32 to 50 inches of excessive precipitation per year are tolerated by it (Goyal *et al*., 2012). According to Canavan *et al*., (2017), there are around 1662 species of bamboo classified into 121 genera, with native species found in 122 nations and various islands/regions. With 900 species and 65 genera of bamboo, Asia is a continent with tremendous diversity (Hore, 1998). Asia is home to about half of the species, with the majority growing in the Indo-Burmese region, which is also thought to be where they originated (Grosses and W. Liese, 1971).

China, known as the "Kingdom of Bamboo," ranks first among the nations rich in native bamboo and has harnessed the potential of their bamboo resources to a more significant level. It contains about 500 species in roughly 40 genera. According to Chen *et al*., (2009), China possesses 500 species of bamboo divided into 48 genera, as opposed to the world's 1500 species and 87 genera. In "Illustration to Bamboos of China," Yuming & Chaomao (2010) listed 857 species (including variations and forms) and 43 genera.

India ranks the second-richest nation in terms of bamboo genetic resources after China (Bystriakova *et al*., 2003). According to Bahadur and Jain (1981) -"there are 113 species across 22 genera in India, of which three are foreign, and 19 are native" (pp. 286). Bamboo is a plentiful material in Kerala. In his monograph on bamboo, Tewari (1992) described "128 species of bamboo from 23 taxa in India, 77 of which are located in the Eastern Himalayan region" (pp. 276). According to Kumar (2006), "there are 118 species in India, divided into 21 genera, of which 78 species and 14 genera are indigenous to the country" (pp. 201). In India, there are "148 species and four variants among 29 taxa" (pp. 22), according to Sharma and Nirmala (2015). According to reports, India is home to over 25% of the world's bamboo species, particularly in the Western Ghats and North-East India (Biswas, 1988; Rai and Chauhan, 1998). According to Qureshi and Deshmukh (1962), bamboo can be found in India's understorey of dry and damp deciduous, wet evergreen, or tropical evergreen forests, as well as in pure bamboo breaks.

The variety of bamboo germplasm in north-eastern India was described by Kochar *et al*., in 1992. According to Tewari *et al*., (2015), "the North-

Eastern states hold a majority of the growing stock of bamboo" (pp.18). According to studies by Hore (1998) and Barooah & Borthakur (2003), "there are 78 different species of bamboo in North East India, 42 of which may be found in Assam". According to Sharma *et al*., (2016), "Assam is home to 45 different species of bamboo, some of which are endemic" (pp.184).

Gamble (1896) only included four species of *Arundinaria* in his massive study on the bamboos of Nagaland: "*Arundinaria elegans*, *Arundinaria prainii*, *Arundinaria hirsuta*, and *Arundinaria rollona*. *Dendrocalamus sikkimensis*, *D. hookeri*, *D. patellaris*, *Pseudostachyum polymorphum*, *Teinostachyum griffithii*, *Cephalostachyum funchsianum*, and *Arundinaria griffithiana*" (pp.445) were among the nine species of grasses from Nagaland that Bor (1940) noted while studying the grasses of Assam. In their collection study based on a literature review, Seethalakshmi and Kumar (1998) included 23 species under 7 genera from Nagaland. From Nagaland, Naithani (2011) identified 40 species and 3 types of bamboo. According to NBDA (2015), Nagaland is home to 43 different species of bamboo.

2.2. The flowering of Bamboo:

Currently, scientists and foresters are battling an intriguing challenge related to the research of bamboo flowering (Naithani and Sanwal, 2017). Since most kinds of bamboo do not flower, there are not many historical accounts of it, and those that do exist lack proper corroboration (Taylor and Qin, 1988). Annual flowering plants from the genera *Arundinaria*, *Bambusa*, and others are widespread throughout South America. Only a few plants are known to bloom annually in India and Sri Lanka. The intervals between succeeding flowering stages reveal a significant variance between species. Flowers may begin to appear in certain species after 20–30 years but not in others until 120–150 years of the initial bloom or even as soon as three years in some circumstances. Bamboos can flower in one of three ways i) In successive years, the entire region experiences gregarious blossoming, followed by the clump's death (McClure, 1966). This forces the plant to expend a tremendous amount of energy, resulting in the entire population's death (Janzen, 1976; Franklin, 2004). ii) Sporadic flowering: flowering on only a few clumps or culms of a clump. iii) Annual flowering: blooms every year (Janzen, 1976). After flowering, the flowering culms lose their leaves, turn yellow, and eventually dry out. Every flowering cohort's culms finish flowering in three months after setting seeds, and then the culms begin to dry out and eventually die.

Because even-aged stands flower synchronously regardless of size before dying, the bamboo flowering event offers the chance to study and understand reproduction-size connections (Nath *et al*., 2012). The mystery exists because the nature and pattern of bamboo flowering are not adequately described in public sources. Bamboos can flower frequently or infrequently; during gregarious flowering, they all bloomed at once over a considerable region (Franklin, 2004).

Sinha *et al*., noted *Bambusa cacharensis* fruiting and flowering in Tripura (2012). From 1990 to 1996, "*Dendrocalamus giganteus*" clumps bloomed at six different sites in Sri Lanka's Kandy area, according to Ramanayake and Yakandawala (1998). However, new reports from the Barak Valley mention the blossoming of "*Melocalamus compactiflorus*" (Das *et al*., 2014), "*Bambusa balcooa*" (Das *et al*., 2017a), and "*Bambusa vulgaris*" (Das *et al*., 2017b). After 43–49 years of vegetative growth, *B. bamboos* have recently (2014–2016) flowered in a large area of Uttarakhand and Uttar Pradesh (Naithani and Sanwal 2017). According to Sharma *et al*., (2014), "*Dendrocalamus longispathus* from Mizoram has begun to bloom. People whose way of life depends on bamboo have been devastated by this event's unpredictability". Therefore, knowledge of flowering in this category of plants is necessary (Ramanayake, 2006; Das *et al*., 2017a and Das *et al*., 2017b).

2.3. Vegetative Phenology of Bamboo:

The study of plant phenology is crucial today because plants' growing cycles and growing seasons are being affected by global climate change occurrences. The study of phenology examines how the timing of seasonal events like budburst, shooting, leaf flushing, leaf fall, flowering, and dormancy changes through time. Bamboo forests have an excellent ability for carbon sequestration, making vegetation phenology an essential component influencing forest carbon intake and storage. The effective interactions between biotic and climatic conditions and the adaptation of the various bamboo species through natural selection, which affects the growth phases and propagation of plant species, cause the phenomena of plant growth (Nath *et al*., 2008 and Van Schaik *et al*., 1993).

Bamboo forests are crucial for preserving the carbon balance on the planet and combating climate change. Scientists have become interested in bamboo because of its rapid growth habit (Taylor and Zisheng, 1988; Liese, 1997; Li *et al*., 2013; Nath *et al*., 2007), unusual life cycle, and other characteristics (Nath *et al*., 2015b; Nath *et al*., 2012; Makita, 1992; Makita *et al*., 1995; Nath and Das, 2010; Janzen, 1976). Although bamboo species develop quickly, there are little studies on their growth dynamics and behaviors (Ding *et al*., 2011). Using the GPP (gross primary productivity) and NEP (net ecosystem productivity) data of bamboo forests based on the leaf area index (LAI) assimilation based phenology from 2001 to 2011, the effects of changes in vegetation phenology were examined (Li *et al*., 2021). They found that bamboo forest ecosystems maintain substantial carbon sequestration and function as carbon sinks, as evidenced by the mean annual GPP value "434.74 257.93 g C m^2 yr^1" and NEP values "141.42 82.54 g C m^2 yr^1". Additionally, they discovered that in roughly 62% of the Chinese region they studied, an increase in the LOS (length of the growing season) causes GPP and NEP to increase through a positive connection. Information comparing several bamboo species is not widely available.

The growth of bamboos is typically influenced by air temperature and precipitation, as was the case with *Phyllostachys nidularia*. As the effect of soil temperature on the growth of *P. praecox f. prevernalis* was explored, soil temperature also has a significant role in the development of bamboo new shoots (Yu, 1997). According to their findings, shooting began when the soil temperature reached “8–8.5 °C”, and the quantity of shoots rose between “10–16°C”. The shoot sprouting reduced and eventually stopped when the soil temperature reached about “16 °C”. Other authors concluded that the primary factor influencing how quickly bamboo sprouts is air temperature (Mei *et al*., 2020). Additionally, as was observed for moso bamboo, height impacts the phenology of bamboo. As seen in the case of the vegetative phenology and growth of deciduous bamboo “*Bambusa arnhemica*”, precipitation and water availability in the soil are also significant elements impacting bamboo phenology.

2.4. Soil physico-chemical Properties:

The IPCC (Intergovernmental Panel on Climate Change) has considered topics such as the quality and usage of arable lands and conservation management when forecasting the emergence of new global climate scenarios (IPCC, 2007). “Soils serve as both a source and a sink for atmospheric CO2 by capturing and storing carbon in organic and inorganic forms” Bhattacharyya *et al*., 2008 (pp.482). In order to preserve soil quality, soil organic carbon (SOC) is thought to be of the utmost importance. Because SOC is tightly linked to various physical, chemical, and biological characteristics of soil, it plays a crucial role in soil processes and functioning (Smith *et al*., 2000). “One of the critical carbon (C) pools for the Land Use Land Use Change in Forestry (LULUCF) industry, according to the IPCC, is the soil organic carbon (SOC) pool” IPCC, 2003.

According to Yen and Hsu (1950), who found 2.2% of organic matter in bamboo plants' surface and subsurface soil, leaching is prevented by the bamboo's ability to take up roots. Most bamboo species are said to favor slightly acidic soil with a *p*H between 5 and 6.5. (Uchimura, 1978; Hassan *et al*., 1988; Rao, 1993). When working with “*D. strictus*”, Totey *et al*. (1989) reported the significance and function of soil accessible P and SOC as limiting factors in bamboo biomass accumulation. In comparative research, Qureshi *et al*., (1969) found that the soils that sustain “*B. bambos*” are finer in texture, more acidic, more capable of holding moisture, and richer in nitrogen, organic matter, iron, and aluminum, exchangeable magnesium, and potassium than the soils that support “*D. strictus*”.

Although bamboo thrives in rich, deep loams, sandy loams, and fertile clayey loams, some species from genera like “*Oxytenanthera*” prefer to grow on plateaus and hilltops where the soil is damaged (Tewari, 1992;

Banik, 2000). The nutritional condition of the soil is significantly improved and maintained by bamboo (Kleinhenz and Midmore, 2001). According to Singh (2002), "bamboo plantations (*Bambusa pallida*) have long-term effects on the physicochemical composition of the soil. While accessible phosphorous, Copper, Mn, Fe, and potash exhibit a falling trend, soil *p*H, organic carbon, exchangeable Ca, Zn, and Mg show a rising tendency" (pp. 73).

In the soils of "*Guada angustifolia*" plantations in the Montane region of Equador and also in the soils beneath "Moso bamboo (*Phyllostachys pubescens*)" in Japan by Hiraoka and Onda, Tian *et al*., (2007) showed that soil BD and SOC rose with the increase in clump age (2012). According to Zhou *et al*., (2006), the SOC stock in a managed "*Phyllostachys pubescens*" plantation in China's Zhejiang region ranged from "25 to 35 Mg/ha up to a depth of 30 cm". Bamboo plantations' soil was found to contain "57.3 t ha-1 of carbon up to a depth of 30 cm" (Nath *et al*., 2009a).

Nath *et al*., (2015b) evaluated that "the soil's physio-chemical characteristics in agroforestry systems based on bamboo to verify the farmers' description of the soil's hierarchical structure and how it correlated with bamboo productivity. According to their findings, balu mati had the lowest culm production (19 culms/clump) and kalo mati (black soil) had the most (27 culms/clump) (sandy soil)" pp.96. In their study of the soil physico-chemical properties in bamboo plantations in NE

India", Nath *et al*., (2016a, pp.610)) found that "as plantation age increases, the soil bulk density (BD) declines, going from 1.42 Mg m^{-3} in a two-year-old plantation to 1.27 Mg m^{-3} in 20-year-old plantations. On the other hand, as the plantation age grew, the WHC (30.3 -3 41.5%) and SOC (0.68-1.17%) increased. The sequestration rate for SOC was 0.14-0.39 Mg/ha/yr up to a soil depth of 10 cm, and the SOC stock ranged from 9.66 to 14.86 Mg/ha". They also stated that the depth of the soil affects the physical and chemical characteristics of the soil. With increasing soil depth, soil BD and WHC rose, whereas *p*H, SOC, total N, accessible N, and exchangeable K+ decreased. The SOC stock varied "between 26 and 35 Mg^{-1} C ha , and the sequestration rate up to 30 cm of soil depth varied between 0.28 and 0.59 Mg^{-1} C ha" .

According to Brady and Well (2008), bamboo soil has a significant role in managing atmospheric carbon dioxide, and soil *p*H significantly affects the availability of nutrients to plants and the interactions of soil microbes. For the stability of the ecosystem and sustainable growth, soil organic carbon has been regarded as a crucial aspect (Clapp and Hayes, 1999). According to Bremer *et al*., (1995), "soil organic carbon dynamics reveals information on soil fertility and the carbon cycle" (pp 1398). Additionally, it can help with the growth of vegetation and the soil's ability to store organic carbon (Bhattacharyya *et al*., 2004). Plants receive the appropriate amount of nitrogen and carbon.

Less carbon is stored in sites with damaged forests and abandoned agricultural land. Therefore, it is possible to increase carbon stocks by promoting bamboo-based land-use systems that have increased capacity for carbon sequestration (Walson *et al*., 2000). According to Schlesinger and Andrew (2000), soil respiration plays a significant role in the exchange of carbon dioxide between soil and atmosphere. It is a significant contributor to the global carbon dioxide flux. The carbon budget is regulated by soil respiration, which also speeds up carbon sequestration. Future atmospheric carbon dioxide concentrations and the land ecosystem's carbon dioxide sink robustness will likely be significantly impacted by how soil respiration responds to climate change. Due to several environmental parameters, including temperature, soil moisture, soil organic matter, litter, kind of vegetation, topographical features, and soil texture, soil respiration differs from one habitat to the next. Among these variables, soil moisture and temperature are crucial in boosting soil carbon dioxide outflow.

2.5. Bamboo in climate change research:

Most bamboos require a warm environment, plenty of rain, and fertile soil, while some may tolerate temperatures as low as “-20°C”. (Wang and Shen, 1987). According to Lee *et al*., (1994), smaller bamboo species are more common in higher elevations or temperate latitudes, while larger species are common in tropic and subtropical regions. Bamboo is quite flexible. Bamboo may grow in well-drained sandy to clay soil or on rocks with a *p*H range of "5.0 to 6.5" (Abd. Latif and Abd. Razak, 1991). Bamboo is a rapidly expanding species that produces a lot of renewable resources.

"Bamboo forests play a significant role in carbon sequestration by absorbing atmospheric carbon dioxide, turning it into biomass, and respiring it out to release oxygen" Waran and Patwardhan (2001). More biomass is produced when more photosynthesis takes place, which lowers the amount of carbon in the atmosphere and sequesters it in the tissue of the plants above and below the growing area (Lobovikov *et al*., 2009; Yiping *et al*., 2010). The idea of carbon capture and storage is new, and environmentalists continue to question its potential use.

Climate change is one of the most challenging global environmental, economic, and social issues (Chawan and Rasal, 2010; Jordan *et al*., 2009). Bamboo has enormous potential for reducing climate change and preparing for it (Nath and Das, 2011; Wang *et al*., 2009). Additionally, providing various ecosystem services and benefits for livelihood, bamboo forests are efficient and effective carbon sinks (Jia Qui *et al*., 2017). "*Bambusa vulgaris* can store 77.67 TC/Hac on its own at age five" Sohel *et al*., (2015).

According to Jia Qui *et al*., (2017), numerous "*Phyllostachys*" species, including "*P. edulis*", are connected with high-carbon biomass in China. In "*P. edulis*", Xinzhan *et al*., (2017) noted that the species' rapid growth rate, high photosynthetic rate, ample water, and heat availability, together with high atmospheric nitrogen and phosphorus deposition, all contribute to the regulation of the NEP dynamic and its carbon sequestration efficiency. The Moso bamboo forest's ability to absorb carbon suggests they have a high potential for reducing climate change. According to Teng *et al*., (2016), sympodial bamboo has a higher carbon sequestration rate and storage rate than other bamboo species.

“22 genera and 136 species of bamboo make up 12.8% of the country's total forest area in India” Bahadur and Verma, (1980); Sharama, (1987). One of India's bamboo reserves is said to be in the North-East. Out of 148 species of bamboo in India, 29 genera are home to plants that grow wild or are cultivated in tropical and subtropical regions (NMBA, 2008). Of the 64 bamboo species recorded from the North East, 46 have been found in Nagaland. There are presently few studies on the ability of several Indian bamboo species to sequester carbon. According to Nath and Das (2007), bamboo is a crucial part of the “agro-silviculture” system in North-East India and has a significant impact on the ecosystem's carbon balance by digesting atmospheric carbon dioxide. Bamboo plays a significant role in rural North-East of India (Nath and Das, 2012). However, there is little evidence available on the carbon stock and storage in the forest ecosystems of North-East India (Baishya *et al*., 2009; Yadava, 2010; Thokchom and Yadava, 2013; Yadava and Thokchom, 2013).

Estimating biomass helps determine how much energy is moving through the ecosystem and estimate how much carbon is in the forest (Brown and Lugo, 1984; Brown, 1997). The assessment of ecosystem productivity and the role of tropical forests in the global carbon cycle begins with the calculation of biomass (Ketterings *et al*., 2001; Parresol, 1999).

There needs to be more information on bamboo's role in the generation of biomass and terrestrial carbon (Nath *et al*., 2015b). Few genera, including "*Phyllostachys*" in China (Yen and Lee 2010; Zhang *et al*., 2014) and "*Bambusa*" in India, have been the subject of studies on bamboo biomass (Shanmughavel *et al*., 2001; Nath and Das, 2009b). Numerous studies have demonstrated that bamboo's above-ground biomass accumulation rises with age (Yen *et al*., 2010). Therefore, it is crucial to create age-specific biomass estimating models.

Calculating above-ground biomass in short-rotation forest plantations is typical to enhance decision-making and specify harvest cycles under market conditions (Verwijst and Telenius, 1999). Two strategies exist for estimating biomass: the direct method, often known as destructive techniques, and the indirect method, which involves creating allometric equations. Destructive methods take a lot of effort and money (Willebrand *et al*., 1993). The most recommended measurement method is the development of allometric equations, which takes less time and costs less than destructive methods (Sochacki *et al*., 2017). The ratio of fresh (wet) weight to dry weight, another crucial component in calculating bamboo biomass, may change with age since younger culms are wetter, or have more moisture, than older culms (Hunter and Junqi, 2002). To comprehend their involvement in the global carbon cycle, researchers have been studying the above- and below-ground carbon stocks and fluxes in tropical forest components more and more (Malhi and Grace, 2000). Options for biotic and abiotic C sequestration are complementary to one another and have a fair chance of reducing the dangers associated with climate change (Lal, 2008). Management of agricultural systems to trap carbon has been acknowledged as a part of the solution to climate change, according to Morgan *et al*., (2010). Growing trees may sequester carbon, a cost-effective way to reduce CO emissions brought on by human activity (Pan *et al*., 2011).

Bamboo biomass and production vary by species and are also influenced by age and stock density. The induction of new shoots rises until a particular age, then gradually declines to depend on the soil and climate circumstances (Banik, 2000; Shanmughavel and Francis, 2001). According to Chinte (1965), for "*Bambusa vulgaris* and *Gigantochloa aspera*, the yearly yield of air-dried bamboo per ha of a 3–4 year old plantation was determined to be 6-7 t ha^{-1}" (pp. 37).

For the bamboo species that can be found in jhum land, Rao (1986) stated that the aboveground biomass ranged from "0.08 to 6.2 t ha^{-1}". According to Kigomo and Kamiri (1987), "the order of the leading bamboo components' relative contributions to the biomass was: bamboo culm>

bamboo branch> bamboo leaves" (pp. 28). According to Pande *et al*., (2012), the yearly production and productivity of bamboo "were 5.0, 3.2, and 0.3 million tonnes year^{-1}" in China, India, and Japan, respectively. "The carbon stock in *Dendrocalamus strictus* bamboo stands in the Indian dry tropics was 75.4 t ha^{-1}" (pp. 148), according to Tripathi and Singh (1996), of which "23-28% was distributed in plants, 2% in the litter, and 70-75% in soil". According to Qiu *et al*., (1992), "the above-ground woody biomass increments for a seminatural lowland stand of *Phyllostachys pubescens* in Zhejiang Province, China, averaged 7.7 t ha^{-1} year^{-1} (8.8 and 6.6 t ha^{-1} year^{-1} in 1986 and 1987, respectively)" pp186. This mature stand, which was subject to harvesting poles older than 8 years, had a maximum height of "15-20 m" and above-ground biomass of "56 t ha^{-1}". According to Li *et al*., (1998), "the dry matter allocation for *P. pubescens* was 49, 10, and 3 t ha^{-1} at disturbed stands for the plant's various components (culm, branches, and leaves)" pp. 115.

According to Singh *et al*., (2004), the standing crop of *D. strictus* in improved plantation stands was "144.34 t ha^{-1}". According to Singh, "*B. pallida* accumulated above-ground biomass at 134.13 t ha^{-1}, 116.5 t/ha, and 113.16 t ha^{-1} at clump densities of 278 n/ha, 204 n/ha, and 156 n/ha, respectively (2002)" pp. 109.

Total carbon storage has reportedly grown from "318.6 Tg C (1950–1962) to 631.6 Tg C", according to Chen *et al*., (1999 to 2003). According to Zhou and Jiang (2004), "a typical Moso bamboo ecosystem has a total carbon storage capacity of 106.36 t ha^{-1}, including the carbon stored in the soil. Of this amount, 34.3 t ha^{-1} is stored by the green vegetation above ground, making up 32.3% of the total, and 72.2 t ha^{-1} is stored by the forest floor and soil (0 to 60 cm in depth), making up 67.7% of the total" pp. 24.

The above-ground stand biomass in the village bamboos of Barak Valley, North East India was "121.51 t ha^{-1}, of which 86% was contributed by the culm component, followed by branch (10%) and leaf (4%)". Nath *et al*., (2008) developed allometric relationships for biomass estimation of village bamboos of Barak Valley, North East India. In that order, *B. cacharensis* accounted for 46% of the biomass in the entire stand, followed by "*B. vulgaris* (28%) and *B. balcooa* (26%)". "61.05 t ha^{-1}" of carbon was stored in the above-ground biomass. "C was distributed more evenly among culm components (53.05 t ha^{-1}) than among branches and leaves (5.81 t ha^{-1}) (2.19 t ha^{-1}). The plantation's gross C stock was calculated to be 120.75 t"- Nath *et al*. (2008) pp. 48.

In Cachar district, Assam, northeast India, Nath and Das (2012) evaluated the carbon (C) pool and sequestration capability of bamboos in the land managed by farmers. Between 2003 and 2006, the above-ground biomass's C pool varied from "21.69 Mg ha^{-1} to 76.55 Mg ha^{-1}". C was distributed more evenly throughout culm components "(85-89%)" than among branches "(8-10)" and leaves "(3-4%)". "The whole above-ground C pool was made up of both current and one-year-old culm, which made up 58–

73% (15.86–35.63 Mg ha^{-1}) of the total. With a mean of 21.36 Mg ha^{-1} yr^{-1}, the rate of above-ground C sequestration ranged from 18.93 to 23.55 Mg ha^{-1} yr^{-1}"- Nath and Das (2012) pp. 214.

According to Nath *et al*., (2015b), "woody bamboos have a mean carbon storage and sequestration capacity of 30-121 Mg ha^{-1}, 6-13 Mg ha^{-1} yr^{-1}, and a net primary productivity of 12-26 Mg ha^{-1} yr^{-1}". According to research was done by Wang *et al*., (2013) on the biomass carbon of moso bamboo forests, the biomass ranged from "219.56 to 299.31 Mg ha^{-1}, accounting for 4.7–5.9%" of the total forest biomass carbon in China from 1977 to 2008. In a sub-tropical bamboo forest in Lengpui, Northeast India, Devi *et al*., (2018) evaluated the above-ground biomass production of "*M. baccifera* and *B. tulda*. They found that the combined AGB of *M. baccifera* was 106.68 Mg ha^{-1} and that of *B. tulda* was 97 Mg ha^{-1}".

According to Singnar *et al*., (2017), "*S. dullooa*, *P. polymorphum*, and *M. baccifera* forests had above-ground biomass carbon densities of 23 Mg ha^{-1}, 21 Mg ha^{-1}, and 58 Mg ha^{-1}, respectively". In a study by Tariyal *et al*., (2013), which examined the total carbon stock and carbon sequestration potential of four important bamboo species in Uttarakhand (*Bambusa balcooa*, *Bambusa nutans*, *Bambusa vulgaris*, and *Dendrocalamus strictus*), it was discovered that *D. strictus* had the highest total carbon stock "(381.50 t ha^{-1})", while *B. vulgaris* had the lowest stock "(160.11 t ha^{-1})". Contrarily, *B. balcooa* had the highest carbon sequestration potential “(99.81 t ha^{-1} yr^{-1})”, while *B. vulgaris* had the lowest “(57.77 t ha^{-1})”.

2.6. Socioeconomic Impact of Bamboo:

One of the most effective non-timber forest products (NTFPs) in the world is bamboo. It has been suggested that regulated bamboo harvesting and sale can help reduce poverty in many different parts of the world (Singh, 2008). According to Marsh and Smith (2007), the industrial aspect of the bamboo industry has excellent potential as far as its influence on reducing poverty is concerned. In the Asia-Pacific area, bamboos have substantial national and international commercial value and play a key part in local economies worldwide (INBAR, 1999). According to Zhou *et al*., (2005), bamboo's biological characteristics and growth pattern make it an excellent financial investment that can be used in various ways. It also has a significant amount of potential for reducing numerous environmental effects. Since bamboo is a tall grass that is beneficial in practically every part of life, growing it can yield a profit in a relatively short time and contribute significantly to the country's economy (Ray and Ali, 2017). There are more than 1500 documented uses for bamboo, and as new development projects are launched globally, this number is proliferating (Ranjan, 2001).

In the past, humans used bamboo to make things like homes, tools and other implements, musical instruments, and other handicrafts (McClure, 1966). According to Sharma (1980), “26 species of bamboo are utilized throughout Asia traditionally for food”. According to Ueda (1981), there are three main uses for bamboo: (a) domestic use as vegetable stakes, trellises, poles, shades, and laths; and (b) use in building construction, food preparation, and the manufacture of fishing poles and rods, furniture, crafts, and musical instruments. (c) applications for ornamentation, landscaping, and conservation.

According to Tewari (1992), Assam and North-East India have long used bamboo. Formerly referred to as "poor man's timber," bamboo is now seen as the timber of the future. Bamboo is used extensively and in various ways in this region of the country. Because it is a versatile, multipurpose forest plant that contributes significantly to the human economy by producing a variety of items, bamboo is particularly essential to rural communities. This rapidly expanding species has managed to keep its place as a provider of daily necessities in the modern world of plastic and steel while also gaining relevance as an industrial raw material (Tewari, 1992).

INBAR (2001) estimates that the “6 million tonnes of bamboo produced each year in India result in 48–60 million working days for harvesting and 60–72 million for processing, loading, and unloading” pp. 11.

According to Handique *et al*., (2010) study of the Nyishi community in Arunachal Pradesh's usage of bamboo, in addition to domestic uses including construction, fencing, firewood, indigenous materials, ceremonies, and functions, the tribal people also market bamboo culms, shoots, and products. There are a total of 20 popular bamboo crafts that the locals are known to use.

Sikkim primarily uses bamboo to build homes, scaffolding, fencing, garden supports, feed, handicrafts, and other everyday items. You can eat young bamboo shoots as a vegetable (Tamang *et al*., 2014). To determine whether a plantation would be economically viable under various soil conditions, Pande *et al*., (2012) conducted an economic analysis of bamboo utilizing data from three significant ravine systems, namely the Mahi, Chambal, and Yamuna. In addition to the benefits accrued to society in terms of the value of nutrients saved through soil conservation and incremental soil carbon build-up "(Rs. 41,000/ha)", they reported a 33 cash outflow ranging from Rs. "30,550/ha to Rs. 48,000/ha" to individual stakeholders in the region from the seventh year onward. This was done with the recommended harvest practice of harvesting one-third of old culms per clump over the life of the plantation.

In rural places, bamboo is crucial to everyday life for the locals. The shoots with nutritional solid and therapeutic benefits can supplement dietary shortages in nutrients and feed the world's expanding population. The North-East of India's people has improved socioeconomic conditions thanks largely to bamboo cultivation (Basumatary *et al*., 2015).

Bamboos are used for a variety of functions in daily life, primarily by the poor and indigenous population. Bamboos grown in backyard gardens are also in high demand as building materials, fencing, animal feed, and a source of fiber for the paper industry. Some bamboo species are used to create furniture, bridges, field fence, mats, fishing traps, baskets, bows and arrows, and fodder for cattle. The young shoots are also delicious. Some species of culms are employed in religious ceremonies to raise prayer flags (Sharma *et al*., 2018).

Bamboos are an essential part of rural families in this area and are essential to the socioeconomic development of rural people. Additionally, bamboo significantly contributes to the current state of global climate change. The purpose of the current study is to comprehend how village bamboos contribute to socioeconomic development and has the potential to reduce global carbon emissions.

Chapter 3

Description of the Study Site

3.1. Geographical Location:

The Mokokchung district is situated in Nagaland's northern region, with coordinates ranging from 26°19'N to 94°31'E. This district covers 1,615 square kilometers in total. The area is situated between 150, and 1800 meters above mean sea level (amsl). Most members of the Ao Naga tribe live there. It is bordered to the north by the state of Assam, to the west by the Wokha district, to the east by the Tuensang and Longleng districts, and the south by the Zunheboto district. The Tsula, Dikhu, and Milak rivers are the principal waterways that encircle this area. This area has 1,349 square kilometers (or 83%) of forest cover and receives 250 to 400 millimeters of rain annually. With elevation comes an increase in rainfall typically. It experiences a moderate climate between 25˚ C- 35˚ C.

3.2. Physiography of Mokokchung District:

The district of Mokokchung has 1,615 km2. The state capital Kohima is about 145 km from the district headquarters, located at Mokokchung Town. The district's physiography consists of six different hill ranges. The ranges are aligned northeast/southwest and nearly parallel to one another. Ongpangkong, Asetkong, Jangpetkong, Japukong, Langpangkong, and Tsurangkong are the names of these hill ranges. The area is located between 26.20 and 26.77 degrees north latitude and 94.29 and 94.76 degrees east longitude. Mokokchung's entire district is conveniently separated into ranges. Tsurang, Changki, and Milak Valleys are the principal valleys. The Changki-Longnak, Tsurang, Milak, and Dikhu valley regions are critical agricultural areas. The two main industrial areas are the Tuli-Milak region and the Changki-Longnak valley.

The main occupation is farming. The climate in Mokokchung district is moderate, which benefits bamboo productivity because physical and climatic factors influence the latter.

The current investigation was carried out at three distinct altitudes in the Mokokchung district: Tuli 160 m amsl, Chungtia 800 m amsl, and Longkhum 1800 m amsl.

3.3. Climate of Mokokchung District:

The district experiences a humid subtropical climate. The district receives 2,500 mm of precipitation on average per year. The months of June and July see the most precipitation. Rainfall often starts in April and lasts through the end of September. As the altitude rises, the rainfall increases. The average maximum temperature is cool, ranging from 24 C in January to 33 C in August and 27 C in other months (Nov). The dry season begins in December and lasts until February, whereas the monsoon season lasts from May to November.

Figure 3.1: Annual temperature for last 5 years in Mokokchung district, Nagaland

Source: District Soil and Water Conservation, 2018-2022, Mokokchung, Nagaland

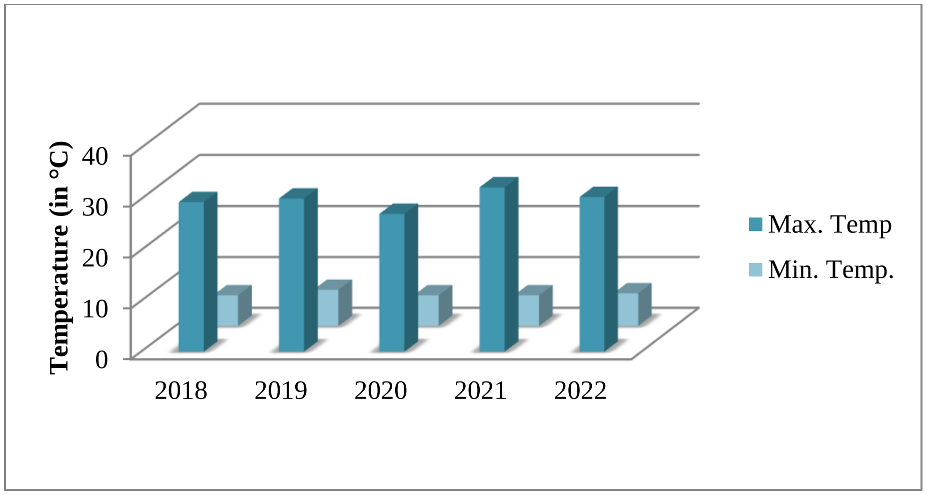


Figure 3.2: Annual rainfall for last 5 years in Mokokchung district, Nagaland

Source: District Soil and Water Conservation, 2018-2022, Mokokchung, Nagaland

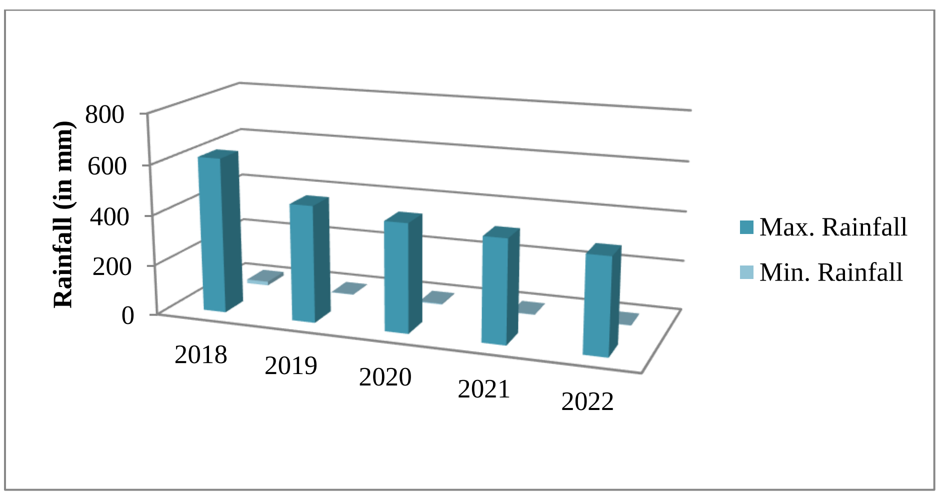
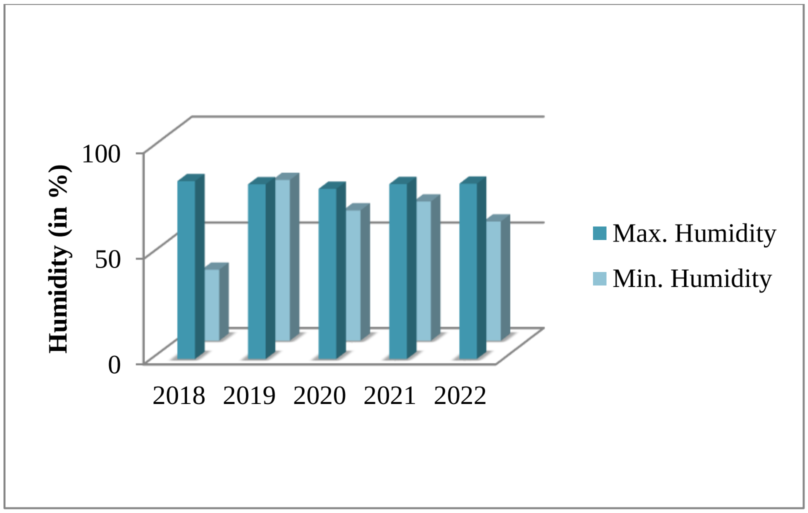


Figure 3.3: Annual humidity for last 5 years in Mokokchung district, Nagaland

Source: District Soil and Water Conservation, 2018-2022, Mokokchung, Nagaland



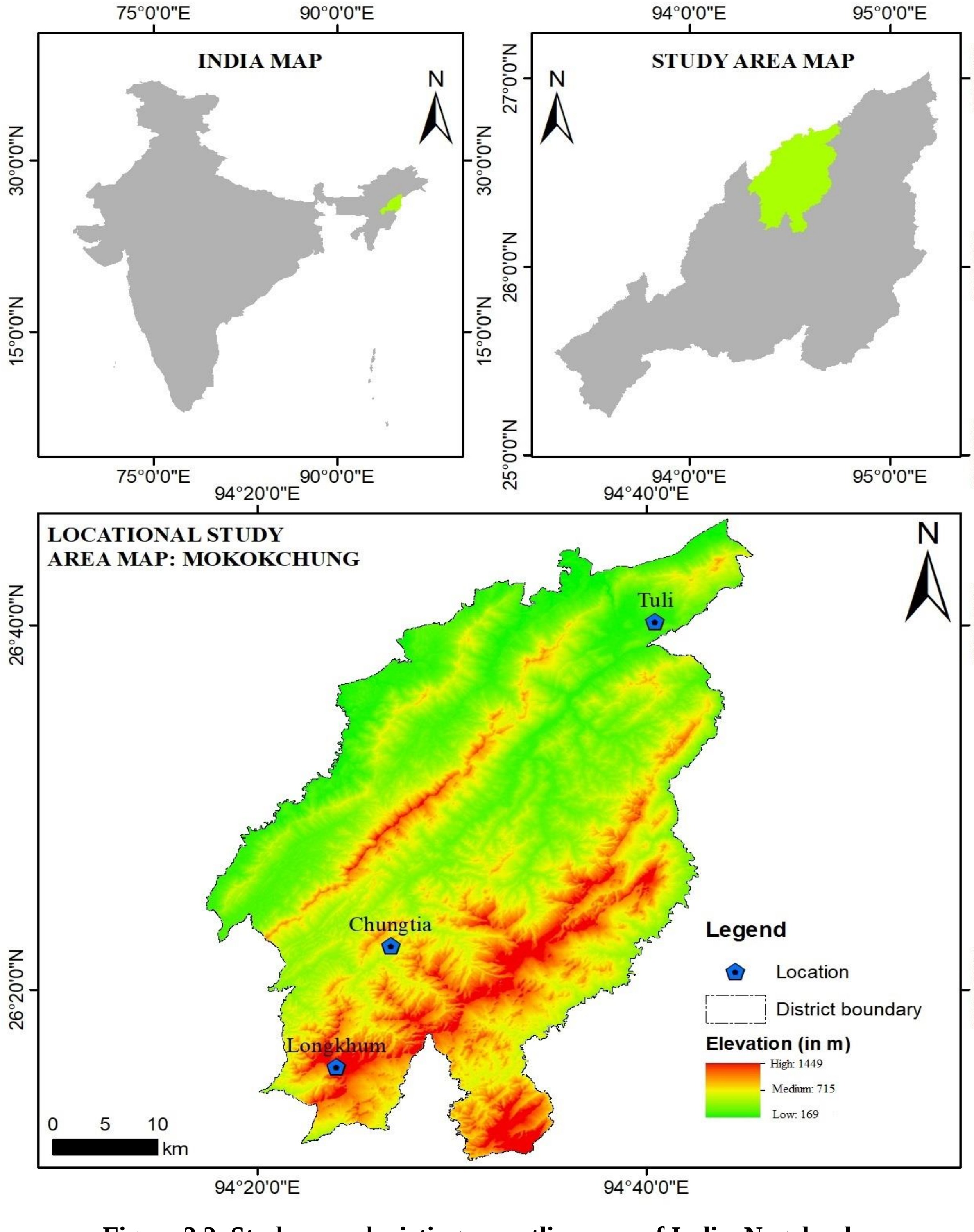


Figure 3.2: Study map depicting an outline map of India, Nagaland state and sampling sites under Mokokchung district, Nagaland

3.4. Vegetation of the study sites:

i. Tuli (160 amsl):

The vegetation at lower elevations is obviously of the Moist Deciduous type due to the rain shadow effect. This form of forest can be found in a variety of settings, and plant associations change depending on many ecological circumstances. *Ailanthus integrifolia*, *Albizia lebbeck*, *Bombax ceiba*, *Butea monosperma*, *Cassia fistula*, *Ficus*, *Mangifera sylvatica*, and *Garuga pinnata* are the dominating species in this area. *Dendrocalamus hamiltonii*, *D. hookeri*, *Bambusa pallida*, *B. tulda*, *Melocanna baccifera*, *Pseudostachyum polymorphum*, etc., are essential bamboo species.

ii. Chungtia (800 amsl):

The predominant vegetation type in Chungtia is a dense, semi-evergreen forest with a wide range of tree species. Moist deciduous and wet evergreen trees can be found in such a forest. *Ficus* sp., *Mangifera* sp., *Schima khasiana*, *Zanthoxylum* sp., *Areca* sp., *Quercus* sp., *Prunus* sp., and more species are found in this area. *Bambusa tulda*, *B. alemtemshii*, *Dendrocalamus asper*, *D. halmitonii*, and other species of bamboo are dominant.

iii. Longkhum (1800 amsl):

Broad-leaved evergreen forest type, the Mokokchung area, is well-represented at Longkhum. This type is distinguished by the predominance of *Castanopsis* and *Quercus*, prominent species that make up a significant portion of the forest. *Acer campbelii*, *Castanopsis hystrix*, *Cinnamomum zeylanicum*, *Quercus*, *Rhododendron* sp., *Rhus*, different orchids, and ferns are the main species encountered in this woodland. The dominant bamboo species in this type of forest are *Bambusa tulda*, *B. alemtemshii*, *Dendrocalamus asper*, *D. hamiltonii*, etc.

Chapter 4

Diversity and Distribution Patterns of Bamboo Species at Different Altitudes in Mokokchung District, Nagaland

4.1. Introduction

Bamboo is known as the wonder plant that originated in the North East of India and is deeply ingrained in the sociocultural makeup of the local community. Most of India's bamboo resources, including seven North Eastern states and West Bengal, are located in Eastern India (ISFR, 2017). A total of “50,555 square kilometers, or around 32.23%” of the country's total bamboo area, are covered in bamboo in the NE Region. Arunachal Pradesh has the most extensive area of bamboo (15,125 square kilometers) among the seven North-Eastern Indian states, followed by Manipur (10,687 square kilometers) and Assam (8,955 square kilometers) (ISFR, 2017). Bamboo supports 70% of the rural labor force in the area and is inextricably woven into the tradition and culture of the people of the North Eastern region. (Anonymous, 1999; Trivedi and Tripathi, 1984).

In India, 14 priority bamboo species require national action and 38 species of widely scattered priority bamboo (Williams and Rao, 1994; Rao *et al*., 1998). (NMBA 2004). According to Haridasan and Tewari (2008), “there are 19 priority bamboo species in India, the majority of which produce clumps”. “There are 78 species of bamboo in North East India, 42 of which are found in Assam”- Hore, (1998); Barooah and Borthakur, (2003). In North-eastern hilly states, there are “90 species of bamboo, of which 41” are found to be indigenous to this area, according to Sharma and Nirmala (2015).

The diversity of a specific species in an area depends on the number of species present and their relative abundance (Shinwari and Qaiser, 2011). Diversity serves as a critical measure for understanding the relationship between species richness and abundance in a given area and represents vegetation's stability or degree of variety (Chawla *et al*., 2008). Given that the number of species in biological communities varies, it is crucial to know how many species are present there in order to comprehend the community's structure (Argon and Oesterheld, 2008). Both species richness and evenness—the relative quantity of species in a community—are considered indices of variety (Mclntosh, 1967). “Examples include frequency, diversity, cover, density, abundance, dominance, and other quantitative characteristics. Studying the diversity of species in a community is crucial”- Rosenfeld (2002). Calculating the frequency, density, and RIV, this can be investigated. In addition to helping with fundamental site comparisons, quantifying species richness is crucial for addressing the saturation of locally populated areas with regional source pools (Msuha *et al*., 2012).

A key indicator of community variables used by ecologists, species richness is the foundation of many ecological models and conservation tactics (Seefeldt and Booth, 2006). The most diverse habitat is not usually visible to the discernable eye (Shahneen *et al*., 2012). As a result, numerous biodiversity indexes based on various perspectives on biology and definitions of diversity have been developed to measure species diversity (Spellerberg *et al*., 2003). These include Shannon's diversity (H') and Simpson's diversity indices, whose interpretations are different (Pyke *et al*., 2002). In contrast to a less diverse system dominated by one or a few species, Shannon noted in 1948 that in a very diverse system, an unknown individual could belong to any species, resulting in considerable uncertainty in predicting its identity. Shannon index is a widely used diversity index, claims ecological literature. It gauges the diversity of species (Tandon *et al*., 2007; Pandey and Kulkami, 2006; Prince, 1975).

The Simpson index, which measures evenness, calculates the likelihood that two randomly chosen individuals belong to two species (Khan *et al*., 2012). A low evenness rating suggests that only one or a small number of species predominated in that area. In contrast, a high value shows that there were roughly equal numbers of each species' members (Desalegn, 2002). From now on, biodiversity indices can be used to determine a community's dynamics (Del Vecchio *et al*., 2015).

There are 148 species of bamboo in India, and of those, 64 are found in the northeast, of which 41 are indigenous. In Nagaland, 46 of these species can be found. Bamboos are widely distributed in Nagaland (Loushambam *et al*., 2017).

Loss of species and habitat will impede the ecosystem's ability to function normally and provide ecological services to people (Espelel *et al*., 2004). Therefore, the structure of species richness and evenness of vegetation is crucial for long-term biodiversity conservation (Faggi and Dadon, 2011). The quantitative analysis of the bamboo variety in the Mokokchung district of Nagaland has not been attempted. Therefore, the current study's hypothesis attempts to use Shannon and Simpson diversity index to note bamboo diversity and distribution patterns at various elevation gradients.

4.2. MATERIALS AND METHODS:

The field survey was carried out in the selected bamboo forest (20.1 ac) at different elevation gradients. A total of 80 quadrates (10m x10m) were laid randomly, and primary data were collected for statistical analysis. The bamboo species which fall under the quadrates were recorded. Attributes such as density, frequency, and RIV were calculated using the following formulae:

1. $\text{Density} = \frac{\text{No.of individuals of the species}}{\text{No.of individual of all species}} \times 100$
2. $\text{Frequency} = \frac{\text{No.of occurance of the species}}{\text{No.of occurance of all species}} \times 100$

Species richness and evenness were calculated after Shannon and Simpson index.

1. Shannon Diversity Index: Shannon index is commonly used to characterize species diversity in a community and accounts for species richness in a particular area. Shannon index is calculated using the following formulae:

$$H' = -\sum_{i=1}^{s} \text{Pi In Pi}$$

Where H'= Shannon Index

Pi = proportion of total sample represented by species

s= no. of species

ln= natural log

2. Simpson's Index: It is used to characterize species evenness and can be calculated using the following formulae:

$$D = 1 - \frac{n\,(n-1)}{N\,(N-1)}$$

Where D = Diversity index

n = no. of individual of a particular species

N = no. of individual of all species

4.3. RESULT:

Along the three various height gradients of the Mokokchung district in Nagaland, a total of 9 bamboo species from 4 genera were identified. It was discovered that *Bambusa* was the dominating genus of bamboo species, while *Bambusa tulda* was the most common species.

Table 4.1: Bamboo species in the study sites

S/No	Scientific Name	Local Name
1	*Bambusa pallida* Munro	Ashi Longmi
2	*Bambusa tulda* Roxb	Longmi
3	*Bambusa jaintiana* Majumdar	Ana
4	*Cephalostachyum capitatum* Munro	Dibu
5	*Chimonocalamus griffithianus* (Munro) Hsueh & Yi	Rangnik
6	*Dendrocalamus asper* Schult.f.	Changpu
7	*Dendrocalamus giganteus* Munro	Warok
8	*Dendrocalamus hamoltinii* Nees & Arn.	Watsa
9	*Phyllostachys manni* Gamble	Ashi

Table 4.2: Characteristic features of bamboo species of Mokokchung district, Nagaland.

Bamboo Species	Characteristic features
Bambusa pallida Munro	Young shoots have a spear-like appearance, and the fistular, smooth, olive-green, 12- to 30-meter-tall culms are covered in white powder. 50–80 cm long internodes with a thin wall. Culm sheath: Straight, truncate, 17–30 cm long, 25 cm wide, coated in white hairs at the top.
Bambusa tulda Roxb	Young shoots are yellowish green with black

	hairs, 6–20 m tall, green culms, slightly swollen nodes, and internodes 20–70 cm long with a thin wall. Culm sheath covered in white or brown hairs, measuring 15–32 cm long and 25–34 cm wide at the base.
Bambusa jaintiana Majumdar	3-6 m tall, diameter 3-6 cm, internodes somewhat sulcated, thickly tufted culms, When young, the culm sheath is green, 10–14 cm long, and 12–15 cm wide.
Cephalostachyum capitatum Munro	Green, 4–10 cm tall, internodes that are frequently 1 m long, 2.5–3 cm in diameter, and have walls that are 5-8 mm thick. 15–30 cm length and 5–7.5 cm wide is the culm sheath.
Chimonocalamus griffithianus (Munro) Hsueh & Yi	Culm, 7–15 m tall, olive green in color, with noticeable nodes and internodes measuring 7.5–22 cm long and 2.5–5 cm in girth. Dark brown hair-covered culm sheaths with striations are 15–30 cm long and 10–12.5 cm wide at the base, where they bear a belt of dense, soft tawny hairs.
Dendrocalamus asper Schult.f.	Aerial roots grow from the nodes of the erect 15–30 m tall, 15–28 cm in diameter, and 40–50 cm long culms. 40–50 cm long culm sheaths with dark brown hairs and 7mm high auricles.

Dendrocalamus giganteus Munro	Young shoots have a cone shape and are blackish with purplish hairs covering them. Culm 30–50 m tall, 18–30 cm in diameter, 2.5 cm thick on the wall, with hairy nodes and internodes of 30–40 cm in length. The culm sheath is large, 40–50 cm in width and 25–50 cm long, covered with golden or brown hairs.
Dendrocalamus hamoltinii Nees & Arn.	Culms are 12–25 m tall, 10–18 cm in diameter, with internodes 30–50 cm long and roots identifying the nodes. They are dull green. Culm sheaths are 35–45 cm long and 20–30 cm wide. They are long and stiff.
Phyllostachys manni Gamble	Internodes are 20-25 cm long and 2.5-3 cm wide, and green and flattened on one side. Culms are 5-6 m tall. Culm sheath, 20–22 cm long, 2.5–5 cm wide, straw-colored, rounded at the top and truncate, expanded into two noticeable fimbriate, caduceus-curved auricles near the base of the blade.

1. Tuli (160m amsl):

For all bamboo species, a total of 4 species and 143 individuals were noted. The most prevalent species, with a frequency, density, and RIV value of 40.7%, 48.9%, and 89.6, was *Bambusa pallida*. The Simpson index value was 0.65 and the Shannon index value was 1.167 with Hmax being 1.386.

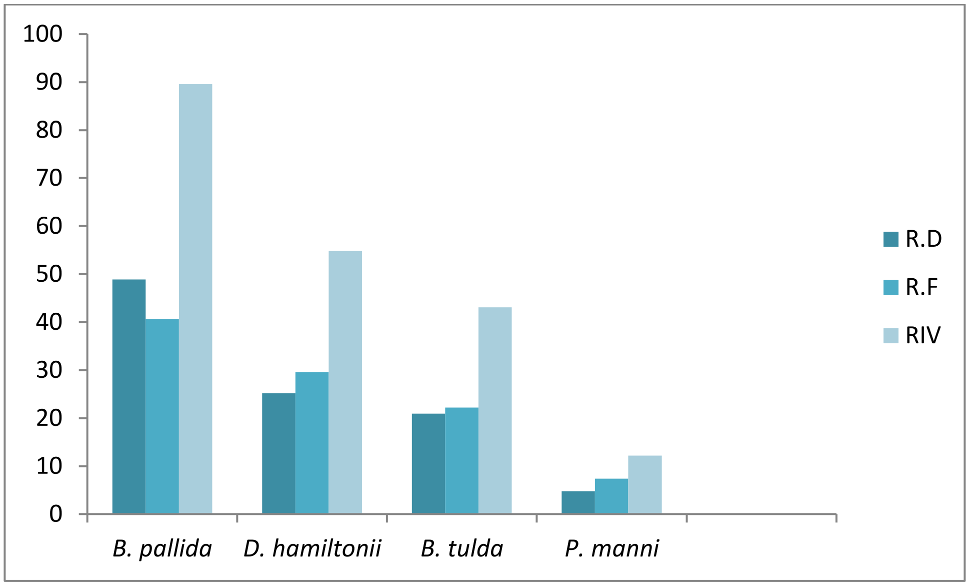


Figure 4.1: Occurrence of bamboo species in lower elevation.

2. Chungtia (800m amsl):

Seven bamboo species totaling 131 distinct species were identified at this altitude. B. tulda was discovered to be the dominating species, with values of frequency, density, and RIV of 54.5%, 70.2%, and 124.7, respectively. Even though 7 species were recorded from this region, *Dendrocalamus gigantus* and *Bambusa mokohchungean* only show the existence of one clump each. As a result, only 5 species were taken into account when calculating species richness and evenness because, according to the Simpson index, species with only one individual have no diversity. Simpson index value was 0.47, Shannon index value was 0.924, and Hmax was 1.609.

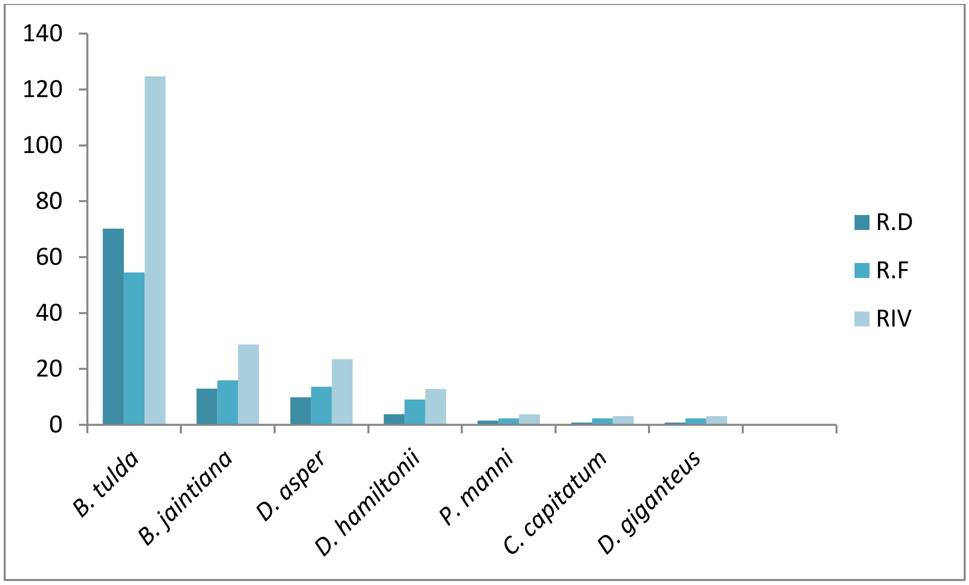


Figure 4.2: Occurrence of bamboo species in middle elevation.

3. Longkhum (1800m amsl):

B. tulda was the leading species with a frequency value of 51.7%, density of 60.8%, and RIV of 112.5. A total number of species recorded from this area was 5, with 69 clumps of individual species. Shannon index value for this elevation was 1.122 with Hmax 1.609, and Simpson index value was 0.59.

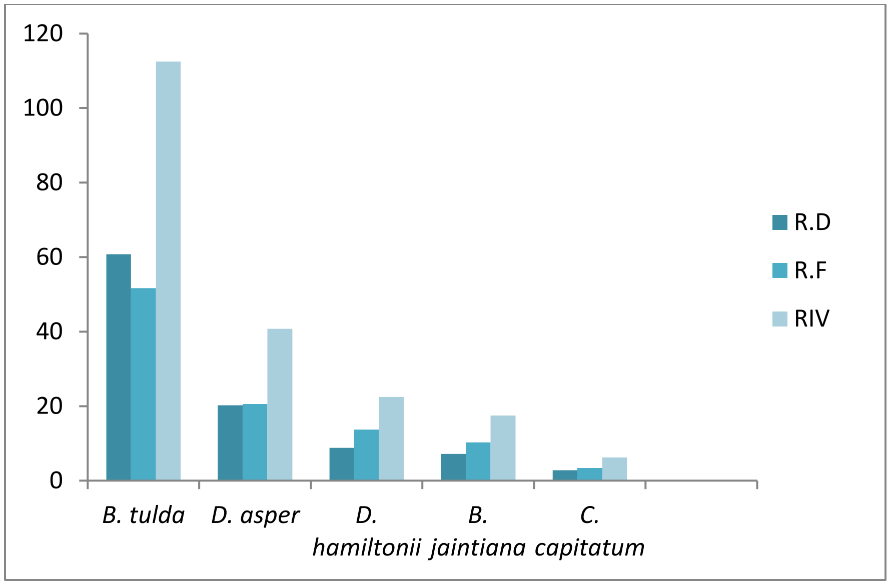


Figure 4.3: Occurrence of bamboo species in higher elevation.

Table 4.3: Shannon and Simpson Index of the study sites.

Elevation Gradient	Shannon's Index Value	Simpson's Index Value
Longkhum (1800 m)	1.122	0.59
Chungtia (800 m)	0.924	0.47
Tuli (160 m)	1.167	0.65

4.4. DISCUSSION:

A total of 80 quadrats were laid, and the intermediate and higher altitudes contained the most diverse species. Similarly, it was discovered that the species composition was higher in these heights. Our results are comparable to those of research from Assam (Sharma, 2012), West Bengal (Yeasmin *et al*., 2017), and Meghalaya (Kharlyngdoh and Barik, 2008), where *B.tulda*, *D.hamiltonii*, *B.jaintiana*, and *B.pallida* were the predominant bamboo species. Additionally, it was discovered that climatic conditions and human activity impact the bamboo variety (Nath and Das, 2008).

Inventorization of bamboo resources revealed that the study sites in Mokokchung district are rich in bamboo resources having 9 species belonging to the genera *Bambusa*, *Dendrocalamus*, *Phyllostachys*, and *Cephalostachyum*.

Elevation significantly impacts the limiting of plant species and community types in hilly areas (Chawla *et al*., 2008). By comparing *B.tulda* RIV values to those of the other bamboo species, the data from the current study demonstrates that *B.tulda* was the dominating bamboo species. RIV is the most accurate way to quantify a species' qualities. RIV identifies the most common bamboo species (Nath and Das, 2008).

However, it was discovered that the RIV of bamboo species varied with physico-geographical variables such as height and climatic condition variations. *Bambusa tulda* RIV was found to be higher in Chungtia than in the Longkhum and Tuli areas. However, *Dendrocalamus hamiltonii* RIV was higher in the Tuli area than in the Longkhum and Chungtia areas. The RIV of B. tulda in the examined locations averaged 197.2 across all 3 sites. The average RIV of 75.1 for *Dendrocalamus hamitlonii* over all three sites comes in second. The species with the lowest RIV were *B. mokokchungeane* (3.1) and *D. giganteus* (3.1). The most common species of bamboo in the chosen region may be a result of the preferences of the locals in the Mokokchung district, where bamboo cultivation directly supports rural life by offering a wide range of goods and services for survival (Nath and Das, 2008). The term "density" refers to the number of people living in a particular area and indicates how closely related different species are to one another. *B. tulda* has the highest density, with a value of 48.09%.

The species richness value (H'), which had a value of 1.167 and a Hmax of 1.386, was higher at lower altitudes. Low species richness is seen at the middle altitude, with an H' value of 0.924 and a Hmax of 1.609. As a result, it should be highlighted that species diversity is richer at lower altitudes. Because there are about equal numbers of each particular species, the lower altitudes have a greater diversity of species. However, let's look at the total number of species from the data collected. We can say that the higher and middle altitudes are more diverse because each altitude has 5 different species of bamboo, whereas the lower species only have 4 species of bamboo. Species richness is simply the number of different species, so the higher and middle altitudes are more diverse than the lower species. However, when we calculated the H', it was discovered that lower elevations had greater species richness than the other two elevations since more individuals were reported there overall.

According to the Shannon index, the average species diversity was calculated, and the Mokokchung district's bamboo species' H' value was 1.443. From this H' value, we can deduce that the bamboo species in the Mokokchung district are numerous and stable and that if the district loses one bamboo species, the other bamboo species will be able to fill up for it. It displays how numerous different bamboo species are in the Mokokchung district.

For lower, middle, and higher elevations, the Simpson diversity index (D) was 0.65, 0.47, and 0.59, respectively. This shows that there are 65%, 47%, and 59% possibilities, respectively, that the two species that were randomly chosen will belong to separate species. The species in the lower elevation gradient are more evenly distributed because, according to Simpson's diversity index, the higher the value, the more evenly distributed the species are. There are 143 species of *B.pallida*, most of which are found in the lower elevation area. Since Simpson's index measures dominance, species evenness is higher at lower altitudes where bamboo species are more evenly distributed, giving the community a higher degree of evenness compared to communities at middle and higher elevations where one species is more prevalent, and the others are uncommon at both sites. Therefore, it can be inferred from the values of the Simpson's index mentioned above that the Mokokchung district has an endless variety of bamboo species because all values are greater than 0 and close to 1. A bamboo forest with a higher species variety is likely to have more successful species and be more stable. Because it is a dominant index, it is influenced by the dominant species.

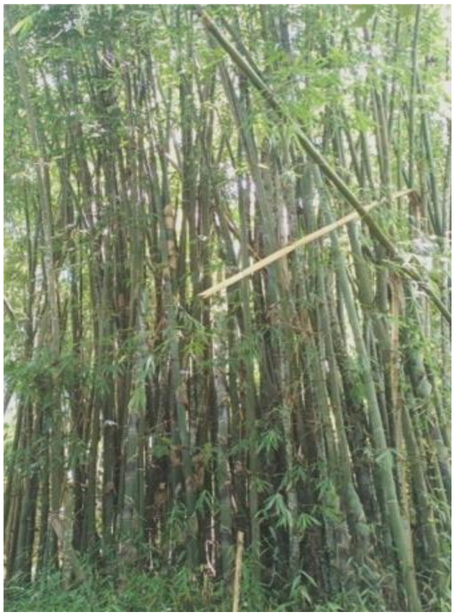
Diversity indices offer crucial details on the rarity and prevalence of species in a community (Shaheen *et al*., 2011). In order to determine the patterns of plant distribution, numerous researches has focused on changes in species richness and diversity along elevation gradients in hilly terrain (Lomolina, 2001). Therefore, based on the results of the current study, the common bamboo species found in the Mokokchung district are *Bambusa tulda*, *Dendrocalamus asper*, and *Dendrocalamus hamiltonii* since these species have been reported at all elevations. In contrast, the rare species are *Bambusa pallida*, which is restricted to the lower elevation (160 amsl), *Cephalostachyum capitatum* from the higher elevation (1800 amsl), and *Dendrocalamus giganteus* (800 amsl). Rahman *et al*., (2016) noted that species are linked to specific habitats and were shown to be more numerous in and around those environments.

4.5. CONCLUSION:

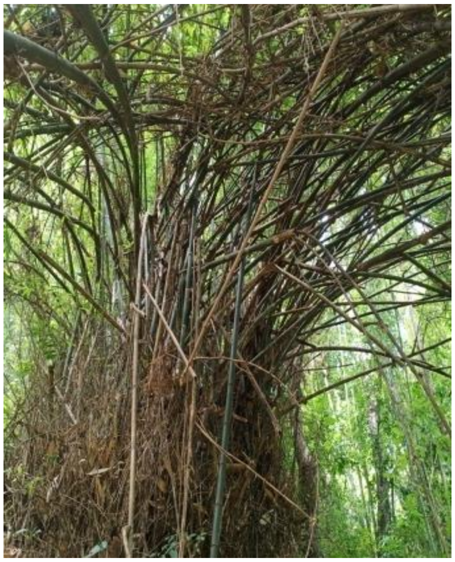
Biodiversity indices give biologists valuable tools to measure the diversity in a community and give a numerical indication of its strength, giving more information than just the simple number of species present. They take into consideration the fact that certain species are rare and others are common. Varied levels of distribution have different effects on the variety of the species, and species richness and evenness are properties of the community. Controlling the deterioration and disturbance processes that are destroying the community structure of the bamboo diversity in the Mokokchung district is necessary. From the present study, altitude does affect the diversity and distribution pattern of bamboo species in Mokokchung district, Nagaland. The limitation of this study is that the data come from 20 ac of study area from each study site. Therefore it does not adequately cover the overall bamboo forest of Mokokchung district. Hence, we recommend that the diversity and distribution pattern model presented here be validated before use in other locations.

Figure 4.4: Four dominant Bamboo species found in Mokokchung district, Nagaland.

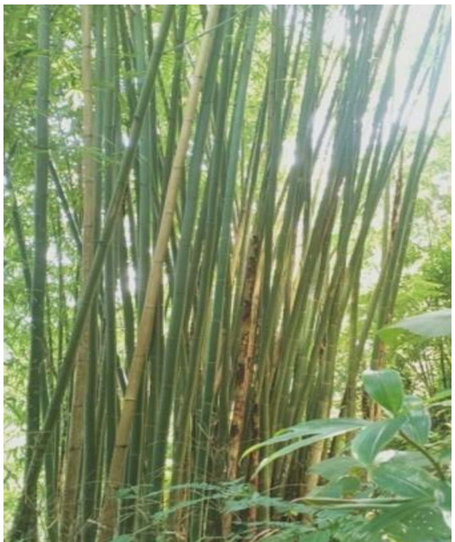
Bambusa pallida Munro



Bambusa tulda Robx.




Dendrocalamus hamiltonii Nees & Arn. ex Munro




Dendrocalamus asper Schult.f. Backer ex Hevne

Chapter 5

Soil Physico- chemical Properties of Bamboo Forest of Mokokchung District

5.1. Introduction:

According to Kleinhenz and Midmore (2001), "bamboo is vital in preserving and enhancing the nutritional condition of the soil. In order to preserve soil quality, soil organic carbon (SOC) is thought to be of the utmost importance". Because SOC is tightly linked to various physical, chemical, and biological characteristics of soil, it plays a crucial role in soil processes and functioning (Smith *et al*., 2000). Batjes (1996) asserts that the soil organic carbon pool is larger than the whole of the biotic and atmospheric carbon pools.

According to a comparative study, bamboo in the forest had a substantial impact on the physico-chemical properties of the soil (Christainity *et al*., 1996). In some parts of China, the relationship between yield and soil nutrient concentration was discovered to be positive (Shanmughavel *et al*., 2001). Bamboo can thrive in infertile soil, effectively utilize nutrients, and create moderately fertile soil surrounding the clumps (Singh and Singh, 1999). In several regions of India, bamboo forests and plantations are primarily produced in nutrient-deficient soils and are exposed to significant biomass removal through bamboo harvest. According to Singh *et al*., (1989), "bamboos effectively utilize the available nutrients in relatively low soil and develop moderately fertile soil surrounding the clumps”. Bamboo contributes significantly to preserving and enhancing the soil's nutrient content (Nath *et al*., 2015b). Shukla *et al*., (2006) contend that taking into account soil's physical, chemical, and biological characteristics and any associated environmental elements can help better understand how soil functions. Bamboo is exceptionally effective at repairing soil deterioration and can regenerate quickly without replanting (Kumari *et al*., 2018). However, the mechanisms and processes of C sequestration in soil still need to be fully understood (Bajracharya *et al*., 1998). Land use and soil management practices may have a major impact on soil organic carbon (SOC) dynamics and C flux from the soil (Post and Kwon, 2000; McGuire *et al*., 2001). The organic carbon in the soil stock and inflexible organic carbon sinks may be significantly altered by intensive forest management techniques such as fertilizer application, tillage, and understory removal (Li *et al*., 2013).

The primary objective of the current study is to determine the physicochemical characteristics of bamboo forests and to comprehend how bamboo affects the soil in the bamboo forest stands located throughout the Mokokchung district of Nagaland. For this investigation, soil samples were taken from the bamboo forest stands along the district's three main altitudinal gradients: Longkhum, Chungtia, and Tuli. This study will inform us about the current physico-chemical characteristics of the soil that are connected to bamboo productivity in individual bamboo forests.

5.2. Methodology:

5.2.1. Soil sampling strategy:

With systematic random sampling, soil samples were taken from several locations. Three replicates of soil samples were taken at depths of 0–10 cm, 10–20 cm, and 20–30 cm. For each depth, a composite sample was made, air-dried, crushed, and sieved through a 2 mm sieve before being placed in a plastic container for storage. Samples that had been oven dried and sieved through a 100-mesh sieve were used to estimate total carbon.

For physicochemical parameters, triplicate samples of each soil depth at a specific location were examined.

By using the core sampling approach, bulk density was measured (Brady and Weil, 2008). The soil texture was determined using Bouyouco's soil Hydrometer method (Allen, 1989a). The hydrometer readings at 40 seconds and 2 hours were used to calculate the various fractions of soil particles (sand, silt, and clay). The USDA Soil Texture Triangle was used to establish the texture class. Soil respiration was determined following the alkali absorption technique (Witkamp, 1966). The water holding capacity (WHC) of self-made tin cups with interior diameters of 5.6 cm and heights of 1.6 cm was measured using the Keen-Raczkowski box (Keen's box) method (Piper, 1950; Baruah and Borthakur, 1997). Jackson describes how the wet digestion method of Walkley and Black, 1934, assessed the soil organic carbon content (%). (1973). In a suspension of

1:2.5 soil to water, soil pH was tested. 50 ml of distilled water and 20 g of air-dried soil were agitated for 30 minutes on a rotary shaker. Soil water was suspended as a result. The *p*H of the soil samples was determined after the microprocessor-based *p*H meter (Systronics, *p*H 362) was calibrated with buffer solutions with *p*H values of 4 and 7.0. Available potassium (K_{ex}) was evaluated by photometric method (flame photometer) following Trivedy and Goel (1986), available phosphorus (P_{av}) by using Bray's no. 1 extraction method using UV-Vis spectrophotometer, and available nitrogen (N_{av}) by following the Kjeldahl method (1883). (Bray and Kurtz, 1945).

5.2.2. Statistical Analysis:

To identify any notable differences among the soil parameters that were analyzed during the experimental phase, a statistical analysis was conducted. The acquired data were statistically analyzed using the SPSS version 16 program. For all of the study sites, mean values with a standard error of the triplicates of each test were processed. To determine statistically significant variations in each of the soil physicochemical parameters across the sampling seasons ($p< 0.05$), a one-way analysis of variance (ANOVA) was performed. If the ANOVA findings were significant, Tukey's HSD post hoc tests were run. To ascertain the effects of site and season on the soil physicochemical characteristics in the four study sites, a two-way analysis of variance (ANOVA) was utilized. To investigate the link between the soil physicochemical parameters, Pearson correlation analysis was conducted. $P< 0.05$ is the significance threshold used in the results.

5.3. Results:

5.3.1. Seasonal soil physical variables:

5.3.1.1. Soil Texture:

Figure 5 depicts the soil texture of bamboo forest of Longkhum, which ranges from sandy loamy to sandy clay loam soil. The average percentage of sand, silt, and clay in the first year is 53.62% of sand, 23.63% of silt, and 22.58% of clay. The average sand, silt, and clay in the second year are 53.75%, 23.41%, and 22.82%, respectively. The sand percentage was more significant at a 20–30 cm soil depth, measuring 51.58% in the first year and 51.26% in the second. Clay content was higher at a depth of 0–10 cm, with an average value of 23.72%, while silt content was higher at a depth of 20–30 cm, with a value of 23.8%. Summer and autumn had record-high sand content, while autumn and winter saw record-high silt content. The soil texture in the bamboo stands for the bamboo species *B. tulda*, *D. asper* and *D. hamiltonii* was found to be dominated by sand content in both the years.

According to the textural classification triangle, the soil texture in bamboo forest of Chungtia was sandy clay loam. The average value of sand, silt, and clay during the first year was 54.31%, 23.39%, and 22.29%, respectively. Sand content increased by 57.6% at 20–30 cm depth, silt increased by 25.85% at the same depth, and clay increased by 25.97% at 0–10 cm depth.

Sand, silt, and clay contents were 22.94% and 22.59%, respectively, in the second year. At a depth of 20–30 cm, sand was more prevalent (57.53%), silt was more prevalent (0–10 cm, 30.33%), and clay was more prevalent (0–10 cm, 25.88%). Summer and autumn were the seasons with the highest levels of sand, whereas winter and fall had the highest levels of silt and spring and winter, respectively, of clay.

According to the textural classification triangle, the soil texture in Tuli bamboo forest was sandy clay loam. Sand, silt, and clay average values in the first year were 45.3%, 25.77%, and 28.94%, respectively. Sand content was high at a depth of 20–30 cm in the first year (45.72%), silt content was more significant at a depth of 20–30 cm (25.76%), and clay content was higher at a depth of 0–10 cm (29.62%). Sand had an average value of 45.30%, silt of 25.55%, and clay of 29.15% in the second year. At a depth of 20–30 cm, sand content was high (45.73%), silt content was more significant (25.59%), and clay content was higher (29.86%). Sand levels were more significant in the summer and fall, silt levels were higher in the winter and fall, and clay levels were higher in the spring and winter in both years.

Table 5.1: Soil texture of Longkhum bamboo forest during 2018-2022

Parameters	Layer	2018-2019				2021-2022			
		Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
Sand	0-10cm	51.1± 0.01^{c}	49.72± 0.05^{d}	54± 0.36^{b}	55.22± 0.07^{a}	51.25± 0.15^{c}	49.58± 0.15^{d}	54.41± 0.18^{b}	55.55± 0.3^{a}
	10-20cm	49.51± 0.29^{d}	50.96± 0.01^{c}	56.73± 0.11^{b}	58.88± 0.11^{a}	49.54± 0.08^{d}	51.7± 0.2^{c}	56..84± 0.06^{b}	58.7± 0.17^{a}
	20-30cm	51.58± 0.36^{b}	55.13± 0.03^{a}	55.13± 0.03^{a}	55.39± 0.01^{a}	51.48± 0.11^{b}	55.29± 0.16^{a}	55.52± 0.24^{a}	55.72± 0.11^{a}
Silt	0-10cm	24± 0.01^{b}	25.07± 0.19^{a}	22± 0.17^{d}	23.34± 0.11^{c}	23.75± 0.12^{b}	24.76± 0.13^{a}	23.05± 0.15^{c}	22.74± 0.41^{c}
	10-20cm	26.41± 0.34^{a}	24± 0.04^{b}	21.26± 0.19^{c}	20.11± 0.02^{d}	26.24± 0.12^{a}	23.97± 0.20^{b}	20.93± 0.17^{c}	20.13± 0.20^{d}
	20-30cm	27.51± 0.19^{a}	21.31± 0.12^{c}	23.52± 0.68^{b}	25± 0.15^{b}	27.71± 0.73^{a}	20.69± 0.54^{c}	22.6± 0.99^{b}	24.34± 0.16^{b}
Clay	0-10cm	24.89± 0.23^{a}	25.20± 0.18^{a}	22± 0.17^{b}	21.43± 0.09^{c}	24.99± 0.03^{b}	25.65± 0.13^{a}	22.53± 0.33^{c}	21.70± 0.12^{d}
	10-20cm	24.07± 0.05^{b}	24.99± 0.27^{a}	22± 0.07^{c}	20.99± 0.03^{d}	24.21± 0.07^{b}	24.95± 0.18^{a}	22.21± 0.11^{c}	21.16± 0.33^{d}
	20-30cm	20.90± 0.79^{bc}	23.52± 0.68^{a}	21.32± 0.12^{b}	19.60± 0.04^{c}	20.8± 0.65^{bc}	23.8± 0.11^{a}	22.88± 0.8^{b}	19.93± 0.08^{c}

Mean ±standard error mean Different letters ($^{abc\ and\ d}$) in the same row in each year indicate significant differences between season ($p<0.05$) after *Tukey post hoc* test

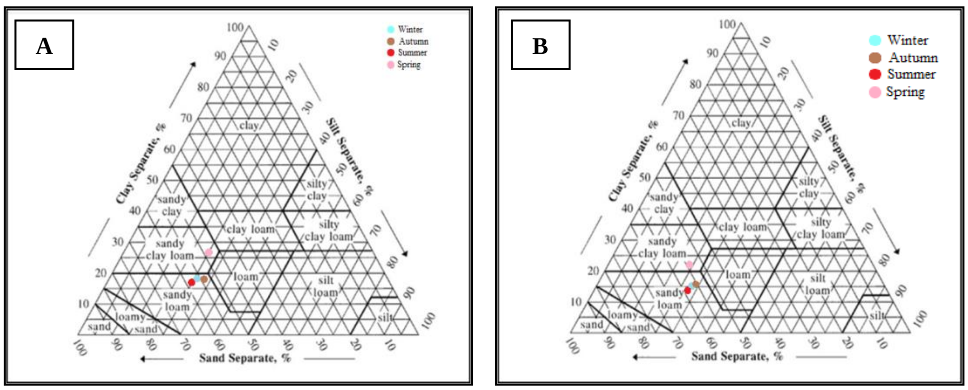


Figure 5.1a: Soil textural classification triangle of Longkhum bamboo forest, A: 2018-19 and B: 2021-22.

Table 5.2: Soil texture of Chungtia bamboo forest during 2018-2022

Parametes	Layer	2018-2019				2021-2022			
		Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
Sand	0-10cm	44.23± 0.02^{d}	55.6± 0.17^{a}	55.13± 0.03^{b}	54.23± 0.07^{c}	43.89± 0.11^{c}	55.51± 0.34^{a}	55.15± 0.05^{ab}	54.78± 0.1^{b}
	10-20cm	55.13± 0.2^{b}	55.54± 0.51^{a}	56.51± 0.06^{a}	55.13± 0.9^{a}	51.38± 0.17^{c}	55.69± 0.47^{b}	56.62± 0.34^{a}	55.95± 0.09^{ab}
	20-30cm	56.73± 0.11^{b}	55.84± 0.14^{c}	57.6± 0.14^{a}	54.07± 0.05^{d}	55.96± 0.08^{b}	55.89± 0.1^{b}	57.52± 0.32^{a}	54.24± 0.11^{c}
Silt	0-10cm	29.76± 0.06^{a}	20.39± 0.08^{c}	23.52± 0.68^{b}	23.97± 0.17^{b}	30.32± 0.09^{a}	20.05± 0.53^{c}	23.30± 0.03^{b}	22.34± 0.86^{bc}
	10-20cm	26± 0.13^{a}	20.79± 0.55^{c}	22.77± 0.15^{b}	24.38± 0.58^{a}	23.72± 0.17^{a}	20.46± 0.50^{c}	22.34± 0.28^{b}	23.28± 0.17^{a}
	20-30cm	21.26± 0.19^{c}	21.07± 0.07^{c}	22.30± 0.08^{b}	25.85± 0.04^{a}	21.45± 0.26^{bc}	20.82± 0.04^{c}	21.81± 0.51^{b}	25.36± 0.22^{a}
Clay	0-10cm	1.56± 0.03^{d}	1.92± 0.05^{c}	2.93± 0.07^{a}	2.75± 0.03^{b}	1.94± 0.13^{b}	2.07± 0.04^{b}	3.03± 0.01^{a}	2.88± 0.05^{a}
	10-20cm	1.49± 0.04^{d}	1.75± 0.03^{c}	2.85± 0.03^{a}	2.66± 0.04^{b}	1.66± 0.02^{c}	1.93± 0.03^{b}	2.97± 0.09^{a}	2.83± 0.11^{a}
	20-30cm	1.37± 0.02^{d}	1.67± 0.02^{c}	2.79± 0.02^{a}	2.58± 0.05^{b}	1.51± 0.04^{d}	1.79± 0.02^{c}	2.90± 0.02^{a}	2.69± 0.03^{b}

Mean ±standard error mean Different letters ($^{abc\ and\ d}$) in the same row in each year indicate significant differences between season ($p<0.05$) after *Tukey post hoc* test

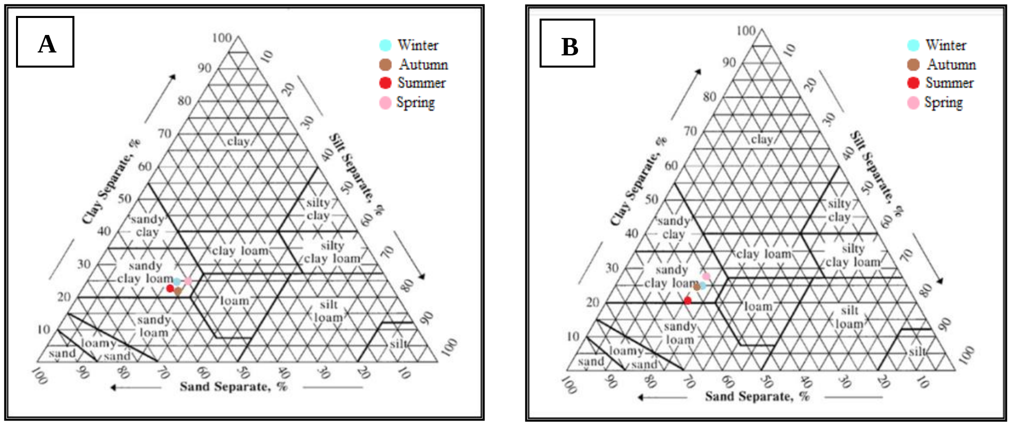


Figure 5.1b: Soil textural classification triangle of Chungtia bamboo forest, A: 2018-19 and B: 2021-22.

Table 5.3: Soil texture of Tuli bamboo forest during 2018-2022

Parameters	Layer	2018-2019				2021-2022			
		Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
Sand	0-10cm	43.22± 0.9^{c}	44.11± 0.32^{c}	46± 0.1^{a}	45.46± 0.05^{b}	43.58± 0.15^{c}	43.58± 0.08^{c}	46.52± 0.06^{a}	45.34± 0.12^{b}
	10-20cm	44.59± 0.04^{c}	44.67± 0.26^{c}	46.65± 0.08^{b}	46.99± 0.1^{a}	43.98± 0.01^{b}	43.93± 0.07^{b}	46.89± 0.06^{a}	46.92± 0.05^{a}
	20-30cm	44.18± 0.03^{d}	44.86± 0.13^{c}	46.88± 0.11^{b}	46.96± 0.06^{a}	44.59± 0.04^{c}	44.67± 0.1^{c}	46.65± 0.08^{b}	46.99± 0.01^{a}
Silt	0-10cm	26± 0.03^{a}	26.02± 0.01^{a}	25.79± 0.02^{b}	26.07± 0.02^{a}	25.36± 0.12^{b}	25.51± 0.06^{b}	24.65± 0.13^{c}	26± 0.21^{a}
	10-20cm	25.63± 0.06^{b}	25.64± 0.20^{b}	26.01± 0.34^{a}	25.1± 0.01^{c}	25.23± 0.21^{b}	26.43± 0.06^{a}	26.03± 0.04^{a}	24.91± 0.06^{b}
	20-30cm	25.97± 0.03^{a}	25.85± 0.04^{a}	25.80± 0.06^{a}	25.40± 0.02^{b}	25.63± 0.06^{b}	25.64± 0.20^{b}	26.01± 0.05^{a}	25.1± 0.01^{c}
Clay	0-10cm	30.93± 0.02^{a}	30.86± 0.03^{a}	28.21± 0.04^{c}	28.47± 0.04^{b}	31.05± 0.08^{a}	30.91± 0.02^{b}	28.82± 0.07^{b}	28.66± 0.1^{b}
	10-20cm	29.77± 0.11^{a}	29.68± 0.13^{a}	27.33± 0.08^{c}	27.93± 0.04^{b}	30.78± 0.2^{a}	29.66± 0.11^{b}	27.07± 0.05^{d}	28.16± 0.06^{c}
	20-30cm	29.85± 0.04^{a}	29.28± 0.04^{b}	27.31± 0.07^{c}	27.63± 0.04^{c}	29.77± 0.11^{a}	29.68± 0.21^{a}	27.33± 0.05^{c}	27.92± 0.04^{b}

Mean ±standard error mean Different letters ($^{abc\ and\ d}$) in the same row in each year indicate significant differences between season ($p<0.05$) after *Tukey post hoc* test

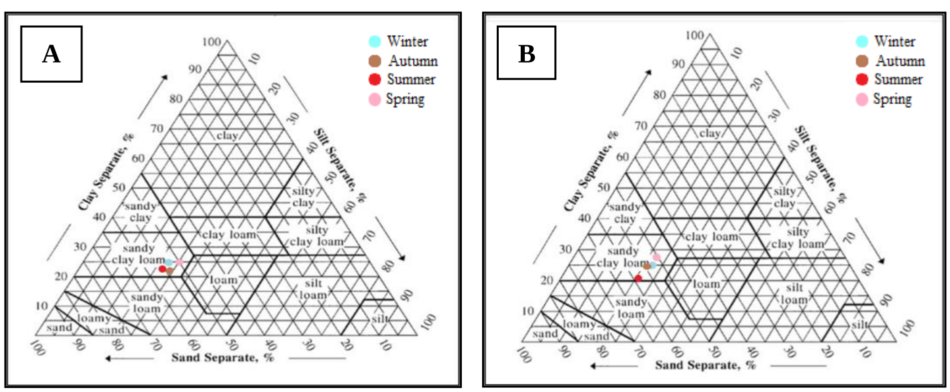


Figure 5.1b: Soil textural classification triangle of Tuli bamboo forest, A: 2018-19 and B: 2021-22.

Significant differences in clay, silt and sand % with soil depth and season was also observed in bamboo forest of Longkhum in both the years

(p<0.05). In Chungtia bamboo forest, the clay, silt and sand % differed significantly with soil depth and season in both the years (p<0.05). In the bamboo forest of Tuli, the clay, silt and sand % differed significantly with soil depth and season in both the years (p<0.05).

5.3.1.2. Bulk Density (g/cm^3):

The study revealed that among the soil physical parameters, the soil bulk density (BD) increases with increase in soil depth (Table: 5.4) and decreases with increase in altitude.

Table 5.4: Soil Bulk Density of bamboo forest of Longkhum, Chungtia and Tuli during 2018- 2022

Sites	Layer	2019-2020				2021-2022			
		Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
Longkhum	0-10cm	1.02± 0.02^{c}	1.13± 0.02^{b}	1.25± 0.01^{a}	1.2± 0.02^{a}	1.1± 0.01^{d}	1.18± 0.02^{c}	1.39± 0.02^{a}	1.3± 0.01^{b}
	10-20cm	0.99± 0.02^{b}	1.09± 0.02^{a}	1.1± 0.01^{a}	1.08± 0.01^{a}	1.02± 0.02^{b}	1.17± 0.02^{a}	1.21± 0.02^{a}	1.19± 0.02^{a}
	20-30cm	0.79± 0.02b	1.01± 0.01^{a}	1.01± 0.03^{a}	0.98± 0.02^{a}	0.85± 0.03^{b}	1.05± 0.07^{a}	1.1± 0.09^{a}	1.06± 0.05^{a}
Chungtia	0-10cm	1.12± 0.02^{d}	1.18± 0.03^{c}	1.33± 0.02^{a}	1.24± 0.01^{b}	1.18± 0.01^{c}	1.21± 0.03^{c}	1.45± 0.03^{a}	1.3± 0.01^{b}
	10-20cm	1.04± 0.01^{c}	1.13± 0.01^{b}	1.19± 0.02^{a}	1.02± 0.02^{c}	1.12± 0.01^{b}	1.17± 0.02^{ab}	1.22± 0.03^{a}	1.01± 0.03^{b}
	20-30cm	0.84± 0.06^{b}	0.98± 0.01^{a}	0.99± 0.04^{a}	1.02± 0.01^{a}	1± 0.03^{b}	1.03± 0.03^{ab}	1.03± 0.04^{ab}	1.1± 0.04^{a}
Tuli	0-10cm	1.32± 0.01^{b}	1.24± 0.02^{c}	1.43± 0.01^{a}	1.34± 0.01^{b}	1.55± 0.01^{b}	1.31± 0.07^{a}	1.48± 0.07^{a}	1.51± 0.05^{a}
	10-20cm	1.08± 0.04^{b}	1.1± 0.02^{b}	1.12± 0.02^{ab}	1.19± 0.03^{a}	1.13± 0.01^{b}	1.19± 0.03^{b}	1.2± 0.03^{a}	1.26± 0.03^{b}
	20-30cm	0.98± 0.01^{b}	1± 0.02^{b}	1.19± 0.01^{a}	0.95± 0.03^{b}	1.05± 0.03	1.1± 0.01	1.23± 0.02	1.06± 0.04

Mean ±standard error mean Different letters ($^{abc\ and\ d}$) in the same row in each year indicate significant differences between season (p<0.05) after *Tukey post hoc* test

In the first and second years, the bamboo forest of Longkhum soil bulk density was 1.052±0.11 (g/cm^3) and 1.13±0.13 (g/cm^3), respectively. The maximum bulk density in the first year is found at a depth of 0–10 cm in summer (1.25±0.01 g/cm^3), while the minimum B.D. is found at 0–10 cm depth in summer (0.96±0.02 g/cm^3). In the second year, B.D. was most significant in the summer at 0–10 cm (1.39±0.02 g/cm^3) and lowest in the winter at a depth of 20–30 cm (0.85±0.03 g/cm^3).

For the first and second years, the average B.D value in Chungtia bamboo forest was 1.09±0.13 g/cm^3 and 1.16±0.12 g/cm^3. In terms of depth, the first year's 0–10 cm summer holds the highest (1.33±0.02 g/cm^3) B.D value, while the 20–30 cm spring holds the lowest (0.98±0.01 g/cm^3) value. In the second year, 20–30 winter has the lowest value (1±0.03 g/cm^3), and 0–10 summer has the highest value (1.33±0.03 g/cm^3) for B.D.

B.D. averages in Tuli bamboo forest were 1.16±0.14 g/cm^3 in the first year and 1.16±0.17 g/cm^3 in the second year. Regarding depth, 0–10 cm (1.43±0.01 g/cm^3) has the highest value, while 20–30 cm (0.95±0.03 g/cm^3) has the lowest value. In the second year, B.D. was observed at its highest during the autumn (1.55±0.05 g/cm^3) in depths of 0–10 cm and at its lowest (1.05±0.03 g/cm^3) in depths of 20–30 cm.

At all of the research sites, the B.D. was highest in the summer and fall months and lowest in the spring and winter. The B.D. reveals a statistical variation across seasons, places, and seasons in Longkhum, Chungtia, and Tuli.

5.3.1.3. Soil Temperature:

A sizable seasonal variation in soil temperature was observed from the study sites. Significant differences in soil temperature were found at different research site depths. In Longkhum, the highest temperature was 24.13°C, and the minimum was 18.8°C at depths of 0–10 cm, 10–20 cm, and 20–30 cm, respectively. At 20–30 cm depths, the maximum temperature was 22.89°C, and the minimum was 16.8°C. Maximum and minimum temperatures in Chungtia were respectively 29.09°C and 21.1°C (0–10 cm), 28.5°C and 20.18°C (10–20 cm), and 26.5°C and 19.45°C (20–30 cm). The highest and lowest temperatures recorded in Tuli were 31.8°C and 24.5°C (0-10cm), 29.6 and 23.3°C (10-20cm), and 28.6°C and 22.3°C (20-30cm). The analysis of variance reveals a significant difference

Table 5.5: Soil Temperature of selected bamboo forests during 2018-2022.

Sites	Layer	2018-2019				2021-2022			
		Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
Longkhum	0-10cm	18.8± 0.25^{c}	21.13± 0.91^{b}	24.13± 0.05^{a}	23.08± 0.02^{a}	15.04± 0.03^{d}	23.4± 0.22^{c}	29.63± 0.2^{a}	266.57± 0.61^{b}
	10-20cm	17.63± 0.2^{d}	20.29± 0.23^{c}	23.75± 0.16^{a}	22.71± 0.13^{b}	14.76± 0.15^{d}	22.77± 0.11^{c}	28.76± 0.11^{a}	25.67± 0.26^{b}
	20-30cm	16.7± 0.36^{d}	19.59± 0.0^{c}	22.89± 0.09^{a}	21.67± 0.22^{b}	13.66± 0.15^{d}	21.88± 0.1^{c}	27.74± 0.12^{a}	24.70± 0.13^{b}
Chungtia	0-10cm	21.43± 0.51^{c}	26.57± 0.61^{b}	29.32± 0.44^{a}	28.67± 0.89^{a}	20.18± 0.03^{c}	27.3± 0.95^{b}	30.31± 0.08^{a}	27.3± 0.95^{b}
	10-20cm	20.21± 0.81^{c}	25.78± 0.61^{b}	28.54± 0.68^{a}	27.86± 0.29^{a}	19.93± 0.04^{c}	26.04± 0.02^{b}	28.81± 0.16^{a}	26.44± 1^{b}
	20-30cm	19.33± 011^{c}	24.80± 0.51^{a}	26.85± 0.27^{a}	26.59± 0.28^{a}	19.44± 0.11^{d}	23.08± 0.02^{c}	27.7± 0.07^{a}	24.85± 0.15^{b}
Tuli	0-10cm	24.73± 0.14^{d}	26.89± 0.31^{c}	31.85± 0.05^{a}	29.60± 0.06^{b}	26.49± 0.08^{d}	28.92± 0.03^{c}	35.26± 0.02^{a}	33.87± 0.09^{b}
	10-20cm	23.43± 0.12^{d}	25.41± 0.09^{c}	29.97± 0.42^{a}	28.61± 0.07^{b}	25.53± 0.11^{d}	27.8± 0.12^{c}	34.82± 0.06^{a}	32.85± 0.08^{b}
	20-30cm	22.57± 0.22^{d}	24.81± 0.14^{c}	28.85± 0.17^{a}	27.61± 0.05^{b}	23.85± 0.11^{d}	26.82± 0.12^{c}	32.81± 0.22^{a}	30.46± 0.12^{b}

Mean ±standard error mean Different letters (^{abc}and^{d}) in the same row in each year indicate significant differences between season (p<0.05) after *Tukey post hoc* test

5.3.1.4. Soil Respiration:

In different bamboo forests and at different depths, soil respiration differed significantly. Seasonally, summer was shown to be the time of year when soil respiration was highest at all the research locations. All forest bamboo stands were observed to be highest at the top soil and to decline with depth gradually. In the first year, Longkhum bamboo forest soil respiration ranges from 1.21±0.02 (µmol Co_2 m^{-2} s^{-1}) to 2.45±0.02 microns; in the second year, it ranges from 1.91±0.06 to 2.96±0.03 µmol m^{-2} s^{-1}. In Chungtia bamboo forest, soil respiration ranges from 1.37±0.02 to 2.93±0.07 in the first year and from 1.5±0.02 to 3.03±0.03 (µmol Co_2 m^{-2} s^{-1}) in the second year. At Tuli bamboo forest, soil respiration ranges from 1.5±0.02 to 3.08±0.01 in the first and 1.58±0.01 to 3.19±0.01 (µmol Co_2 m^{-2} s^{-1}) second years, respectively.

Table 5.5: Soil Respiration (µmol Co_2 m^{-2} s^{-1})of selected bamboo forests during 2018-2022.

Sites	Layer	2018-2019				2021-2022			
		Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
Longkhum	0-10cm	1.3± 0.04^d	1.7± 0.04^c	2.58± 0.03^a	2.18± 0.04^b	1.46± 0.04^d	1.87± 0.03^c	2.96± 0.03^a	2.28± 0.02^b
	10-20cm	1.22± 0.02^d	1.64± 0.03^c	2.45± 0.03^a	2.12± 0.05^b	1.35± 0.03^d	1.82± 0.03^c	2.59± 0.04^a	2.23± 0.03^b
	20-30cm	1.04± 0.03^d	1.35± 0.02^c	2.40± 0.05^a	2.06± 0.03^b	1.19± 0.06^d	1.52± 0.04^c	2.48± 0.05^a	2.17± 0.06^b
Chungtia	0-10cm	1.56± 0.03^d	1.92± 0.05^c	2.93± 0.07^a	2.75± 0.03^b	1.94± 0.13^b	2.07± 0.04^b	3.03± 0.01^a	2.88± 0.05^a
	10-20cm	1.49± 0.04^d	1.75± 0.03^c	2.85± 0.03^a	2.66± 0.04^b	1.66± 0.02^c	1.93± 0.03^b	2.97± 0.09^a	2.83± 0.11^a
	20-30cm	1.37± 0.02^d	1.67± 0.02^c	2.79± 0.02^a	2.58± 0.05^b	1.51± 0.04^d	1.79± 0.02^c	2.90± 0.02^a	2.69± 0.03^b
Tuli	0-10cm	1.94± 0.04^c	2.55± 0.11^b	3.08± 0.02^a	2.99± 0.01^a	2.04± 0.04^d	2.65± 0.03^c	3.19± 0.01^a	3± 0.01^b
	10-20cm	1.65± 0.04^c	2.37± 0.03^b	2.97± 0.06^a	2.90± 0.06^a	1.75± 0.03^d	2.46± 0.03^c	3.04± 0.02^a	2.96± 0.03^b
	20-30cm	1.5± 0.03^d	2.26± 0.1^c	2.96± 0.06^a	2.81± 0.08^b	1.58± 0.02^d	2.34± 0.02^c	2.98± 0.01^a	2.91± 0.02^b

Mean ±standard error mean Different letters (^{abc}and^{d}) in the same row in each year indicate significant differences between season ($p<0.05$) after *Tukey post hoc* test

5.3.1.5. Water Holding Capacity (WHC):

With increasing soil depth, from 0-10, 10-20 and 20-30 cm and increase with altitudes, soil water holding capacity (WHC%) declines in all the bamboo forests. The mean maximum WHC% is seen in the 0 to 10 cm range. In Longkhum, the first year's maximum value was 10-20 cm (46.6±0.26%), and the first year's minimum was 20-30 cm (40.43±0.31%). The figure changes from 40.36±0.31% to 50.06±0.15% in the second year.

WHC of Chungtia bamboo forest varies from 38.83±0.57% to 50.53±0.25% in the first year and 39.3±0.2% to 54±5.27 in the second year. For Tuli bamboo forest, the value varies from 42.53±0.15% to 52.36±0.23% in the first year and 41.90±0.03% to 52.81±0.03% in the second year. All the study sites recorded the highest value in the winter and spring seasons.

Table 5.6: Water Holding Capacity (WHC) of Longkhum, Chungtia and Tuli during 2018-2022.

Sites	Layer	2018-2019				2021-2022			
		Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
Longkhum	0-10cm	44.23± 0.45^{a}	41.16± 0.40^{b}	39.03± 0.32^{c}	40.26± 0.15^{b}	44.77± 0.04^{a}	41.81± 0.08^{b}	40.5± 0.2^{c}	41.5± 0.1^{b}
	10-20cm	45.96± 0.31^{a}	42.93± 0.05^{b}	40.43± 0.31^{c}	43.33± 0.35^{b}	46.6± 0.26^{b}	43.36± 0.15^{d}	50.06± 0.15^{a}	44.36± 0.31^{c}
	20-30cm	46.76± 0.25^{a}	43.1± 0.35^{b}	41.36± 0.35^{c}	39.83± 0.21^{d}	47.66± 1.5^{a}	44.03± 0.15^{b}	41.95± 0.06^{c}	40.36± 0.31^{d}
Chungtia	0-10cm	48.83± 0.06^{a}	46.96± 0.11^{b}	38.83± 0.57^{d}	41.2± 0.3^{c}	49.23± 0.25^{a}	47.33± 0.13^{b}	39.3± 0.2^{d}	41.76± 0.03^{c}
	10-20cm	50.53± 0.25^{a}	48.26± 0.16^{b}	40.4± 0.26^{d}	42.9± 0.1^{c}	54± 0.27^{a}	48.95± 0.03^{ab}	40.74± 0.03^{c}	43± 0.35^{bc}
	20-30cm	47.88± 0.55^{a}	45.5± 0.2^{b}	43.56± 0.35^{c}	40.33± 0.42^{d}	49.16± 0.21^{a}	45.91± 0.04^{b}	43.90± 0.02^{c}	40.61± 0.05^{d}
Tuli	0-10cm	50.7± 0.01^{a}	47± 0.45^{b}	42.53± 0.15^{d}	44.66± 0.2^{c}	51.56± 0.21^{a}	46.28± 0.19^{b}	42.88± 0.03^{d}	44.96± 0.04^{c}
	10-20cm	52.36± 0.23^{a}	48.6± 0.3^{b}	44.16± 0.4^{d}	46.36± 0.25^{c}	52.81± 0.03^{a}	49.3± 0.17^{b}	44.62± 0.19^{d}	46.93± 0.05^{c}
	20-30cm	49.9± 0.26^{a}	45.83± 0.03^{b}	41.43± 0.35^{c}	43.53± 0.21^{c}	50.13± 0.04^{a}	46.1± 0.03^{b}	41.90± 0.03^{d}	43.98± 0.02^{c}

Mean ±standard error mean Different letters (^{abc}and^{d}) in the same row in each year indicate significant differences between season ($p<0.05$) after *Tukey post hoc* test

5.3.1.6. Soil Moisture:

The soil's wetness varied seasonally according to the sites and soil layers. In all bamboo forests, the summer season had the highest soil moisture levels, while the winter had the lowest. In bamboo forest of Longkhum, the maximum value was noted at 0–10 cm during the summer season (47.16±0.03%), and the lowest value was noted at 20–30 cm during the winter season (34.81±0.12%) in the first year. The maximum value was 50.72±0.21% (0-10cm), and the minimum was 32.66±0.13% in the second year (20-30cm).

At Chungtia, the first-year maximum soil moisture value was 0–10 cm (66.58±0.03%), while the first-year lowest value was 20–30 cm (37.82±0.15%). The most significant value in the second year was 64.17±0.21% (0-10cm), while the minimum value was 43.42±0.13%. (20-30cm). The highest value was recorded during the summer in both years, while the lowest was reported during the winter.

In bamboo forest of Tuli, the 0–10 cm range had the highest value (76.61±0.17%), and the 20–30 cm range had the lowest value (50.71±0.14%) in the first year. The greatest value in the second year was 82.91±0.07% (0–10 cm), while the minimum value was 52.32±0.21% (20–30 cm). In both years, summer recorded the greatest value while winter recorded the lowest.

Table 5.7: Soil Moisture of Longkhum, Chungtia and Tuli bamboo forest during 2018-2022.

Sites	Layer	2018-2019				2021-2022			
		Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
Longkhum	0-10cm	36.68±0.02^{d}	37.03±0.02^{c}	47.16±0.03^{a}	38.82±0.21^{b}	41.08±0.03^{b}	41.62±0.35^{b}	50.72±0.21^{a}	41.08±0.03^{b}
	10-20cm	35.89±0.22^{d}	36.74±0.16^{c}	46.73±0.19^{a}	37.68±0.12^{b}	40.22±0.02^{b}	38.82±0.21^{c}	49.62±0.18^{a}	38.67±0.09^{c}
	20-30cm	34.81±0.12^{d}	35.66±0.1^{c}	45.82±0.09^{a}	36.56±0.21^{b}	32.66±0.13^{c}	32.66±0.16^{c}	47.16±0.03^{a}	36.68±0.02^{b}
Chungtia	0-10cm	40.22±0.02^{d}	46.55±0.04^{c}	66.58±0.03^{a}	54.58±0.06^{b}	43.42±0.13^{d}	48.53±0.21^{c}	64.17±0.21^{a}	55.87±0.2^{b}
	10-20cm	39.42±0.66^{d}	45.85±0.24^{c}	65.84±0.22^{a}	53.60±0.15^{b}	44.47±0.11^{c}	47.79±0.12^{d}	63.76±0.13^{a}	55.87±0.2^{b}
	20-30cm	37.82±0.15^{d}	45.49±0.45^{c}	64.6±0.16^{a}	52.84±0.05^{b}	43.66±0.66^{d}	47.21±0.08^{c}	62.96±0.33^{a}	54.87±0.09^{b}
Tuli	0-10cm	52.81±0.12^{d}	60.08±0.34^{c}	76.61±0.17^{a}	64.17±0.26^{b}	55.87±0.2^{d}	80.91±0.9^{b}	82.91±0.07^{a}	77.44±0.11^{c}
	10-20cm	51.67±0.18^{d}	59.72±0.14^{c}	75.69±0.14^{a}	63.81±0.11^{b}	53.82±0.06^{d}	79.61±0.11^{b}	80.48±0.07^{a}	77.02±0.51^{c}
	20-30cm	50.71±0.14^{d}	58.71±0.23^{c}	74.79±0.14^{a}	62.96±0.3^{b}	52.32±0.21^{s}	75.25±0.07^{c}	78.59±0.16^{a}	75.77±0.05^{b}

Mean ±standard error mean Different letters (^{abc}and^{d}) in the same row in each year indicate significant differences between season ($p<0.05$) after *Tukey post hoc* test

5.3.2. Seasonal soil chemical variables:

5.3.2.1. Soil *p*H:

At all the bamboo forests, *p*H is the metric that increases with increasing soil depth (Table). In the first year, the maximum *p*H value in bamboo forest of Longkhum was measured during spring at 20–30 cm (4.35±0.01), and the minimum at 0–10 cm (4.04±0.04). In the second year, the maximum value was recorded during the autumn season at 20–30 cm (4.64±0.19), and the minimum value was recorded during the winter at 0–10 cm (4.12±0.03).

During the initial year, the maximum *p*H value in Chungtia was found to be 4.65±0.02 in the summer and 4±0.01 in the winter. The summer high for the second year was 20–30 cm (4.75±0.06), and the winter minimum was 0–10 cm (3.71±0.45).

The maximum value for Tuli was 20–30 cm (5.03±0.14) in the summer and 10–20 cm (3.69±0.52) in the winter in the first year. The highest and minimum values for the second year were, respectively, 20–30 cm (4.85±0.06) for the summer and 0–10 cm (4.23±0.07) for the winter.

Table 5.8: Soil *p*H of Longkhum, Chungtia and Tuli during 2018-2022.

Sites	Layer	2018-2019				2021-2022			
		Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
Longkhum	0-10cm	4.04 ± 0.04^{c}	4.15 ± 0.01^{b}	4.18 ± 0.03^{ab}	4.24 ± 0.02^{a}	4.12 ± 0.03^{b}	4.16 ± 0.01^{b}	4.31 ± 0.11^{a}	4.39 ± 0.05^{a}
	10-20cm	4.05 ± 0.13^{b}	4.19 ± 0.09^{ab}	4.3 ± 0.04^{ab}	4.34 ± 0.13^{a}	4.18 ± 0.01^{b}	4.28 ± 0.02^{b}	4.48 ± 0.08^{a}	4.51 ± 0.04^{a}
	20-30cm	4.24 ± 0.01^{c}	4.35 ± 0.01^{b}	4.47 ± 0.04^{a}	4.34 ± 0.04^{b}	4.27 ± 0.05^{b}	4.4 ± 0.03^{ab}	4.58 ± 0.08^{b}	4.64 ± 0.19^{a}
Chungtia	0-10cm	4 ± 0.01^{b}	4.25 ± 0.08^{a}	4.26 ± 0.02^{a}	4.36 ± 0.09^{a}	3.71 ± 0.45^{b}	4.07 ± 0.15^{ab}	4.65 ± 0.11^{a}	4.05 ± 0.03^{ab}
	10-20cm	4.13 ± 0.07^{c}	4.4 ± 0.04^{b}	4.62 ± 0.02^{a}	4.28 ± 0.08^{b}	4.39 ± 0.02^{b}	4.63 ± 0.02^{a}	4.58 ± 0.1^{a}	4.54 ± 0.03^{a}
	20-30cm	4.20 ± 0.03^{b}	4.46 ± 0.08^{ab}	4.65 ± 0.02^{a}	4.32 ± 0.31^{ab}	4.46 ± 0.01^{c}	4.59 ± 0.05^{b}	4.75 ± 0.06^{a}	4.47 ± 0.02^{c}
Tuli	0-10cm	4.12 ± 0.11^{c}	4.35 ± 0.01^{b}	4.56 ± 0.01^{a}	4.33 ± 0.05^{b}	4.23 ± 0.07^{b}	4.25 ± 0.15^{b}	4.66 ± 0.03^{a}	4.45 ± 0.06^{ab}
	10-20cm	3.69 ± 0.52^{b}	4.17 ± 0.04^{ab}	4.52 ± 0.02^{a}	4.22 ± 0.03^{ab}	4.34 ± 0.21^{a}	4.69 ± 0.14^{a}	4.71 ± 0.13^{a}	4.72 ± 0.08^{a}
	20-30cm	4.05 ± 0.04^{c}	4.78 ± 0.08^{b}	5.03 ± 0.14^{ab}	4.94 ± 0.05^{a}	4.49 ± 0.07^{b}	4.72 ± 0.1^{ab}	4.85 ± 0.06^{a}	4.75 ± 0.17^{ab}

Mean ±standard error mean Different letters (^{abc}and^{d}) in the same row in each year indicate significant differences between season ($p<0.05$) after *Tukey post hoc* test

5.3.2.2. Soil organic carbon (SOC):

As soil depth and altitude increases, SOC% decreases in all the bamboo forests. In the first year, the mean average SOC value in bamboo forest of Longkhum was 2.72±0.01% (0-10cm) in the summer and 0.86±0.09% (20-30cm) in the winter. The greatest value in the second year was 2.89±0.1% (0-10cm) in the summer, and the minimum value was 1.07±0.06% (20-30cm) in the winter.

The maximum value in bamboo forest of Chungtia was recorded during the summer at 0–10 cm (3.43±0.05%), and the lowest value was recorded during the first year of winter at 20–30 cm (1.13±0.01%). The greatest value in the second year was 3.74±0.14% at 010 cm during the summer, while the minimum value was 1.29±0.05% at 030 cm during the winter.

In bamboo forest of Tuli, the maximum value was measured at 0–10 cm (4.03±0.04%) in the summer, and the smallest value was measured at 20–30 cm (1.61±0.04%) in the spring. In the second year, the greatest value was 4.39±0.12% at 0–10 cm of soil depth in the summer, while the minimum value was 1.9±0.16% at 20–30 cm in the spring.

Table 5.9: Soil Organic Carbon (%) of Longkhum, Chungtia and Tuli bamboo forest during 2018-2022

Sites	Layer	2018-2019				2021-2022			
		Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
Longkhum	0-10cm	1.55± 0.02^{c}	2.48± 0.12^{ab}	2.72± 0.01^{a}	2.2± 0.2^{b}	1.87± 0.01^{c}	2.48± 0.12^{b}	2.89± 0.1^{a}	2.49± 0.13^{b}
	10-20cm	1.04± 0.05^{d}	1.55± 0.02^{c}	1.74± 0.01^{b}	1.94± 0.04^{a}	1.44± 0.03^{b}	1.93± 0.05^{a}	1.97± 0.03^{a}	1.99± 0.05^{a}
	20-30cm	0.86± 0.09^{b}	1.01± 0.01^{b}	1.52± 0.06^{a}	1.72± 0.23^{a}	1.07± 0.06^{b}	1.14± 0.02^{b}	1.90± 0.05^{a}	1.81± 0.27
Chungtia	0-10cm	2.20± 0.09^{c}	2.68± 0.09^{b}	3.43± 0.05^{a}	2.36± 0.03^{c}	2.66± 0.08^{b}	2.81± 0.11^{b}	3.74± 0.14^{a}	2.61± 0.23^{b}
	10-20cm	2.09± 0.01^{c}	1.57± 0.02^{d}	3.13± 0.15^{a}	2.52± 0.05^{b}	2.04± 0.04^{d}	1.33± 0.11^{b}	3.25± 0.09^{a}	2.68± 0.04^{c}
	20-30cm	1.13± 0.01^{c}	0.95± 0.02^{d}	2.18± 0.02^{a}	1.51± 0.05^{b}	1.29± 0.05^{d}	2.09± 0.05^{b}	2.5± 0.09^{a}	1.65± 0.08^{c}
Tuli	0-10cm	3.02± 0.04^{d}	3.19± 0.03^{c}	4.03± 0.04^{a}	3.55± 0.07^{b}	3.19± 0.22^{c}	3.26± 0.04^{b}	4.39± 0.12^{a}	37.8± 0.05^{b}
	10-20cm	2.44± 0.56^{b}	2.6± 0.04^{ab}	3.25± 0.02^{a}	2.93± 0.04^{ab}	2.56± 0.1^{b}	2.75± 0.07^{b}	3.77± 0.12^{a}	3.66± 0.06^{a}
	20-30cm	2.11± 0.57^{b}	1.61± 0.04^{c}	2.61± 0.04^{a}	2.13± 0.04^{b}	2.16± 0.1^{b}	1.9± 0.16^{b}	3.06± 0.33^{a}	2.28± 0.01^{b}

Mean ±standard error mean Different letters (^{abc}and^{d}) in the same row in each year indicate significant differences between season ($p<0.05$) after *Tukey post hoc* test

5.3.2.3. Soil organic carbon density (SOCD):

When soil depth and altitude increases, SOCD drops in all the bamboo forests. In bamboo forest of Longkhum, the maximum value was seen in the summer at 0–10 cm (38.96±0.2Mg/hac), and the lowest value was found in the spring at a depth of 20–30 cm (10.16±0.21Mg/hac) in the first year. The greatest value in the second year was 39.93±0.3 Mg/hac during the summer at a depth of 0–10 cm, and the lowest value was 11.63±0.32Mg/hac during the spring at a depth of 20–30 cm. The SOCD value in bamboo forest of Chungtia varies between 10.1±0.11 to 45.3±0.3Mg/hac in the first year and 11.66±0.2–46.6±0.52Mg/hac in the second year. In both years, the summer season had the highest value, while the spring had the lowest value.

The value in Tuli bamboo forest varies from 19.2±0.2-55.2±0.2Mg/hac in the first year and from 55.83±0.05-19.86±0.11Mg/hac in the second year. The values were 0-10 cm in the summer and 20-30 cm in the spring, respectively, for the highest and lowest values.

Table 5.10: Soil Organic Carbon Density (Mg/hac) of Longkhum, Chungtia and Tuli bamboo forest during 2018-2022

Sites	Layer	2018-2019				2021-2022			
		Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
Longkhum	0-10cm	33.93±0.2^{b}	28.33±0.32^{d}	38.96±0.28^{a}	31.2±0.2^{c}	34.5±0.45^{b}	29.8±0.26^{d}	39.93±0.3^{a}	32.66±0.2^{c}
	10-20cm	22.16±0.21^{b}	15.33±0.25^{c}	22.16±0.2^{b}	24.1±0.05^{a}	23.7±0.03^{b}	16.86±0.15^{c}	23.66±0.32^{b}	25.93±0.2^{a}
	20-30cm	16.43±0.31^{b}	10.16±0.21^{d}	19.44±0.25^{a}	15.1±0.1^{c}	17.6±0.32^{b}	11.63±0.32^{d}	21.1±0.2^{a}	16.56±0.15^{c}
Chungtia	0-10cm	24.93±0.15^{d}	32.2±0.2^{c}	45.3±0.3^{a}	38.4±1.4^{b}	25.83±0.2^{d}	33.73±0.15^{c}	46.6±0.52^{a}	39.63±0.55^{b}
	10-20cm	21.1±0.11^{c}	15.1±0.1^{d}	32±0.05^{a}	25.1±0.11^{b}	22.7±0.2^{c}	16.9±0.1^{d}	33.86±0.15^{a}	26.9±0.1^{b}

	20-30cm	11.96± 0.21^{c}	10.1± 0.11^{d}	21.3± 0.3^{a}	19.4± 0.2^{b}	12.86± 0.15^{c}	11.66± 0.2^{d}	23± 0.1^{a}	21.3± 0.61^{b}
Tuli	0-10cm	37.8± 0.2^{d}	45.33± 0.25^{b}	55.2± 0.2^{a}	42.2± 0.2^{c}	38.36± 0.25^{d}	45.66± 0.08^{b}	55.83± 0.05^{a}	43.23± 0.2^{c}
	10-20cm	24.86± 0.5^{b}	25.2± 0.2^{b}	40.6± 0.2^{a}	24.96± 0.21^{b}	25.23± 0.32^{b}	25.59± 0.21^{b}	41.16± 0.32^{a}	25.56± 0.15^{b}
	20-30cm	25.1± 0.15^{b}	19.2± 0.2^{d}	37.8± 0.2^{a}	21.5± 0.2^{c}	25.1± 0.1^{c}	19.86± 0.11^{d}	38.6± 0.2^{a}	22.7± 0.17^{b}

Mean ±standard error mean Different letters (^{abc}and^{d}) in the same row in each year indicate significant differences between season ($p<0.05$) after *Tukey post hoc* test

5.3.2.4. Soil available nitrogen:

Sites, seasons, and soil depth all greatly affect how much nitrogen is accessible in the soil. The table (Table: 5.11) displays the average nitrogen levels in the soil for each bamboo forests, season, and layer. The average value in bamboo forest of Longkhum was 419.6±0.1-610.3±0.1kg/hac in the second year and 438.5±0.12-601.6±0.2kg/hac in the first year. The first year's data showed that the highest value occurred in the winter at 0–10 cm (601.6±0.2kg/hac), while the minimum occurred in the fall at 20–30 cm (438.5±0.12kg/hac). The highest value in the second year was 610.30.1 kg, which was seen during the winter at 0–10 cm, while the minimum value was 419.60.1 kg/hac, seen in the autumn at 20–30 cm.

The average value in Chungtia varies from 351.6±0.1-573.2±0.12 kg/hac in the first year and from 594.7±0.21 kg/hac in the second year. In the first year, the maximum value was reported at 0-10 cm (573.2±0.12kg/hac), while the smallest value was at 20-30 cm (351.6±0.1kg/hac). The minimum value in the second year was observed during the autumn season at 20-30cm (378.8±0.07kg/hac), while the maximum value was recorded during the winter at 0-10cm (594.7±0.21 kg/hac) in the bamboo forest of Chungtia.

The average value in bamboo forest of Tuli varies between 356.3±0.8-489.6±0.2 kg/hac in the first year and 398.8±0.19-569.7±0.26kg/hac in the second year. In both years, the winter season had the highest value and the fall had the lowest. In all seasons and years, the maximum value was recorded at 0–10 cm, and the minimum at 20–30 cm.

Table 5.11: Soil available nitrogen (Kg/hac) of Longkhum, Chungtia and Tuli bamboo forest during 2018-2022

Sites	**Layer**	**2018-2019**				**2021-2022**			
		Winter	**Spring**	**Summer**	**Autumn**	**Winter**	**Spring**	**Summer**	**Autumn**
Longkhum	0-10cm	601.6± 0.2^{a}	552.5± 0.2^{b}	539.7± 0.4^{c}	498.4± 0.15^{d}	610.3± 0.1^{a}	589.7± 0.1^{b}	492.4± 0.4^{d}	514.6± 0.5^{c}
	10-20cm	578.4± 0.1^{a}	539.7± 0.15^{b}	493.5± 0.2^{c}	438.8± 0.13^{d}	598.6± 0.12^{a}	553.7± 0.6^{b}	458.4± 0.1^{d}	496.6± 0.1^{c}
	20-30cm	563.6± 0.2^{a}	535.4± 0.7^{b}	456.6± 2^{c}	438.5± 0.22^{d}	562.4± 0.1^{a}	548.8± 0.3^{b}	448.6± 0.2^{c}	419.6± 0.1^{d}
Chungtia	0-10cm	573.2± 0.12^{a}	441± 0.37^{b}	407.8± 0.6^{c}	388.4± 0.09^{d}	594.7± 0.21^{a}	488± 0.15^{b}	438.5± 0.12^{c}	402.5± 0.11^{d}
	10-20cm	485.5± 0.9^{a}	438± 0.31^{b}	366.7± 0.13^{d}	376.6± 0.13^{c}	555± 0.25^{c}	459.4± 0.18^{d}	410.6± 0.07^{a}	378.8± 0.07^{b}
	20-30cm	453.7± 0.11^{a}	425.7± 0.12^{b}	351.6± 0.1^{c}	351.8± 0.1^{c}	500.4± 0.18^{a}	448.7± 0.14^{b}	398.4± 0.11^{c}	340.8± 0.17^{d}
Tuli	0-10cm	489.6± 0.2^{a}	465.8± 0.09^{b}	454.3± 0.21^{c}	381.5± 0.16^{d}	569.7± 0.26^{a}	510.9± 0.45^{b}	496.6± 0.13^{c}	420.6± 0.17^{d}
	10-20cm	458.3± 0.73^{a}	455.5± 0.16^{b}	448.8± 0.2^{c}	366.5± 0.54^{d}	542.7± 0.43^{a}	495.4±0 $.12^{b}$	478.7± 0.42^{c}	410.5± 0.28^{d}
	20-30cm	448.8± 0.4^{c}	446.6± 0.24^{b}	401± 0.19^{a}	356.3± 0.8^{a}	520.6± 0.35^{a}	479.6± 0.09^{b}	440.7± 0.14^{c}	398.8± 0.19^{d}

Mean ±standard error mean Different letters (^{abc}and^{d}) in the same row in each year indicate significant differences between season ($p<0.05$) after *Tukey post hoc* test

The available N is classified as very low (140 kg/ha), low (141-280 kg/ha), medium-low (281 - 420 kg/ha), medium (421 - 560 kg/ha), high (561-700 kg/ha), and very high (>700 kg/ha) according to the Procedures Manual of Soil Testing in India (2011). Following this instruction, the N availability ranged from medium to high in Longkhum, Chungtia, and Tuli.

5.3.2.5. Soil available phosphorus:

Sites, seasons, and soil depth all greatly affect how much phosphorus is accessible in the soil. As soil depth increases and increase in altitude, less phosphorus is available in the soil. The table 5.12 displays the mean average values. The average mean value in bamboo forest of Longkhum is between 24.13±0.05-42.14±0.06 kg/hac in the first year and 38.62±0.07-59.78±0.13 kg/hac in the second year. The value ranged from 0 to 10 cm (spring), measuring (42.14±0.06kg/hac), 20 to 30 cm (fall), measuring (24.13±0.05kg/hac).

In bamboo forest of Chungtia, average mean value varies from 19.74±0.13-35.26±0.13kg/hac in first year and 28.77±0.2-42.69±0.6kg/hac in second year. The maximum value was observed during the spring season at 0-10cm, and the lowest value was observed during the winter season at 20-30cm in both years.

In bamboo forest stand of Tuli, the average value of the first year ranges from 10.84±0.13-19.69±0.4kg/hac, while in the second year, it varies from 13.68±0.1-24.78±0.1kg/hac respectively. The maximum value was recorded at 0-10cm soil depth during the spring season, and the minimum value was recorded at 20-30cm during winter in both years.

Table 5.12: Soil available phosphorous (Kg/hac) in bamboo forests of Longkhum, Chungtia and Tuli during 2018-2022

Sites	Layer	2018-2019				2021-2022			
		Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
Longkhum	0-10cm	38.54±0.31^{b}	42.14±0.06^{a}	33.82±0.05^{a}	28.67±0.89^{d}	42.69±0.6^{d}	59.78±0.13^{a}	54.91±0.05^{b}	48.81±0.15^{c}
	10-20cm	36.7±0.13^{b}	38.46±0.22^{a}	30.49±0.05^{c}	27.36±0.54^{d}	41.87±0.04^{d}	55.47±0.09^{a}	53.37±0.07^{b}	47.56±0.5^{a}
	20-30cm	35.54±0.18^{a}	32.55±0.1^{b}	26.57±0.61^{c}	24.13±0.05^{d}	40.82±0.12^{d}	54.22±0.11^{a}	50.41±0.3^{b}	38.62±0.07^{c}
Chungtia	0-10cm	21.45±0.04^{c}	35.26±0.13^{a}	27.7±0.19^{b}	20.29±0.06^{d}	30.1±0.2^{a}	42.69±0.6^{a}	34.65±0.32^{b}	26.44±1.2^{d}
	10-20cm	20.32±0.31^{c}	34.57±0.19^{a}	27±0.49^{b}	19.61±0.06^{c}	29.6±0.06^{c}	41.82±0.14^{a}	33.88±0.09^{b}	25.55±0.12^{d}
	20-30cm	19.74±0.13^{c}	33±0.57^{a}	26.22±0.29^{b}	18.59±0.16^{d}	28.77±0.2^{d}	40.75±0.11^{a}	34.72±0.07^{b}	22.45±0.1^{c}
Tuli	0-10cm	12.51±0.22^{c}	19.69±0.4^{a}	15.54±0.65^{b}	12.75±0.3^{c}	15.65±0.16^{d}	24.78±0.1^{a}	19.81±0.12^{b}	17.89±0.2^{c}
	10-20cm	11.78±0.3^{c}	17.74±0.25^{a}	14.65±0.6^{b}	11.86±0.15^{c}	13.68±0.1^{d}	20.30±0.1^{a}	17.86±0.1^{b}	15.5±0.4^{c}
	20-30cm	10.84±0.13^{c}	16.71±0.22^{a}	13.66±0.4^{b}	10.93±0.05^{c}	12.53±0.3^{d}	18.55±0.1^{a}	15.87±0.1^{b}	14.24±0.1^{c}

Mean ±standard error mean Different letters (^{abc}and^{d}) in the same row in each year indicate significant differences between season ($p<0.05$) after *Tukey post hoc* test

The available P in Longkhum was medium-low to medium; in Chungtia, it was low to medium-low; and in Tuli it was very low to low, according to the Procedures Manual of Soil Testing in India (2011).

5.3.2.6. Soil available potassium:

Soil available potassium varies significantly among sites, seasons, and soil depth. Soil available potassium decreases with an increase in soil depth and altitude. The mean average values of sites, seasons, and layers are shown in the table 5.13. In bamboo forest stand of Longkhum, the average value ranges from 86.54±0.3-382.1±0.1kg/hac during the first year and 116.4±0.5-465.8±0.1kg/hac in second year. The maximum value was recorded in the summer season at 0-10cm, and the minimum was recorded during winter at 20-30cm in the first year. While in the second year, the maximum value was recorded during summer at 0-10cm, and the minimum was recorded during the autumn season at 20-30cm.

In bamboo stands of Chungtia, the average value varies from 75.58±0.18-270.3±0.1kg/hac in the first year and 99.4±0.11-300.3±0.8kg/hac in second year. The highest value was recorded during the summer season at 0-10cm, and the lowest was recorded during winter at 20-30cm in both years.

In bamboo forest of Tuli, the average value varies from 61.51±0.9-172.6±0.16kg/hac in first year and 90.7±0.1- 230.4±0.11kg/hac in the second year. The maximum value was observed during summer at 0-10cm soil depth, and the minimum was observed during winter at 20-30cm in both years.

Table 5.13: Soil available potassium in Bamboo forest of Longkhum, Chungtia and Tuli during 2018-2022

Sites	**Layer**	**2018-2019**				**2021-2022**			
		Winter	**Spring**	**Summer**	**Autumn**	**Winter**	**Spring**	**Summer**	**Autumn**
Longkhum	0-10cm	180.6±0.5^{d}	194.6±0.3^{c}	382.1±0.1^{a}	221.3±0.28^{b}	149.1±0.2^{d}	211.8±0.04^{c}	465.8±0.1^{a}	270±0.12^{b}
	10-20cm	98.73±0.8^{d}	133.1±0.6^{b}	242.1±0.1^{a}	124.4±0.5^{c}	141.65±0.5^{c}	150.9±0.2^{b}	271.7±0.1^{a}	130.6±0.32^{d}
	20-30cm	86.54±0.3^{d}	138.6±0.4^{b}	172.7±0.8^{a}	102.6±0.3^{c}	130.8±0.13^{b}	119.4±0.2^{c}	26.46±0.4^{a}	116.4±0.5^{d}
Chungtia	0-10cm	143.9±0.2^{c}	138.7±0.13^{d}	270.3±0.1^{a}	150.9±0.2^{b}	129.5±0.1^{d}	184.3±0.61^{b}	300.3±0.8^{a}	178.6±0.1^{c}
	10-20cm	94.29±0.12^{d}	121.4±0.4^{c}	266.5±0.5^{a}	134.6±0.3^{b}	119.6±0.16^{d}	150.5±0.17^{b}	129.2±0.15^{a}	148.5±0.1^{c}
	20-30cm	75.58±0.18^{d}	98.4±0.7^{c}	208.9±0.11^{a}	102±0.1^{b}	99.4±0.11^{d}	120.6±0.19^{b}	230.4±0.11^{a}	115.5±0.16^{c}
Tuli	0-10cm	104.3±0.8^{c}	124.4±0.17^{b}	172.6±0.16^{a}	116.5±0.5^{c}	100.6±0.5^{d}	129.8±0.6^{b}	188.5±0.7^{a}	120.7±0.2^{c}
	10-20cm	86.6±0.2^{d}	98.8±0.4^{b}	137.4±0.2^{a}	97.6±0.2^{b}	90.7±0.1^{d}	112.6±0.3^{b}	145.6±0.12^{a}	99.1±0.4^{c}
	20-30cm	61.51±0.9^{d}	77.1±0.04^{b}	120.2±0.2^{a}	71.39±0.2^{c}	57.4±0.9^{d}	80.81±0.6^{b}	132.4±0.1^{a}	75.86±0.5^{c}

Mean ±standard error mean Different letters (^{abc}and^{d}) in the same row in each year indicate significant differences between season (p<0.05) after *Tukey post hoc* test

The available K in bamboo forest of Longkhum was extremely low to high, in bamboo forest of Chungtia it was very low to medium; and in bamboo stands of Tuli it was very low to medium-low, according to the Procedures Manual of Soil Testing in India (2011).

5.3.3. Soil physical and chemical characteristics in relation Bamboo Forests at different altitude:

According to the one-way ANOVA test results, there was a mean significant difference in all of the physicochemical characteristics of the bamboo forest soil between the sampling seasons and altitudes ($p < 0.05$ and 0.01). Tukey's post hoc test of significance for mean differences between sampling seasons (winter-spring, winter-summer, winter-autumn, spring-summer, spring-autumn, summer-autumn) revealed statistically significant variations in all soil parameters at all three research sites in both years (Table 5.14). The results of a two-way ANOVA test between the sampling site and season showed a statistically significant influence of their interaction on all of the soil characteristics ($p<0.01$).

Table 5.14: One way ANOVA of Soil Physico-chemical parameters of selected Bamboo forest in Longkhum, Chungtia and Tuli during 2018-2022

		LONGKHUM				**CHUNGTIA**				**TULI**			
		2019-2020		2020-2022		2019-2020		2020-2022		2019-2020		2020-2022	
Parameter	Layer	F(3,8)	*p* (value)	F (3,8)	*p* (value)	F(3,8)	*p* (value)	F (3,8)	*p* (value)	F(3,8)	*p* (value)	F (3,8)	*p* (value)
pH	0-10cm	21.83	0.000	39.80	0.000	11.39	0.003	7.57	0.010	23.09	0.000	14.12	0.001
	10-20cm	4.49	0.040	33.79	0.000	55.05	0.000	9.99	0.004	4.99	0.031	4.49	0.040
	20-30cm	25.142	0.000	7.45	0.011	4.23	0.045	31.20	0.000	168.66	0.000	5.331	0.026
Moist.	0-10cm	6.28	0.000	1.56	0.000	2.10	0.000	5.56	0.000	5.10	0.000	1.78	0.000
	10-20cm	2.42	0.000	3.73	.000	2.66	0.000	1.01	0.000	1.31	0.000	6.77	0.000
	20-30cm	3.85	0.000	1.05	.000	4.35	0.000	5.20	0.000	6.89	0.000	2.20	0.000
Temp.	0-10cm	73.38	0.000	1.01	0.000	94.56	0.000	120.66	0.000	934.92	0.000	7.06	0.000
	10-20cm	626.00	0.000	3.74	0.000	183.22	0.000	167.29	0.000	515.13	0.000	5.90	0.000
	20-30cm	455.34	0.000	6.60	.000	342.81	0.000	3.34	0.000	600.28	0.000	2.05	0.000
B.D	0-10cm	61.04	0.000	113.71	0.000	75.53	0.000	62.70	0.000	70.25	0.000	11.88	0.003
	10-20cm	13.11	0.002	35.96	0.000	59.37	0.000	11.58	0.003	7.38	0.011	9.61	0.005
	20-30cm	46.53	0.000	14.12	.001	10.86	0.003	5.03	0.030	30.53	0.000	16.43	0.001
OC	0-10cm	54.85	0.000	48.24	0.000	187.69	0.000	81.55	0.000	239.59	0.000	53.34	0.000
	10-20cm	323.91	0.000	178.38	0.000	703.18	0.000	323.24	0.000	4.88	0.032	125.24	0.000
	20-30cm	28.38	0.000	272.07	0.000	1.45	0.000	268.86	0.000	1.17	0.000	20.64	0.000
SOC	0-10cm	998.48	0.000	524.82	0.000	428.99	0.000	1.43	0.000	3.57	0.000	5.57	0.000
	10-20cm	1.154	0.000	712.56	.000	1.51	0.000	7.34	0.000	5.75	0.000	2.32	0.000
	20-30cm	852.55	0.000	668.58	0.000	1.94	0.000	894.13	0.000	7.78	0.000	8.77	0.000
AN	0-10cm	1.49	0.000	9.39	0.000	1.18	0.000	1.53	0.000	3.05	0.000	1.03	0.000
	10-20cm	5.81	0.000	9.43	0.000	805.26	0.000	6.41	0.000	2.64	0.000	2.22	0.000
	20-30cm	5.65	0.000	6.41	0.000	248.57	0.000	7.36	0.000	3.50	0.000	7.28	0.000
AP	0-10cm	452.18	0.000	1.30	0.000	9.15	0.000	377.14	0.000	411.87	0.000	3.59	0.000
	10-20cm	885.27	0.000	1.66	0.000	1.76	0.000	1.15	0.000	336.05	0.000	1.46	0.000
	20-30cm	786.42	0.000	4.573	0.000	1.14	0.000	9.93	0.000	572.35	0.000	1.36	0.000
AK	0-10cm	7.97	0.000	7.27	0.000	7.57	0.000	1.570	0.000	2.99	0.000	5.58	0.000
	10-20cm	4.49	.000	3.80	0.000	2.33	0.000	7.75	0.000	5.08	0.000	2.52	0.000
	20-30cm	1.42	0.000	1.31	.000	7.39	0.000	5.65	0.000	5.37	0.000	4.54	0.000
SAND	0-10cm	545.66	0.000	526.90	0000	8.31	0.000	2.63	0.000	1.86	0.000	944.01	0.000
	10-20cm	2.12	0.000	2.90	0.000	39.93	0.000	178.05	0.000	956.71	0.000	3.88	0.000
	20-30cm	301.31	0.000	429.69	0.000	490.42	0.000	159.34	0.000	738.41	0.000	956.71	0.000
SILT	0-10cm	247.39	0.000	42.08	0.000	357.89	0.000	62.04	0.000	73.84	0.000	44.10	0.000
	10-20cm	594.46	0.000	745.71	0.000	58.06	0.000	62.96	0.000	36.09	0.000	48.47	0.000
	20-30cm	50.31	0.000	57.98	0.000	1.16	0.000	128.12	0.000	23.93	0.000	36.09	0.000
CLAY	0-10cm	598.49	0.000	303.11	0.000	947.11	0.000	793.82	0.000	5.98	0.000	852.15	0.000
	10-20cm	478.25	0.000	223.34	0.000	633.66	0.000	2.41	0.000	480.24	0.000	310.96	0.000
	20-30vm	28.58	0.000	30.43	0.000	1.44	0.000	213.49	0.000	485.35	0.000	480.24	0.000
SR	0-10cm	669.56	0.000	854.97	0.000	510.13	0.000	186.95	0.000	221.55	0.000	919.27	0.000
	10-20cm	1.57	0.000	860.28	0.000	1.04	0.000	397.77	0.000	403.92	0.000	1.31	0.000
	20-30cm	808.52	0.000	435.67	0.000	1.30	0.000	3.32	0.000	390.88	0.000	5.15	0.000
WHC	0-10cm	119.71	.000	691.68	0.000	2.42	0.000	2.036	0.000	511.85	0.000	1.93	0.000
	10-20cm	196.51	0.000	504.00	0.000	1.82	0.000	15.40	0.001	397.05	0.000	2.09	0.000
	20-30cm	296.39	0.000	828.55	0.000	188.72	0.000	3.21	0.000	307.53	0.000	3.73	0.000

Table 5.15: Two way ANOVA of Soil physicochemical parameters of selected Bamboo forest in Longkhum, Chungtia and Tuli during 2018-2022.

Parameters	Source	2019-2020		2020-2021	
		F (3,8)	*p* (value)	F (3,8)	*p*(value)
*p*H	Site	32.74	0.000	13.24	0.000
	Season	28.65	0.000	21.42	0.000
	SitexSeason	7.99	0.000	3.69	0.002
Moist. (%)	Site	7.87	0.000	2.08	0.000
	Season	3.23	0.000	385	0.000
	SitexSeason	199.78	0.000	75.26	0.000
Temp (°C)	Site	387.54	0.00	462.33	0.000
	Season	272.42	0.000	378.72	0.000
	SitexSeason	6.51	0.000	18.28	0.000
B.D (g/cm^3)	Site	614.77	0.000	7.86	0.002
	Season	76.21	0.000	5.49	0.001
	SitexSeason	3.38	0.005	3.04	0.001
OC (%)	Site	207.37	0.000	21.76	0.000
	Season	40.63	0.000	13.43	0.000
	SitexSeason	13.67	0.000	1.54	0.000
SOCD (%)	Site	32.25	0.000	12.13	0.000
	Season	27.68	0.000	11.12	0.000
	SitexSeason	7.42	0.000	1.54	0.000
AN (Kg/hac)	Site	14.25	0.000	77.58	0.000
	Season	10.63	0.000	168.23	0.000
	SitexSeason	9.51	0.000	6.94	0.000
AP (Kg/hac)	Site	169.50	0.000	1.99	0.000
	Season	116.39	0.000	177.71	0.000
	SitexSeason	6.33	0.000	16.94	0.000
AK (Kg/hac)	Site	971.44	0.000	39.77	0.000
	Season	158.35	0.000	55.35	0.000
	SitexSeason	33.72	0.000	3.99	0.001
Sand (%)	Site	27.31	0.000	265.77	0.000
	Season	46.53	0.000	34.31	0.000
	SitexSeason	3.03	0.009	5.38	0.000
Silt (%)	Site	254.72	0.000	26.187	0.000
	Season	28.83	0.000	11.31	0.000
	SitexSeason	4.59	0.000	6.15	0.000
Clay (%)	Site	27.282	0.000	598.96	0.000
	Season	13.38	0.000	75.37	0.000
	SitexSeason	6.75	0.000	4.54	0.000
SR (cm)	Site	86.42	0.000	478.12	0.000
	Season	166.26	0.000	159.31	0.000
	SitexSeason	6.49	0.000	8.42	0.000
WHC (%)	Site	301.92	0.000	16.97	0.000
	Season	758.96	0.000	60.34	0.000
	SitexSeason	10.78	0.000	7.85	0.000

The Pearson's correlation coefficient values of Longkhum, Chungtia, and Tuli bamboo soil properties are presented in Table 5.16- 5.21. Correlations among the soil physical and chemical characters in bamboo forest of Longkhum reveals that during the first year, the temperature was significant with moisture (r=0.763**, p=0.00). Bulk density was positively correlated with *p*H (r=0.439**, p= 0.002), moisture (r=0.524**, p=0.001) and temperature (r=0.760**, p=0.00). Soil organic carbon was positively correlated to *p*H (r =0.439^{*8}, p= 0.007), moisture (r=0.474**, p=0.004), temperature (r=0.717**, p=0.00) and bulk density (r=0.865**, p=0.00) at significant level 0.01. Soil organic carbon density was positively correlated to *p*H (r=0.457**, p=0.005), bulk density (r=0.667**, p=0.00) and organic carbon (r=0.744**, p=0.00) at significant, and correlated to moisture (r=0.391*, p=0.018) and temperature (r=0.369*, p=0.27). Available nitrogen was negatively correlated to temperature (r=-0.663**, p=0.00). Available phosphorus was negatively correlated to temperature (r=-0.519**, p=0.001) and positively correlated to available nitrogen (r=0.886**, p=0.00). Available potassium was positively correlated to moisture (r=0.769**, p=0.00), temperature (r=0.769**, p=0.00), bulk density (r=0.773**, p=0.00), organic carbon (r=0.731**, p=0.00) and soil organic carbon density (r=0.740**, p=0.00) at and positively correlated to *p*H (r=0.409*, p=0.013) at. Sand was correlated to temperature (r=0.662**, p=0.00), with moisture (r=0.409*, p=0.013) at 0.05 level) and negatively correlated to available nitrogen (r=-0.826**, p=0.00) and available phosphorous (r=-0.845**, p=0.00). Silt was negatively correlated to moisture (r=-0.469**, 0.004), temperature (r=-0.682**, p=0.00), bulk density (r=-0.528**, p=0.001), available potassium (r=-0.442**, p=0.007) and sand (r=-0.760**, p=0.00) and positively correlated to available nitrogen (r=0.449**, p=0.006) and available phosphorous (r=0.387*, p=0.020). Clay was positively correlated to available nitrogen (r=0.734**, p=0.00) and available phosphorus (r=0.857**, p=0.00) and negatively correlated to sand (r=-0.690**, p=0.00) and temperature (r=-0.361*, p=0.031). Soil respiration was positively correlated to moisture (r=0.838**; p=0.00), temperature (r=0.966**; p=0.00), bulk density (r=0.683**; p=0.00), organic carbon (r=0.672**; p=0.00), available potassium (r=0.662**, p=0.00) and sand (r=0.649**; p=0.00), soil organic carbon density (r=0.349*, p=0.03) and negatively correlated to available nitrogen(r=-0.865**, p-0.00), available phosphorus (r=-0.581**, p=0.00), silt (r=-0.594**, p=0.00) and clay (r=-0.458**, p=0.00).

In the second year, bulk density was positively correlated to moisture (r=0.681) and temperature (r=0.751) at p<0.01. Organic carbon is positively correlated to moisture (r=0.656), temperature (r=0.640), and bulk density (r=0.836) at p<0.01 level. SOCD was positively correlated to moisture (r=0.626), bulk density (r=0.665), and OC (r=0.752) at p<0.01 level and negatively correlated to *p*H (r=-0.503) at 0.01 level. Available N is negatively correlated to moisture (r=-0.355) and temperature (r=-0.755) at p<0.01 level. Available P was profoundly correlated to pH (r=0.467), temperature (r=0.554), bulk density (r=0.564), OC (r=0.468) at p<0.01, and moisture (r=0.398) at p<0.05 level. Available K was observed to be positively correlated to moisture (r=0.826), temperature (r=0.632), bulk density (r=0.749), OC (r=0.703), SOCD (r=0.688) and available phosphorus (r=0.471) at p<0.01 level. The sand was profoundly correlated to temperature (r=0.680) at p<0.01, bulk density (r=0.330) at p<0.05 level, and negatively correlated to available nitrogen (r=-0.790) at p<0.01. The silt was observed to be correlated to available nitrogen (r=0.434) at p<0.01 and negatively correlated to temperature (r=-0.666), bulk density (r=-0.581), available phosphorus (r=-0.428) and sand (r=-0.782) at p<0.01 level. Clay was observed to be positively correlated to available nitrogen (r=0.746) and available phosphorus (r=0.495) at p<0.01 level and negatively correlated to sand (r=-0.675) at p<0.01 level. SR was observed to be positively correlated to moisture (r=0.781), temperature (r=0.939), bulk density (r=0.783), OC (r=0.711), available potassium (r=0.772), and sand (r=0.630) at p<0.01 level and SOCD (r=0.419), available phosphorus (r=0.398) at p<0.05 level, negatively correlated to available nitrogen (r=-0.752), silt (r=-0.550) and clay (r=-0.344). WHC was negatively correlated to temperature (r=-0.406) at p<0.05 level and with bulk density (r=-0.426) and OC (r=-0.571) at p<0.01 level.

Table 5.16: Correlation of soil properties in Bamboo forest of Longkhum of 2018-2019

Para meter	pH	Moisture	Temp.	B.D	OC	SOC	AN	AP	AK	SAND	SILT	CLAY	SR	WHC
pH	1													
Moist ure	.076 .659	1												
Temp.	.220 .198	.762** .000	1											
B.D	.492** .002	.524** .001	.760** .000	1										
OC	.439** .007	.474** .004	.717** .000	.865** .000	1									
SOCD	.457** .005	.391* .018	.369* .027	.667** .000	.744** .000	1								
AN	.137 .427	-.316 .060	-.663** .000	-.161 .347	-.207 .225	.241 .156	1							
AP	.203 .235	-.319 .058	-.519** .001	-.001 .993	.001 .996	.224 .189	.886** .000	1						
AK	.409* .013	.769** .000	.674** .000	.773** .000	.731** .000	.740** .000	.049 .778	.046 .790	1					
SAND	-.054 .756	.409* .013	.662** .000	.193 .260	.132 .443	-.097 .574	-.826** .000	-.845* .000*	.157 .361	1				
SILT	-.155 .367	-.469** .004	-.682** .000	-.528** .001	-.318 .059	-.143 .404	.449** .006	.387* .020	-.442** .007	-.760** .000	1			
CLA Y	.144 .402	-.259 .127	-.361* .031	.159 .354	-.007 .966	.145 .397	.734** .000	.857** .000	.029 .869	-.690** .000	.101 .557	1		
SR	.171 .319	.838** .000	.966** .000	.683** .000	.672** .000	.349* .037	-.685** .000	-.581** .000	.662** .000	.649** .000	-.594** .000	-.458** .005	1	
WHC	-.216 .206	-.635** .000	-.878** .000	-.722** .000	-.721** .000	-.327 .052	.527** .001	.408* .014	-.678** .000	-.444** .007	.477** .003	.270 .112	-.857** .000	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 5.17: Corelation of soil properties in Bamboo forest Longkhum during 2021-2022

Parameter	pH	Moisture	Temp.	B.D	OC	SOC	AN	AP	AK	SAND	SILT	CLAY	SR	WHC
pH	1													
Moisture	-.134 .435	1												
Temp.	.231 .175	.623** .000	1											
B.D	-.065 .708	.681** .000	.751** .000	1										
OC	-.143 .405	.656** .000	.640** .000	.836** .000	1									
SOCD	-.503** .002	.626** .000	.212 .215	.665** .000	.752** .000	1								
AN	-.130 .450	-.355* .034	-.755** .000	-.272 .108	-.219 .199	.152 .377	1							
AP	.467** .004	.398* 016	.554** .000	.564** .000	.468** .004	.159 .353	.039 .819	1						
AK	-.113 .511	.826** .000	.632** .000	.749** .000	.703** .000	.688** .000	-.295 .080	.471** .004	1					
SAND	.069 .689	.187 .274	.680** .000	.330* .049	.093 .589	-.071 .683	-.790** .000	.009 .959	.172 .316	1				
SILT	-.197 .249	-.288 .089	-.666** .000	-.518** .001	-.191 .266	-.042 .810	.434** .008	-.428** .009	-.188 .271	-.782** .000	1			
CLAY	.114 .508	.060 .728	-.290 .086	.092 .593	.097 .575	.180 .294	.746** .000	.495** .002	-.042 .808	-.675** .000	.068 .694	1		
SR	.028 .873	.781** .000	.939** .000	.783** .000	.711** .000	.419* .011	-.752** .000	.398* .016	.772** .000	.630** .000	- .550** .001	-.344* .040	1	
WHC	-.104 .547	-.066 .704	-.406* .014	-.426** .010	-.571** .000	-.251 .141	.242 .155	-.180 .295	-.276 .103	-.072 .676	.065 .706	.037 .831	-.370* .027	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Correlations among the soil physical and chemical characters in bamboo forest of Chungtia reveals that moisture was positively correlated to pH (r=0.776) at $p<0.01$. At $p<0.01$ level, the temperature was positively correlated to *p*H (r=0.575) and moisture (r=0.841). Bulk density was correlated to moisture (r=0.443) and temperature (r=0.546) at $p<0.01$. OC was highly correlated to *p*H (r=0.497), moisture (r=0.592), temperature (r=0.535 and bulk density (r=0.759) at $p<0.01$. At $p<0.01$ level, SOCD was positively correlated to *p*H (0.442), moisture (r=0.602), temperature (r=0.615), bulk density (r=0.869), and OC (r=0.904) at $p<0.05$ level. At $p<0.01$ level, available nitrogen was observed to be negatively correlated to *p*H (r=-0.530), moisture (r=-0.735), and temperature (r=-0.717).Available potassium was recorded to be positively correlated to pH (r=0.722), moisture (r=0.876), temperature (r=0.657), bulk density (r=0.638), OC (r=0.796) and SOCD (r=0.723) at $p<0.01$ and negatively correlated to available N (r=-0.350) at $p<0.05$). The sand was positively correlated to moisture (r=0.454), temperature (r=0.441) at $p<0.05$ level, and available P (r=0.339) at $p<0.05$ and negatively correlated to available N (r=-0.785) at $p<0.01$ level. The silt was negatively correlated to available P (r=-0.644) and sand (r=-0.844) at $p<0.01$ level and positively correlated to available N (r=0.395) at $p<0.05$. At $p<0.01$ level, clay was found to be positively correlated to available N (r=0.928) and negatively correlated to *p*H (r=-0.497), moisture (r=-0.726), temperature (r=-0.580) and sand (r=-0.686) and negatively correlated to available K (r=-0.374) at p<0.05. At p<0.01, SR was positively correlated to *p*H (r=0.691), moisture (r=0.939), temperature (r=0.876), bulk density (r=0.428), OC (r=0.575), SOC)r=0.647) and available K (r=0.736) and negatively correlated to available N (r=-0.780) and clay (r=-0.781) and positively correlated to sand (r=0.381) at p<0.05 level. WHC was positively correlated to available N (r=0.765) and clay (r=0.792) and negatively correlated to pH (r=-0.545), moisture (r=-0.860), temperature (r=-0.823), bulk density (r=-0.574), SOC (r=-0.574), available K (r=-0.643) and SR (r=-0.918) at p<0.01 level. At p<0.05 level, WHC was found to be negatively correlated with OC (r=-0.423) and sand (r=-0.405).

In the second year, at p<0.01 significant level of moisture was positively correlated to *p*H (r=0.621), the temperature was positively related to pH (r=0.600), and moisture (r=0.856), bulk density was positively correlated to temperature (r=0.560), CO was positively correlated to moisture (r=0.627), temperature (r=0.625) and bulk density (r=0.746), SOC was positively correlated to moisture (r=-0.613), temperature (r=0.676), bulk density (r=0.877) and OC (r=0.922). Available nitrogen was negatively correlated to pH (r=-0.463), moisture (r=-0.712), and temperature (r=-0.656). Available P was positively correlated to *p*H (r=0.531), moisture (r=0.848), temperature (r=0.819), bulk density (r=0.629), OC (r=0.809), and SOC (r=0.741). The sand was positively correlated to moisture (r=0.503) and temperature (r=0.556) and negatively correlated to available N (r=-0.703). The silt was negatively correlated to available P (r=-0.525) and sand (r=-0.862). Clay was correlated to available N (r=0.920) and negatively correlated to *p*H (r=-0.439), moisture (r=-0.799), temperature (r=-0.587), and sand (r=-0.669). SR was positively correlated to pH (r=0.581), moisture (r=0.939), temperature (r=0.827), bulk density (r=0.468), OC (r=0.653), SOC (R=0.684) and negatively correlated to available N (r=-0.733) and clay (r=-0.768). WHC was positively correlated to available N (r=0.779) and clay (r=0.792) and negatively correlated to *p*H (r=-0.372), moisture (r=-0.821), temperature (r=-0.743), OC (r=-0.459), SOC (r=-0.532), available K (r=-0.596) and SR (r=-0.852).

At $p<0.05$, bulk density was positively correlated to moisture (r=0.412), OC was positively correlated to *p*H (r=0.342), and sand was positively correlated to pH (r=0.361) and available K (r=0.336). The silt was positively correlated to available N (r=0.333) and negatively correlated to temperature(r=-0.356). Clay was positively correlated to available P (r=0.410) and negatively correlated to available K (r=-0.411). SR was positively correlated to sand (r=0.337). WHC was negatively correlated to *p*H (r=-0.372), bulk density (r=-0.397), and sand (r=-0.411).

Table 5.18: Corelation of soil properties of Bamboo forest in Chungtia during 2018-2019

Parameter	pH	Moisture	Temp.	B.D	OC	SOC	AN	AP	AK	SAND	SILT	CLAY	SR	WHC
pH	1													
Moisture	.776** .000	1												
Temp.	.575** .000	.841** .000	1											
B.D	.310 .066	.443** .007	.546** .001	1										
OC	.497** .002	.592** .000	.535** .001	.759** .000	1									
SOCD	.442** .007	.602** .000	.615** .000	.869** .000	.904** .000	1								
AN	-.530** .001	-.735** .000	-.717** .000	.003 .986	-.077 .656	-.165 .335	1							
AP	.049 .775	.097 .575	.269 .112	.261 .124	.055 .748	-.021 .902	.003 .987	1						
AK	.722** .000	.876** .000	.657** .000	.638** .000	.796** .000	.723** .000	-.350* .036	.198 .247	1					
SAND	.269 .112	.454** .005	.441** .007	-.093 .590	-.108 .530	-.057 .743	-.785** .000	.339* .043	.187 .275	1				
SILT	-.006 .970	-.093 .588	-.177 .302	.060 .729	.208 .224	.186 .277	.395* .017	-.644** .000	.015 .930	-.844** .000	1			
CLAY	-.497** .002	-.726** .000	-.580** .000	.093 .589	-.083 .630	-.154 .371	.928** .000	.261 .125	-.374* .025	-.686** .000	.211 .216	1		
SR	.691** .000	.939** .000	.876** .000	.428** .009	.575** .000	.647** .000	-.780** .000	-.120 .485	.736** .000	.381* .022	.045 .792	-.781** .000	1	
WHC	-.545** .001	-.860** .000	-.823** .000	-.405* .014	-.423* .010	-.574** .000	.765** .000	.125 .467	-.643** .000	-.405* .014	-.022 .901	.792** .000	-.918** .000	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 5.19: Corelation of soil properties of Bamboo forest in Chungtia during 2021-2022

Parameter	pH	Moisture	Temp.	B.D	OC	SOC	AN	AP	AK	SAND	SILT	CLAY	SR	WHC
***p*H**	1													
Moisture	.621** .000	1												
Temp.	.600** .000	.856** .000	1											
B.D	.179 .297	.412* .012	.560** .000	1										
OC	.342* .041	.627** .000	.625** .000	.746** .000	1									
SOCD	.318 .059	.613** .000	.676** .000	.877** .000	.922** .000	1								
AN	-.463** .004	-.712** .000	-.656** .000	-.011 .948	-.060 .727	-.163 .344	1							
AP	.084 .628	-.129 .454	.220 .196	.089 .608	.000 1.000	-.068 .695	.265 .119	1						
AK	.531** .001	.848** .000	.819** .000	.629** .000	.809** .000	.741** .000	-.303 .073	.236 .166	1					
SAND	.361* .031	.503** .002	.556** .000	-.101 .556	-.059 .730	-.008 .961	-.703** .000	.221 .196	.336* .045	1				
SILT	-.185 .279	-.142 .408	-.356* .033	.100 .560	.173 .314	.100 .561	.333* .047	-.525** .001	-.169 .323	-.862** .000	1			
CLAY	-.439** .007	-.799** .000	-.587** .000	-.003 .988	-.162 .345	-.200 .241	.920** .000	.410* .013	-.411* .013	-.669** .000	.226 .184	1		
SR	.581** .000	.939** .000	.827** .000	.468** .004	.653** .000	.684** .000	-.733** .000	-.305 .071	.723** .000	.337* .045	.034 .842	-.768** .000	1	
WHC	-.372* .025	-.821** .000	-.743** .000	-.397* .017	-.459** .005	-.532** .001	.779** .000	.222 .193	-.596** .000	-.411* .013	.042 .809	.792** .000	-.852** .000	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Correlations among the soil physical and chemical characters in bamboo forest of Tuli reveals that at $p<0.01$ significant level, moisture was positively correlated to *p*H (r=0.810), and the temperature was significantly correlated to *p*H (r=0.705) and moisture(r=0.917). Bulk density was correlated to temperature (r=0.578). OC was positively correlated to moisture (r=0.436), temperature (r=0.589), and bulk density (r=0.817). SOC was positively correlated to moisture (r=0.436), temperature (r=0.589), and bulk density (r=0.817). Available P was positively correlated to available N (r=0.450). Available K was positively correlated to *p*H (r=0.428), moisture (r=0.761), temperature (r=0.795), bulk density (r=0.804), OC (r=0.836), SOC (r=0.915) and available P (r=0.426). Sand is positively correlated to *p*H (r=0.713), moisture (r=0.708), and temperature (r=0.653) and negatively correlated to available N (r=-0.731). The silt was observed to be negatively correlated to sand (r=-0.597). Clay was negatively correlated to *p*H (r=-0.735), moisture (r=-0.786), temperature (r=-0.711), and sand (r=-0.937). SR was positively correlated to *p*H (r=0.793), moisture (r=0.883), temperature (r=0.947), SOC (r=0.482), available K (r=0.641), and sand (r=0.713) and negatively correlated to available n (r=-0.548) and clay (r=-0.742). WHC was positively correlated to available (r=0.536), clay (r=0.830) and negatively correlated to *p*H (r=-0762), moisture (r=-0.886), temperature (r=-0.834), available K (r=-0.501), sand (r=-0.760) and SR (r=-882).

At $p<0.05$, bulk density was positively correlated to moisture (r=0.389), and available N was negatively correlated to *p*H (r=-0.404), moisture (r=-0.301), and temperature (r=-0.409). Available P was positively correlated to SOC (r=0.331) and available N (r=0.450). The silt was positively correlated to available N (r=0.371). SR was positively correlated to bulk density (r=0.424) and OC (r=0.372). WHC was negatively correlated to SOC (r=-0.393), respectively.

In the second year, at $p<0.01$ significant level, moisture was positively correlated to *p*H (r=0.691), and the temperature was positively correlated to *p*H (r=0.498) and moisture (r=0.767). OC was positively correlated to temperature (r=0.606), SOC was positively correlated to temperature (r=0.611), bulk density (r=0.744), and OC (r=0.917). Available nitrogen was negatively correlated to *p*H (r=-0.608), moisture (r=-0.606), and temperature (r=-0.609). Available K was positively correlated to moisture (r=0.634), temperature (r=0.755), and bulk density (r=0.583). OC (r=0.804), SOC (r=0.75), and available P (r=0.585). The sand was positively correlated to *p*H (r=0.644), moisture (r=0.502), and temperature (r=0.770) and negatively correlated to available N (r=-0.755). Clay was observed to be significantly correlated to available N (r=0.771) and negatively correlated to *p*H (r=-0.735), moisture (r=-0.563), temperature (r=-0.753), and sand (r=-0.926). SR was positively correlated to pH (r=0.604), moisture (r=0.899), temperature (r=0.948), OC (r=0.453), SOC (r=0.510) available K (r=0.682), sand (r=0.730). WHC was positively correlated to available N (r=0.695), and clay (r=0.758) and negatively correlated to *p*H (r=-0.717), moisture (r=-0.812), temperature (r=-0.801), SOC (r=-0.435), available K (r=-0.546), sand (r=-0.747) and SR (r=-0.871).

At p<0.05 significant level, bulk density was positively correlated to temperature (r=0.407) and negatively correlated to *p*H (r=-0.331). SOC was observed to be positively correlated to moisture (r=0.389). Available P was positively correlated to bulk density (r=0.349) and OC (r=0.372), and SR was positively correlated to available P (r=0.411), respectively.

Table 5.20: Correlation of soil properties of Bamboo forest in Tuli during 2018-2019

Parameter	pH	Moisture	Temp.	B.D	OC	SOC	AN	AP	AK	SAND	SILT	CLAY	SR	WHC
pH	1													
Moisture	.810** .000	1												
Temp.	.705** .000	.917** .000	1											
B.D	.034 .845	.389* .019	.578** .000	1										
OC	.063 .715	.436** 008	.589** .000	.817** .000	1									
SOCD	.196 .252	.575** .000	.665** .000	.849** .000	.915** .000	1								
AN	-.404* .015	-.301 .074	-.409* .013	.174 .311	.229 .180	.253 .136	1							
AP	.182 .289	.214 .210	.143 .405	.224 .188	.139 .418	.331* .048	.450** .006	1						
AK	.428** .009	.761** .000	.795** .000	.804** .000	.836** .000	.915** .000	.194 .256	.426** .010	1					
SAND	.713** .000	.708** .000	.653** .000	-.058 .738	-.064 .711	-.012 .946	-.731** .000	-.278 .101	.190 .268	1				
SILT	-.270 .111	-.138 .424	-.155 .367	.114 .507	.267 .116	.230 .178	.371* .026	.086 .619	.083 .632	-.597** .000	1			
CLAY	-.735** .000	-.786** .000	-.711** .000	.035 .840	-.030 .863	-.077 .657	.721** .000	.285 .092	-.256 .132	-.937** .000	.282 .096	1		
SR	.793** .000	.883** .000	.947** .000	.424* .010	.372* .026	.482** .003	-.548** .001	.212 .214	.641** .000	.713** .000	-.253 .137	-.742** .000	1	
WHC	-.762** .000	-.886** .000	-.834** .000	-.218 .202	-.194 .257	-.393* .018	.536** .001	-.141 .411	-.501** .002	-.760** .000	.184 .283	.830** .000	-.882** .000	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 5.21: Corelation of soil properties of Bamboo forest in Tuli during 2021-2022

Parameter	pH	Moisture	Temp.	B.D	OC	SOC	AN	AP	AK	SAND	SILT	CLAY	SR	WHC
pH	1													
Moisture	.691** .000	1												
Temp.	.498** .002	.767** .000	1											
B.D	-.331* .048	.161 .349	.407* .014	1										
OC	-.222 .193	.271 .110	.606** .000	.753** .000	1									
SOCD	-.057 .741	.389* .019	.611** .000	.744** .000	.917** .000	1								
AN	-.608** .000	-.606** .000	-.609** .000	.156 .362	.102 .553	.126 .463	1							
AP	.167 .331	.672** .000	.277 .102	.349* .037	.372* .025	.518** .001	.071 .680	1						
AK	.247 .147	.634** .000	.755** .000	.583** .000	.804** .000	.875** .000	-.012 .944	.585** .000	1					
SAND	.644** .000	.502** .002	.770** .000	-.096 .579	.116 .502	.129 .452	-.755** .000	-.242 .156	.306 .070	1				
SILT	.198 .248	.129 .454	-.088 .611	-.154 .371	-.151 .380	-.111 .517	-.002 .992	.181 .291	-.064 .712	-.245 .150	1			
CLAY	-.735** .000	-.563** .000	-.753** .000	.156 .362	-.060 .726	-.090 .602	.771** .000	.176 .305	-.289 .087	-.926** .000	-.139 .418	1		
SR	.604** .000	.899** .000	.948** .000	.328 .051	.453** .005	.510** .001	-.704** .000	.411* .013	.682** .000	.730** .000	-.061 .726	-.722** .000	1	
WHC	-.717** .000	-.812** .000	-.801** .000	-.097 .573	-.276 .103	-.435** .008	.695** .000	-.306 .070	-.546** .001	-.747** .000	.011 .949	.758** .000	- .871** .000	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

5.4. Discussion:

5.4.1. Seasonal variation in soil physical parameters of selected Bamboo Forests:

The analysis of soil physicochemical variance showed that all the soil parameters differed seasonally except for sand, clay, silt and bulk density in all the bamboo forests. This may be the result of biotic factors, such as organic matter from litterfall, and environmental factors, such as rainfall, atmospheric humidity, atmospheric temperature, wind, erosion, thermal regulation, nutrients cycles, and regional conditions, as these factors play a significant role in the cumulative function of the soil at different seasons.

The summer season has a modest rise in soil moisture, OC, SOD, bulk density, and soil respiration compared to the other seasons, in the bamboo forest of Longkhum, Chungtia, and Tuli. Available nitrogen was higher in winter, while available phosphorus was higher in spring. The frequent availability of soil moisture can explain such findings, warmer temperatures coupled with higher levels of organic matter and microbial activity in the soil during the rainy summer and post-monsoon autumn seasons of the year in the study area; similar trends were reported by Leishangthem and Singh (2021) in soil from a tropical forest in Nagaland. Both the increased rate of mineralization and the availability of rainfall are typically to blame for the variation in soil parameters (Grogan *et al*., 2003; Ahmad *et al*., 2011).

5.4.2. Soil Physical Characteristics:

5.4.2.1. Soil texture:

The soil texture in the bamboo stands for Longkhum and Chungtia were found to have more significant sand percentages. The presence of more silt and clay in Tuli suggests that the soil beneath the forest was better at storing and making available nutrients to plants (Rawat *et al*., 2021). In every bamboo forest, the soil physical characteristic known as clay diminishes as soil depth rises. As a substrate for organic matter and water retention, clay was much more abundant in Tuli throughout the year. It influences nutritional composition by sequestering and stabilizing nutrients in bamboo forests, leading to higher soil fertility.

Table 5.14 results from a one-way ANOVA study revealed a significant influence of sampling season ($p<0.05$). According to the two-way ANOVA results (Table: 5.15), there was a significant difference between the study sites in the distribution of soil textural components such as sand, silt, and clay ($p<0.01$). The correlation data shows that the sand was substantially associated ($p<0.05$ and $p<0.01$) with *p*H, soil moisture, and temperature, and their association was strong and positive. The increased moisture caused by more rainfall and a warmer summer climate in the current study may be the source of the greater sand percentage throughout the summer. There was a significant positive and negative correlation between silt and *p*H, bulk density, moisture, temperature, SOC, available N, available P, available K, sand and clay, clay showing a significant positive correlation with available N, available P, available K and significant negative correlation with *p*H, temperature, and moisture. Sand showed a positive correlation with soil pH, temperature, and moisture.

In contrast, sand showed a negative correlation with available N and available P. Significant positive correlations had been found between soil respiration and *p*H, moisture, bulk density, temperature, OC, SOCD, available N, available K, and sand. In contrast, negative correlations have been found with silt and clay. In the current study, WHC was connected favorably with available N, P, silt, and clay and negatively with *p*H, moisture, temperature, bulk density, OC, SOC, K, sand, and SR. The weathering of rocks, pebbles, and stones can also modify the soil texture over time, so our study showed a higher percentage of soil with a sand texture (Foth, 1990; Brady and Weil, 2002).

5.4.2.2. Soil Moisture:

According to Rawat *et al*., (2021), soil moisture affects microbial activity, which affects the amount of organic carbon in the soil. Because variations in soil moisture content can affect bamboo productivity, clump development, the availability of soil nutrients, the formation of the bamboo canopy, and the diversity of bamboo species, it is crucial to maintain an ideal moisture content in the soil so that bamboo can easily absorb water. In all the study sites, soil moisture content was found to be highest in the summer and lowest in the winter during the study period. This is because there was more precipitation in the summer and less in the winter. The amount of moisture in the soil reduces with increasing soil depth and with increasing altitude. Since gravity causes water to flow downward, steeper slopes often contain less soil moisture than flatter ones. Kumar *et al*., reported a similar outcome (2010). This was further ascertained by the significantly positive correlation (p<0.01) between soil moisture, soil temperature, and bulk density in all the sites.

5.4.2.3. Soil temperature:

Many chemical and biological activities are regulated by soil temperature, a significant soil attribute. The air temperature near the ground, soil depth, bamboo root metabolism, and bacteria are all factors that affect the surface soil temperature (Kasper and Bland, 1992). The rate of organic matter breakdown, mineralization of different organic components, and variations in solar radiation and energy traveling through the soil surface may all contribute to its seasonal, monthly, and daily variations (Onwuka, 2016). The temperature of the soil varied significantly in all the bamboo forests throughout the seasons. Due to the influence of greater air temperatures, summertime in all of the sites had the highest soil temperatures recorded. At the same time, the onset of the chilly winter months saw a progressive decline in soil temperatures. Since the deeper layers are less exposed to sunlight, soil temperature falls with depth in all the bamboo forests, consistent with Leishangthem and Singh's soil research in tropical forests from 2021. The interaction effect for soil temperature between the research site and season was similarly significant ($p<0.01$).

5.4.2.4. Bulk density:

The study revealed that bulk density increases with soil depth in all the bamboo forest and decreases with the increase in altitude. The findings suggest that as soil depth increases, so does soil compactness. The impacts of the weight of the underlying soil and the associated decrease in the quantity of soil organic matter are highlighted by the propensity of bulk density to increase with depth (Brady and Weil, 2002). Because soil organic matter is higher in the upper surface than the lower sub-surface layer, bulk density rises as soil depth increases. “At all the bamboo plantations in Northern Mindanao, the Philippines, the bulk density values of the soil ranged from 1.11 g/cm^3 to 1.59 g/cm^3” Pongon *et al*., (2016). “The soil becomes porous and less compacted due to organic matter and bamboo roots in the upper layer, ultimately promoting soil fertility” Tripathi and Singh (1994), Embaye *et al*., (2005), Nath (2008), Handique (2011), Nath *et al*., (2016a), Tripathi *et al*., 2005, Tripathi *et al*., and Xu *et al*., 2018). Because to the significant rainfall, bulk density was higher in the summer and higher at lower elevations (Tuli). Altitude increases cause a drop in soil bulk density, which may be caused by decreasing soil organic matter and pore space. Imtimongla *et al*., reported a similar outcome (2021).

Table 5.13's results from a one-way ANOVA study revealed a significant influence of sampling season (*p*<0.05). The results of the two-way ANOVA (Table 5.14), which considered the interaction between site and season, revealed a significant difference. According to correlation data, moisture content and temperature at the study sites were substantially associated (*p*<0.05 and *p*<0.01) with bulk density in both years.

5.4.2.5. Soil respiration:

According to Hibbard *et al*., (2005), the complicated biogeochemical process of soil respiration is closely related to ecosystem production, leaf area index, and soil fertility, demonstrating a linkage between carbon dioxide uptake by vegetation and emission from the soil (Bahn *et al*., 2008). In both years, soil respiration exhibits a distinct seasonal pattern, peaking in the summer, followed by the fall, and toughing in the winter. The soil respiration rate is influenced by the temperature at various altitudes and soil depths, with summer having the highest rate and winter having the lowest. The soil depth and altitude have an impact on SR's seasonal volatility. Tang *et al*., (2016) and Song *et al*., (2016) revealed similar findings in Moso bamboo frost in subtropical China (2013). SR was highest in the 0–10 cm depth range and subsequently decreased, indicating that the organic layer is where most of the respiration occurs (Davidson *et al*., 2006). According to variation analysis and correlation results, temperature, moisture, and organic carbon (OC) drives soil respiration at *p*<0.01.

5.4.2.6. Water holding capacity:

For every region under study, it was discovered that the soil depth increased the water retention capacity. This may be because silt and clay particles increase with soil depth while sand particles decrease, improving the soil's capacity to hold water. The amount of organic matter in the soil rises as altitude falls, which may also have a more significant impact on the ability of the soil to hold water. Nath made similar reports as well (2008). According to Birmingham (2003), the water retention capacity was the most significant texture-dependent attribute. More SOC was accumulated from the litter mass at lower elevations, affecting the soil's WHC (Nath *et al*., 2015a). WHC were significant (p<0.01) in all the bamboo forest and in all the season. At all the sites, WHC was discovered to be positively connected with soil respiration and clay in both years.

5.4.3. Soil Chemical Properties:

5.4.3.1. Soil *p*H:

The results of a study on soil *p*H showed that all soil depths had extremely acidic soil samples and that altitude and soil depth both affect *p*H. The distribution of soil organic matter at various depths and altitudes may be connected to the *p*H decreasing with depth and rising with height. Similar studies were also published by Kleinhenz and Midmore, Cai and Wang (1985), Nath (2008), and (2001). In Japan, *Sasa kurilensis* bamboo was grown in woods with highly acidic soil (Tripathi *et al*., 2005). “In Japan's mountainous regions, bamboo soils were discovered to have a *p*H of 4.35± 0.53"- Takamatsu *et al*., 1997.

At all of the study sites, there was a substantial seasonal change in soil pH (*p*<0.01), with higher soil *p*H values observed in the fall and summer and lower values throughout the winter. The current investigation also found a strong positive association between soil *p*H, temperature, and moisture (*p*<0.01). Regarding soil acidity, bamboo forest of Longkhum had the highest value, followed by the bamboo forest in Chungtia and Tuli.

5.4.3.2. Soil organic carbon:

For all bamboo forest at all three sites, it was discovered that the soil organic carbon decreased with soil depth and increased with altitude. This finding may be related to litter deposition in the upper surface layer. The surface soil becomes rich in SOM and SOC due to the decomposition and mineralization of this litter, which also contributes to organic compounds. The SOM and SOC rise as a result of increased litterfall and decomposition. At increasing soil depth, the SOC content dropped (Tripathi *et al*., 2005); (Xu *et al*., 2018). According to Wang et al., (2002), root exudates, secondary metabolites, root decrepitude, and mortality significantly impact the surface SOC content (Mora *et al*., 2014; Leppalammi-Kujansuu *et al*., 2014). Due to decreased root quality and litter transference in deeper soil layers, the effects of litter and roots on

SOC grow weaker, and SOC declines as soil depth increases (Mora *et al*., 2014). The soil texture also affects the SOC stock (Lal, 2005).

In both years, the peak seasons for soil organic carbon were summer and fall, as opposed to winter and spring, at every study site. This results from the high soil temperature, moisture content, and bulk density impacting the pace of organic matter decomposition. ANOVA demonstrated a significant difference in one direction. At the $p<0.01$ level, a two-way ANOVA revealed a significant difference between the seasons, sites, and sites and seasons. According to correlations, SOC was favorably linked with temperature, bulk density, moisture, and *p*H at the p.0.01 level.

5.4.3.3. Soil Carbon Density:

According to Nath et al., 2007, the carbon storage stock (Carbon density Mg ha) is comparatively high in the bamboo forest of Mokokchung 1 district. The difference may be due to the fact that the present study was conducted in a naturally growing bamboo forest, whereas Nath *et al*., 2018 examined bamboo-based home gardens. According to a correlation analysis, SOCD was positively linked with *p*H, bulk density, and OC at a *p*-value of 0.01 and with moisture and temperature at a p-value of 0.05. Season, soil depth, and altitude all exhibited substantial variation in the one- and two-way ANOVA variation analyses.

5.4.3.4. Soil Nutrient Parameters:

The availability of soil nutrients, including nitrogen, phosphorus, and potassium, promotes soil organic matter formation (Six *et al*., 2002). Wibowo and Kasno (2021) also highlighted that the soil's ability to hold onto nitrogen would rise and fall with its concentration of organic matter and proposed that by maintaining the soil's organic matter composition, the soil's nitrogen availability could be maintained. The bamboo forests in Longkhum, Chungtia, and Tuli's mean concentrations of available N, P, and K decreased in the successive strata. Since higher amounts of coarsetextured soils (sand) exhibit a delayed process of nutrient accumulation and are not as effective nutrient accumulators as fine-textured soils, (silt + clay).

In both years, it was discovered that the amount of accessible N was higher at 0–10 cm in the winter and spring months compared to the summer and autumn. This may be due to a drop in soil temperature and moisture content, which slows the pace at which ammonia and nitric acid volatilize (Eldiabani *et al*., 2018). In all three sites, the topsoil (0–10 cm) has the highest nutrient concentration and falls with depth throughout the year as soil organic matter accumulates more quickly. Lkr *et al*., (2020) reported the same trend. At the p<0.05 level, seasonal variation demonstrates a substantial difference. At the p<0.01 level, a two-way ANOVA reveals that the available N reveals a significant difference between the study location, season, site, and season. N in the soil exhibited a negative connection with moisture, temperature, and pH, which was significant at $p<0.01$.

In all of the bamboo forests during the spring seasons of the analyzed years, accessible P levels were high at a soil depth of 0 to 10 cm. Higher bamboo biomass and rooting intensity may have contributed to the increase in soil P by causing the soil's inorganic phosphate to dissolve (Venkatesh *et al*., (2005). One-way and Two-way ANOVA analyses revealed that the differences in soil-accessible P content caused by seasonal variations and soil depth were significant at $p<0.01$. This may be caused by the organic matter accumulated throughout the winter, as phosphorus availability increases as organic matter are added to the soil. At p0.01, available P correlates well with moisture, *p*H, SOC, and available N; at $p<0.05$, it correlates favorably with bulk density and OC. A $p<0.01$ level of significance reveals a negative association between available P and temperature.

In the Mokokchung district, a considerable variation in the amount of K was discovered. The highest value was found in the bamboo forest of Longkhum (86.540.3-465.80.1 kg/hac), the lowest in Tuli (61.510.9-230.40.11 Kg/hac), and the middle value was found in bamboo forest of Chungtia (75.580.18-300.30.8 Kg/hac). From a bamboo forest, a similar outcome was noted by Gaikwad *et al*., in 2022. The fact that available K declines with soil depth and is higher in the summer and fall than in the spring and winter may be attributed to the temperature, *p*H, moisture, and in-situ litter composition. Higher altitudes were shown to produce higher values. One Way and Two Way ANOVA analysis discovered that the differences in soil accessible K content caused by seasonal variations and soil depth were significant at $p<0.01$. Available K positively correlates with *p*H, moisture, temperature, OC, SOCD, and available phosphorus in both years at a significant $p<0.01$ in every study site.

5.5. Conclusion:

The study thus demonstrates that the altitude impact the soil physicochemical properties in bamboo plantations. The study also showed that because sediments are deposited during water runoff, which raise the silt and clay contents and the SOC content, the soil of bamboo forest in Tuli area is better than that in Longkhum and Chungtia areas. With the increase in depth and altitude, the soil's organic carbon content remains consistent in the bamboo forest. So, under the current scenario for climate change mitigation, bamboo plantations offer significant potential for managing soil carbon sinks. More research is necessary to fully grasp the potential of additional bamboo crops in terms of SOC stock and sequestration.

Chapter 6

Vegetative Phenology of Four Dominant Bamboo Species in Mokokchung District, Nagaland

6.1. Introduction

A widely used plant called bamboo is sometimes referred to as the "Green gold of the 21st century" (Tariyal *et al*., 2013). They are a crucial part of the native vegetation in tropical, subtropical, and untamed temperate areas (Boschma and Kwant, 2013). “Bamboo has 1400 species and 88 genera; 80% is only found in Asia, primarily in China, India, and Myanmar” FAO, (2010); Song *et al*., (2011); Chen *et al*., (2009). Compared to other plant species, bamboo grows quickly, reaching heights of up to 45 meters in just six weeks (Aggarwal, 2007). (Mertens *et al*., 2008). Additionally, according to Kamanga *et al*., (2009) and Tesfaye *et al*., (2011), bamboo is connected to social, economic, and ecological values (Lou et al., 2010). The traditional uses of bamboo are mostly found in the construction, cottage industry, handicrafts, food, fuel, and medical industries (INBAR, 2013; EBC, 2016; Taryial, 2016). As a result, bamboo's many applications highlight its potential to strengthen the rural economy (Marsh and Smith, 2007). Because of its rapid growth rate, it plays a crucial part in carbon sequestration together (Lobovikov *et al*., 2009; Yiping *et al*., 2010; Nath *et al*., 2011).

Bamboo phenology is essential for various management, conservation, and research challenges. The effective interactions between biotic and climatic conditions and the adaptation of the various bamboo species through natural selection, which affects the growth phases and propagation of plant species, are what cause the phenomena of plant growth (Nath *et al*., 2008a and Van Schaik *et al*., 1993). A strange and fascinating occurrence, bamboo flowering offers many opportunities for conducting breeding operations (Abe and Shibata, 2014). Most bamboo flowers once during their life cycle (Das *et al*., 2017). Before blossoming, producing seeds, and dying, it grows vegetative for a set amount of time. However, the information on bamboo phenology that is now accessible only covers a few physiognomies, such the emergence of shoots (Banik, 1999; Rao *et al*., 1990; Ueada, 1960), branch initiation, and leaf pattern (Banik, 1999; Lodhiyal *et al*., 1998) (Rao *et al*., 1990). As a result, it is essential to examine bamboo's periodic life cycle to comprehend the species-specific leaf and sheath dynamics and their ecological importance for plant adaptation to growing in the same climatic requirement.

Bamboo is one of the most common plant species in the Mokokchung district of Nagaland. The four most prevalent species in the area are "*Bambusa tulda*, *Bambusa pallida*, *Dendrocalamus asper*, and *Dendrocalamus hamiltonii*" (Walling and Puro, 2018). Despite being a plant that grows quickly, relatively little research has been done on the growth dynamics and behaviors of bamboo species (Ding *et al*., 2011), particularly in Nagaland, where it is spread throughout the state; there is no baseline data on this subject. In order to investigate the growth variance among the four prominent bamboo species in the Mokokchung district of Nagaland, the current study was conducted.

6.2: Methodology

6.2.1: Flowering of *Bambusa jaintiana* Majumdar

B. jaintiana blooms from January to May 2019. To research the blossoming behavior, 100 flowering clumps were randomly selected, and weekly field surveys were conducted regularly.

6.2.2: Culm growth strategies

Each species 30 freshly sprouted culms were chosen at random and given numbered foil labels. June through November 2021 saw the observation of culm growth. The average height of the entire culm was considered to investigate the growth pattern. A total of 120 newly vegetated culms, or 30 from each species with an initial height of 3 to 10 cm, were chosen randomly. Measurements were made using an electronic hypsometer on a daily basis for 30 days, on alternate days for three months, and then once a week during the final phase. The following formulas were used to determine the average height growth rate of each bamboo species across any two time periods:

$$\frac{y2 - y1}{t2 - t1}$$

Where y_1 and y_2 are height at t_2 and t_1 are time

Post-hoc analysis was employed to quantify the specific differences after one-way ANOVA was used to analyze the significant differences.

6.2.3: Vegetative Phenology

The current research aims to understand better how some of the most common bamboo species in Nagaland's Mokokchung area thrive. Phenological studies were conducted on one, two, three, and four-yearolds from each study site. Ten randomly chosen culms from each age group of culms were marked with paint and ribbons. 360 culms in all were chosen for the phenological investigation. Phenological observations were made for sheath appearance, sheath fall, branch emergence, leaf appearance, leaf fall, and change in culm colour every month from January 2019 to December 2019.

6.3: Result

6.3.1: Flowering of Bambusa *jaintiana* Majumdar

B. jaintiana began to bloom in January 2019, and the flowering stage was visible from the next month, February, through May 2019. Regeneration began when the seeds began to fall off between July and September of the same year. According to field research, all clumps flower at the same time, generate seeds, and then die off consequently.

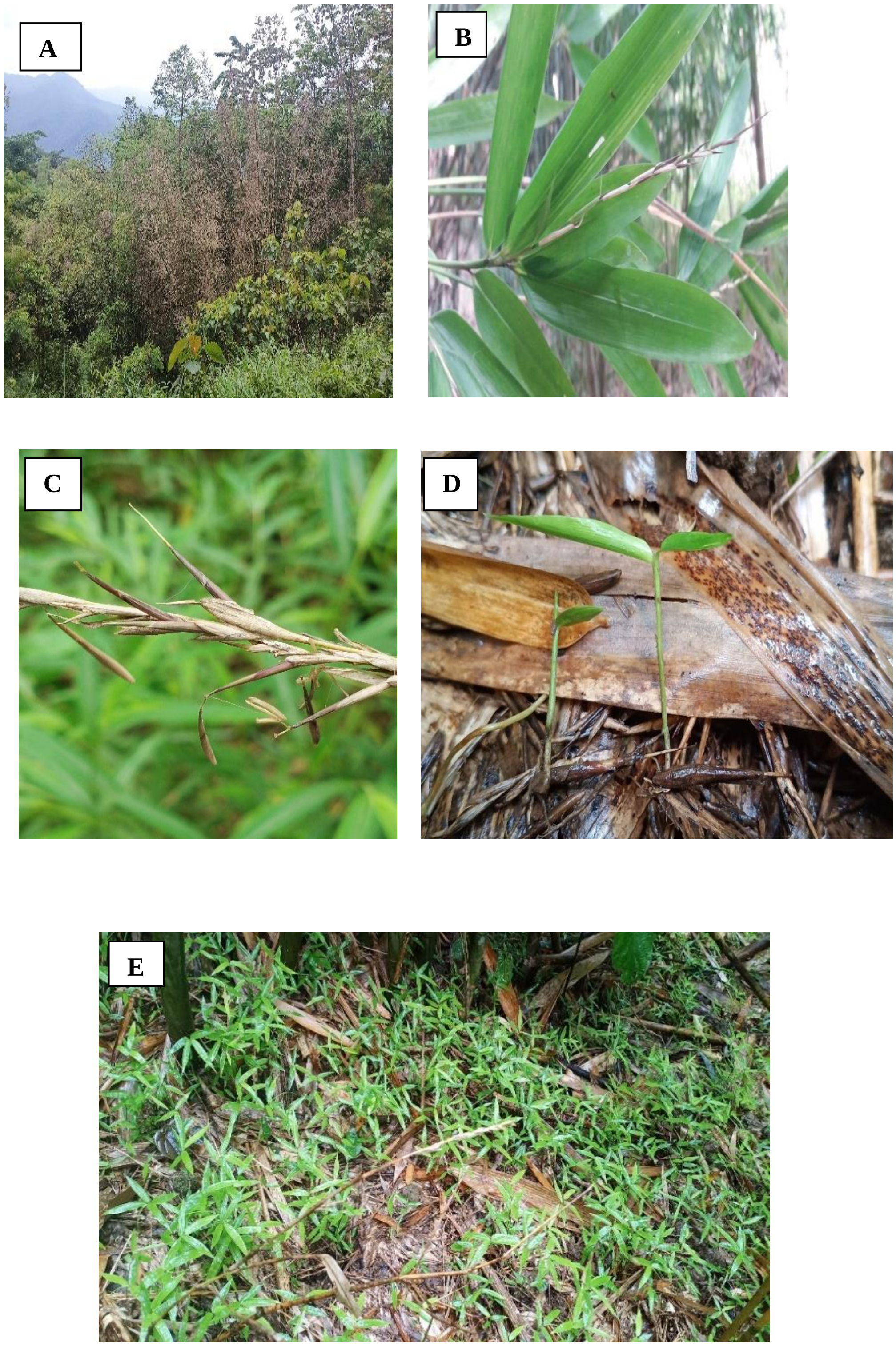
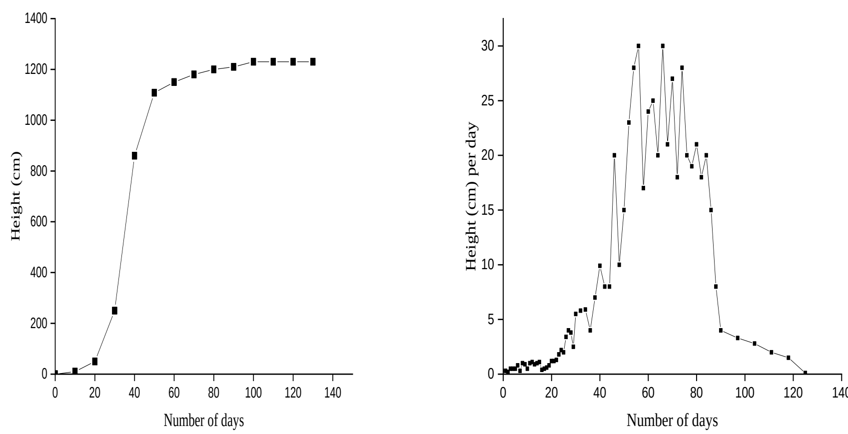


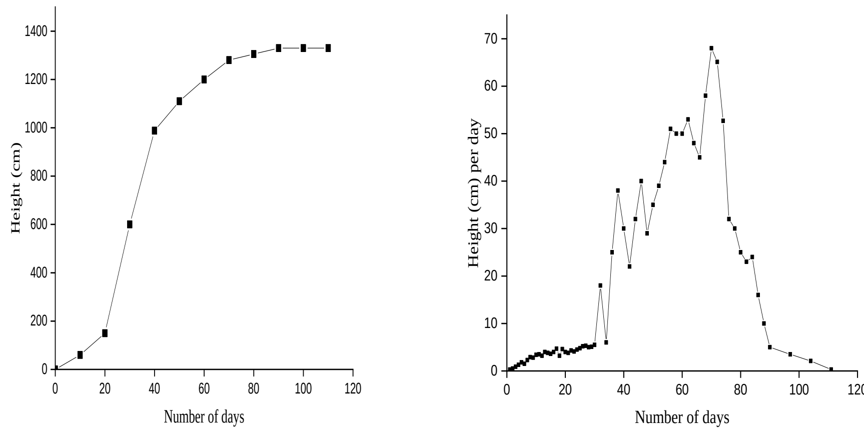
Figure 6.1 : A flowering clump (a), buds (b) spikelet with anther (c), regeneration of seedlings (d& e) of *Bambusa jaintiana* in Mokokchung district, Nagaland.

6.3.2: Culm growth rate

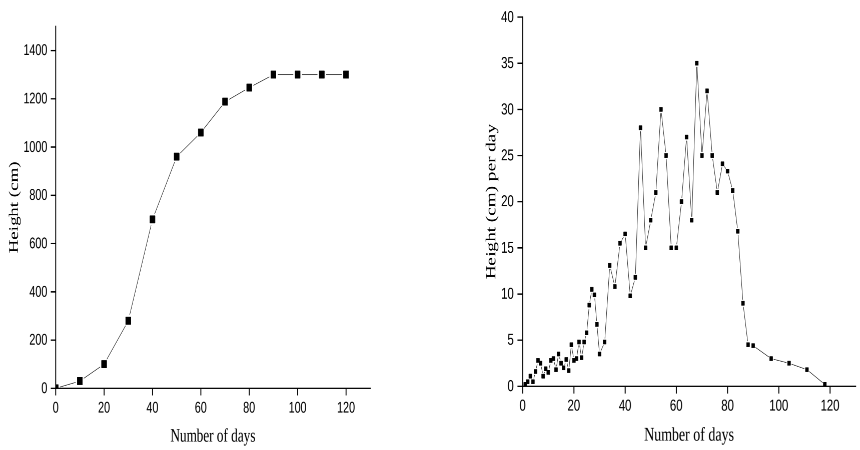
The Nagaland forest contains a prominent intrinsic species of bamboo. The current study aims to support the growth variation of the four most prevalent bamboo species in Mokokchung district, Nagaland, namely Bambusa tulda, Bambusa pallida, Dendrocalamus asper, and Dendrocalamus hamiltonii. The shoots appear in May and reach their most significant height in October. Each species' culm growth curves exhibit a rounded S shape. The growth curves outline the change in bamboo culm size and length at various time intervals. In *B. tulda*, *B. pallida*, *D. asper*, and *D. hamiltonii,* full culm expansion took 110±3, 121±1, 116±2, and 128±2 days, respectively.



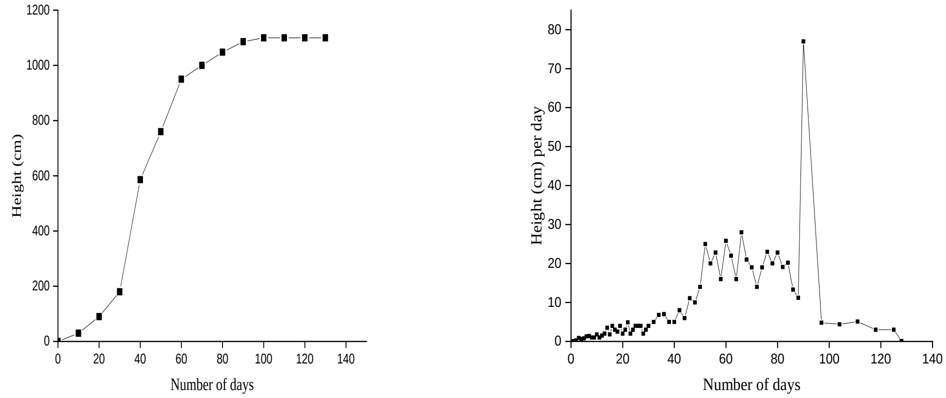
(a) *B. pallida*



(b) *B. tulda*



(c) *D. asper*



(d) *D. hamiltonii*

Figure 6.2: Culm growth curves for four dominant bamboo species

Table 6.1: One-way ANOVA with *p* and F values of the variation of culm growth rate between the dominant species.

	F(3,116)	*p*
Total time period for culm elongation	226.107	**0.001**

Note* Significant level at *p*<0.005

One-way ANOVA was used to analyze the significant differences (Table 6.1) in the total time period of culm elongation among the four dominant species. The result suggests significant variation among the species ($F_{3,116}$=226.107, p<.005). Further, Post-hoc analysis was done to measure the specific differences between the pair of means (Table 6.2).

Table 6.2: Result of Post-hoc Duncan multiple range test of the culm growth rate

B. tulda	110.6333^{a}
D. asper	116.5333^{b}
B. pallida	121.0667^{c}
D. hamiltonii	128.5333^{d}

Note* Values in the same column with different superscripts are significantly different at 5% level by Duncan's multiple range test

6.3.3: Vegetative phenology

With a peak in July and August for all the species, culm appears in *B. pallida* and *B. tulda* from late June to early September, *D. hamiltonii* from May to August, and *D. asper* from July to September. In *B. pallida*, the culm sheath was green with a black tint and covered in thick white hair at the early stages of culm emergence. The sheath of *B. tulda* is yellowish green with black hairs, that of *D. asper* is pale green with dark brown hairs, and that of *D. hamiltonii* is yellowish brown.

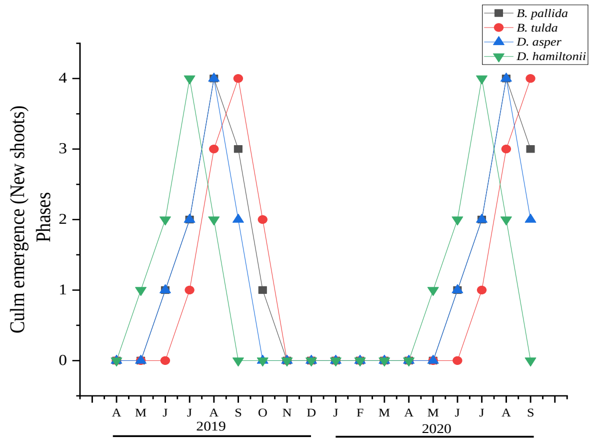


Figure 6.3. Culm emergenceof *B.pallida*, *B.tulda*, *D.asper* and *D.hamiltonii*

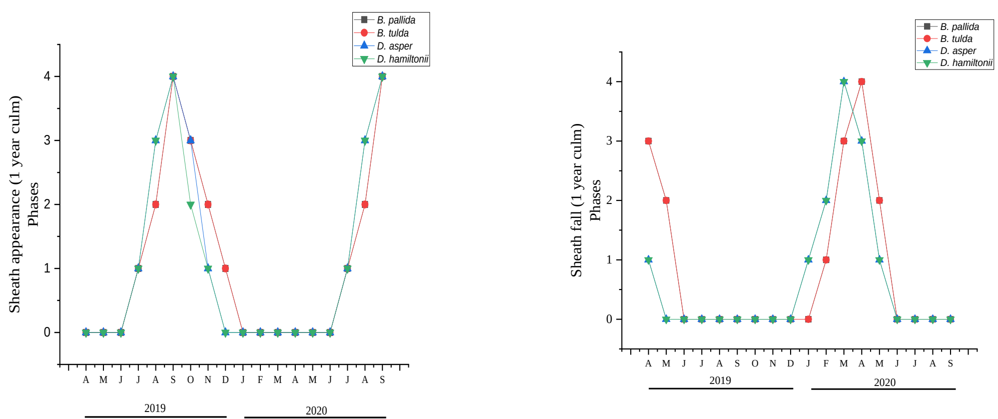


Figure 6.4. Sheath phenology for 1 year old culms of *B.pallida*, *B.tulda*, *D.asper* and *D.hamiltonii* .

Table 6.3. Culm color in different age classes of *B. pallida*, *B. tulda*, *D. asper* and *D. hamiltonii*.

Species	1 year	2 years	3 years	4 years
B.pallida	Olive green covered with white powder	Dark green with some white powder	Dark green with white spots	Yellowish green with black, white, and brown spots
B.tulda	Green covered with white powder	Dark green	Dark green with white patches	Greenish brown with large white patches and brown spots
D.asper	Dull light green	Dull dark green	Dark green with white patches	Brownish green with large white and brown patches
D.hamiltonii	Dull green covered with whitish brown pubescence	Shining dark green	Dark green with white patches	Brownish green with white and black patches

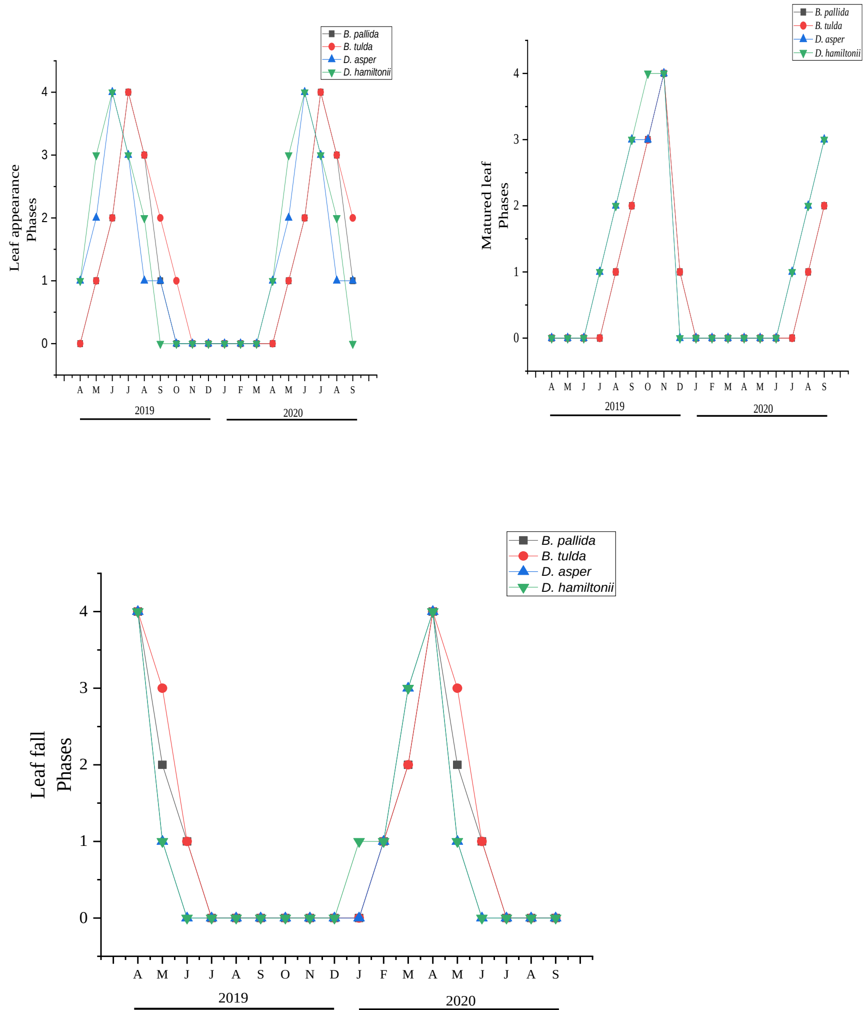


Figure 6.5: Leaf phenology *B.pallida*, *B.tulda*, *D.asper* and *D.hamiltonii*

6.4: Discussion:

Bambusa jaintiana Majumdar is a perennial plant that forms large clumps and grows as high as 1800 meters. It is abundantly available in Arunachal Pradesh, Assam, Meghalaya, Manipur, Nagaland, Bhutan, and Bangladesh (Naithani, 2011). It can be found in the Nagaland districts of Kohima, Phek, Dimapur, Wokah, Peren, and Mokokchung. *B. jaintiana Majumdar* is native from Eastern Nepal to Mayanmar (Clayton et al., 2006). The local name for it in the Mokokchung district is Ana (Ao dialect). This species is utilized to produce handicrafts such as “baskets, mats, and bamboo walls for building land dwellings, fences, and garden accessories” (Walling and Puro, 2018). The culms grow to a height of “3.6 m”, are dull green, and have a base diameter of 0.8 to 3.0 cm (Naithani *et al*., 2010). Young culm sheaths are conical, green when young, and measure “10–14 cm in length and 2–5 cm in width”. The young shoots are a yellowish-green color. The blades are imperfect, conical, and cordate.

Because it is an exceptional and uncommon event in plant life, bamboo flowering is a fascinating phenomenon. The current study's objective is to record the blossoming and regeneration events in *B. jaintiana* Majumdar that took place in 2019 throughout the Mokokchung area of Nagaland, between 26.20 and 26.77º N latitude and 94.29 and 94.76º E longitude. From January 2019 through August 2019, routine fieldwork was done to gather data. In order to chronicle the species' flowering cycle and periodicity, various literary works, as well as interviews with residents of the study area, were conducted. *B. jaintiana* began to blossom in January, and from February through May, the flowering stage was visible. Regeneration began when the seeds began to fall off between July and September during the rainy season (Fig 6.1). According to field research, all clumps flower at the same time, generate seeds and then die off consequently. According to interactions with the local population, the estimated intermediate flowering cycle for this plant is 30-35 years.

According to Alam (1999), it first bloomed in the Chen Hills in Myanmar in 1903, North Cachar Hills in Assam in 1915, and Chittagong and Gazipur in Bangladesh between 1978 and 1986.

With a peak in July and August for all the species, culm appears in *B. pallida* and *B. tulda* from late June to early September, *D. hamiltonii* from May to August, and *D. asper* from July to September. Soft culms are protected in the early growth phase by culm sheaths, which are kept for nearly two years throughout the initial growth phase (Chua *et al*., 1996). The culm sheaths detach off the culms as the culms grow in height and diameter. As the culm grows longer and wider, its color also changes. B. pallida culm initially has an olive green hue and is dusted with white powder, but as it grows, it turns dark green. In *D. asper* and *D. hamiltonii* separately, the color of the culms of *B. tulda* shifts from dull light green to dull dark green, dull light green to dull dark green, and dull green covered in pale brown pubescence to sparkling dark green.

Each species' development curve displays a smooth S shape (Fig 6.2). The growth curves' form represents the culm growth pattern's rate across various time intervals. In *B. tulda*, *B. pallida*, *D. asper*, and *D. hamiltonii*, the total time for culm elongation were 110±3, 121±1, 116±2, and 128±2 days separately. The culm growth graph shows that the culm elongation was modest during the first 30 days and subsequently accelerated until September. All species see growth in culm height of up to 1 to 5 cm each day during the first 30 days. Contrarily, the growth rate was rapid over the following 45-75 days, from late July to late August, ranging from 5 to 30 cm in *B. pallida*, 45 to 73 cm in *B. tulda*, 3.5 to 35 cm in *D. asper*, and 4-28 cm in *D. hamiltonii*. Peak growth occurs during this time (Nandy *et al*., 2004). At this time, nearly 80% of total height in *B. tulda*, 70% in B. pallida, 75% in *D. asper*, and 60% in *D. hamiltonii* are attained. From the second week of September forward, the growth rate steadily decreases to 4-10 cm. All species' growth rates reach their zero phases in the middle of November. The culm stops increasing in height at this point during this time. One-way ANOVA indicates a significant difference.

The study emphasizes that each species' growth pattern varies despite being subject to the same environmental regime. The productivity and sustainable management of bamboo resources can be studied using the findings of our current study.

In *B. pallida*, the culm sheaths are green with a black tint and covered in repressed white hair during the early stages of culm emergence. The sheath of *B. tulda* is yellowish green with black hairs, whereas that of *D. asper* is pale green with dark brown hairs and that of *D. hamiltonii* is yellowish brown. The sheath's green tint takes at least 50 days to stay that way in *B.pallida* and *B.tulda*. All species' sheaths mature to a strawcolored color. As the culm increases in height and diameter, its color changes. In *B.pallida* and *B.tulda*, younger culms are covered in a white powder that vanishes when they reach maturity. Each age group has a unique color of carpet (Table 6.3).

The phenology of leaves varies with species and age groups; Nath *et al*., (2008) described a related phenomenon. In the *D. hamiltonii* and *D. asper* one-year culm, leave initiation takes place from April to July, and after eight months, it stops in February during the windy season. Within 3 to 4 months, the leaves reach their mature state (August-November). In *B. tulda* and *B. pallida*, leaves begin to develop in the wet months of May and August, and leaf maturity is seen 6 to 8 months following the start. The leaf initiation was seen from the top in all of the species' one-year-old culms. All species' leaf productivity peaks during the wet season (May to September). After the leaves have reached maturity, the plant goes into dormancy from November through January. Then, starting in February, the leaves begin to fall off, reaching their peak in April.

Similar to this, the culm sheath of all species begins to detach from 1 year old as the nodes begin to form branches and detach from the base to the top. Deciduous plants include *B.pallida*, *B.tulda*, *D.asper*, and *D. hamiltonii*, which can be identified by the retention of the sheath and the subsequent sheath fall. All species' culm sheaths begin to deteriorate in January. However, it was found that the sheaths fell most frequently between March and April when the mature nodes began to branch out. The sheath's shading during the rainy season is crucial for preserving soil moisture (Nath *et al*., 2008).

The *D. hamiltonii* culm experiences a leafless period in different age classes between the months of late February and early March, and a new leaf only appears in the month of April; this results in a periodic growth deciduous type leaf pattern. Rao *et al*., (1990) also noted similar leaf patterns in *D. hamiltonii*, *B. balcooa*, and *B. vulgaris* by Nath *et al*., (2008). The sheath breaks off in the same pattern across all species in a 1-year-old culm during the elongation from the base to the top.

The most crucial qualities for determining how environmental influences affect a plant species' development behavior are altitudinal gradients. The differences in shoot emergence, culm elongation, leaf appearance, sheath fall, sheath emergence, and branching activities between species and different age classes are thought to contribute to physiological adaptation and altitude. Along the geographical gradient, there was a 5-7-day delay in shoot emergence, culm growth, leaf appearance, sheath fall, and branching for every rise in height. Higher altitudes experience a delay in the phenological characteristics due to a drop in temperature.

At lower altitudes, physiological processes begin quickly, taking longer as you ascend. Additionally, different age groups showed variations in physiological activity. This pattern most likely represents a species' attempt to adapt to the current environmental circumstances. The tendency of leaf and sheath fall in the bamboo species concentrated during the winter is possibly related to low temperature and decreased soil moisture content (Nath *et al*., 2004). The phenological study in the present investigation reflects the difference in ecological adaptability among species subjected to the same environmental regime.

6.5: Conclusion

Between January and May 2019, *B. jaintiana* blossoming was noted. The seed begins to fall out between July and September, and the old plant begins to wither. It was discovered that all clumps of *B. jaintiana* blossom simultaneously, generate seeds, and then dissipate. It was noticed that this species' estimated 30-35-year intermediate blooming cycle.

A perception of how bamboo species that grow in the same environmental conditions share growth patterns to various gradations was shown by examining culm growth strategies in the current study. Culm growth demonstrates the culm short periodicity. The brief growth period might be a tactic to direct resources toward increasing the culm thickness, similar to *B. tulda*. The growth rate initially showed signs of being slow, gradually peaked for two months, and then declined to zero between October and November. During this time, the culm stopped gaining height. Therefore, even though each species is treated to an identical environmental regime, it may be inferred that the overall time required for culm elongation varies. To improve culm production and sustainably manage bamboo resources, the culm growth plan study can be put into practice. The bamboo species' ability to adapt to various environmental conditions influences the growth stages and reproduction. Each species growth and development follows a unique timetable. The strong environmental force of altitude governs all species phenological activities. All bamboo species experience a delay in phonological activity as the altitudinal gradient increases.

Chapter-7

Development of Allometric Biomass Models for Bamboo Species

7.1. Introduction:

International action has been taken through the Framework Convention on Climate Change to reduce carbon dioxide (CO2) in the earth's atmosphere. The global environment debate has grown significantly over the years, from the Stockholm Conference on Environment in June 1972 to the Earth Summit in Rio de Janeiro in June 1992 and beyond. A post-Kyoto framework that stimulates the implementation of demonstration operations to sequester C through forestry was discussed at the 13th Session of the Conference of the Parties of the UNFCCC, held in Bali in December 2007 (Neeff, 2009). Over the past few decades, studies on forest C and its role have drawn more and more attention (Woodwell *et al*., 1978; Liu et al., 2000; Fang and Chen, 2001; Li *et al*., 2004; Zhou *et al*., 2006).

Bamboo have a significant part in C storage, which has been a serious global concern in recent years. Because of its quick growth and great productivity, bamboo has recently attracted current interest, particularly in the context of growing climate change concerns and rising energy costs (Widenoja, 2007; INBAR, 2009). In addition to providing other crucial ecosystem services that support human lives, bamboo's capacity to store carbon can be efficiently used to mitigate and hedge against the looming effects of future climate change (Yuen *et al*., 2017).

The MAD Challenge of Mitigation of, Adaptation to, and Development in the Face of Climate Change should be approached with bamboo as a beneficial tool (Lou *et al*., 2010).

There are a number of generalized allometric equations that have been developed for tropical trees (Brown, 1997; Chave *et al*., 2005), but there is still a dearth of allometric models for determining bamboo biomass, despite some studies on biomass accumulation, carbon storage, net production, and nutrient cycling in various species of bamboo that have been reported by many groups in India (Choudhury *et al*., 2015; Nath and Das, 2011; Nath *et al*., 2009, 2008; Kumar *et al*., 2005; Shanmughavel and Francis, 2001) and abroad (Yen, 2016; Chen *et al*., 2009; Isagi *et al*., 1997). Allometric equations for estimating bamboo biomass have been developed in around 100 studies, however the majority of these studies were carried out in China, Taiwan, and India (Yuen *et al*., 2017).

"The analysis of allometric correlations in locations with limited research opportunities may help with the assessment of bamboo ecosystems globally because bamboo species and their physical characteristics vary locally" -Xayalath *et al*., (2019) pp. 157. There are currently very few speciesspecific allometric equations for bamboos (Yuen *et al*., 2016; 2017). When employing allometric models created by other researchers, the variability between biomass estimations may be underestimated or overestimated (Brown *et al*., 2012).

According to several studies (Brown *et al*., 2012; Chave *et al*., 2005; Chaturvedi *et al*., 2012), this may be a result of the differences in species and climatic zones as well as the independent factors employed in the regression model. A number of publications have suggested an alternative to this problem, including Litton *et al*. (2008) and Makungwa *et al*. (2013). They suggested favoring allometric models built on regional or local aggregates. For the most accurate assessment of biomass, species specific equations should be developed (Xayalath *et al*., 2019).

7.2. Methodology:

Each bamboo culm's diameter and age were measured at breast height (DBH), and an age-based stratified sample technique was adopted. Four age classes were distinguished for culm including 1, 2, 3 and 4 years old.

7.2.1. Statistical Analysis:

Diameter (D) and height (H) are the two fundamental input variables applied in many growth processes. Compared to D, obtaining H takes a bit more time and requires more effort (Huang *et al*., 2000). When diameters are measured in the field, H-D models are frequently employed to forecast the heights that are deficient. This study investigated 12 of the most popular H-D models in bamboos (Huang *et al*., 2000; Gao *et al*., 2016; Kaushal *et al*., 2016; Singnar *et al*., 2017; Nath *et al*., 2018) in order to determine which model was most effective at predicting H-D relationships.

The 12 functions are as follows:

Asymptotic: H = a - bcD

Chapman-Richards: H = a (1-exp (-bD))c

Exponential (2-parameter): H= a (exp (bD))

Exponential (3-parameter): H= a – b (exp(-cD)))

Gompertz: H= a (- exp (b-cD)

Hyperbolic: H= a+ b/D

Logistic: H= a/(1 + exp (b - cD))

Michaelis-Menten: H= aD/b+D

Monomolecular: H= a (1 – exp (-b(D-c)))

Power law: H= aDb

Richards function: H= a / (1+exp (b-cD))

Weibull: H= a-b (exp (-cDd))

The H-D models were tested after combining all the data for both years of each species, which helped to maintain a sufficient sample size and improve the effectiveness of the test. The AIC, pseudo R^2, MSE, and normality of the residuals (Shapiro-Wilk test) were used to determine the adequacy of the model. Another criterion that was applied was the algorithm's convergence. Estimated parameters and their standard errors will be erroneous if the method is unable to converge. In this analysis, an equation was deemed inadequate if the algorithm did not converge after several iterations of changing the parameter values and refitting the model.

7.2.2. Estimating Biomass allometry parameters:

The data were fitted to a regression model with the following specifications in order to test the hypothesis that biomass accumulation in the four species of bamboo follows allometric scaling models:

Model 1: $ln\ (AGB) = ln\ (\alpha) + \beta\ (ln D) + e$

Model 2: $ln\ (AGB) = ln\ (\alpha) + \beta\ (ln H) + e$

Model 3: $ln\ (AGB) = ln\ (\alpha) + \beta\ (ln(HD^2)) + e$

where HD^2 represents culm fresh weight and ln (α), β being parameter estimates and and e is the error term. In each model fitted lines were generated by multiplying predicted values with the correction factor. The suitability of each model was compared based on the AIC weights, pseudo R^2, MSE and normality of residuals (Shapiro-Wilk test). AIC weights are more informative than AIC values when comparing biomass estimation models (Sileshi, 2014). The models performance was evaluated based on graphical analyses of the scatter plots and considered the R^2 - value as the goodness of fit statistic.

7.3. Results:

7.3.1. The H-D model:

In this analysis a model was deemed unsuitable if the algorithm did not converge after repeated changes of the starting values of parameters and refitting the model. The power-law has the highest value of the explained variation (pseudo R^2) among the models, whereas the variability among the other models were minimal (Table 7.1).

The power-law function had a 42% likelihood of being the best of the H-D models evaluated, followed by the Chapman-Richard model (27% likelihood), with the remaining models having a <12% likelihood (Table 7.1). Table 7.2 (Fig. 7.1) lists the exponents of the H-D scaling in the species *B. pallida*, *B. tulda*, *D. asper*, and *D. hamiltonii*.

The exponents in each case were significantly lower than predicted by the geometric and stress similarity growth models. The H-D allometry's intercepts and slopes did not substantially differ among species, and their 95% confidence intervals overlapped (Table 7.2).

Table 7.1: Estimates of the maximum height (Hmax) and comparison of heightdiameter (H-D) models using the AICw, pseudo R^2 , root mean square of error (RMSE), and P value of the Shapiro-Wilk test of normality of errors

Model	Hmax	AICc	AICw	R^2	RMSE	Shapiro-Wilk
Power law	NA	**2329.2**	**0.38**	**0.924**	**76.3**	0.3420
Chapman-Richard	3967.0	2328.1	0.27	0.912	76.2	0.3447
Weibull*	6467.7	2329.7	0.11	0.922	76.3	0.3887
Asymptotic	2775.3	2229.9	0.10	0.922	76.5	0.2898
Monomolecular	2753.7	2229.9	0.10	0.922	76.5	0.2898
Michaelis-Menten	3310.6	2233.4	0.02	0.920	77.1	0.6192
Gompertz	2184.2	2234.4	0.01	0.920	77.1	0.1618
Richard*	2175.5	2336.6	0.00	0.920	77.3	0.1592
Logistic	1976.1	2339.1	0.00	0.919	77.8	0.0956
Exponential (3-p)*	-17659.0	2360.7	0.00	0.912	81.0	0.2363
Exponential (2-p)	674.1	2230.0	0.00	0.885	81.0	0.0003
Hyperbolic	1677.4	2433.2	0.00	0.826	112.0	0.0078

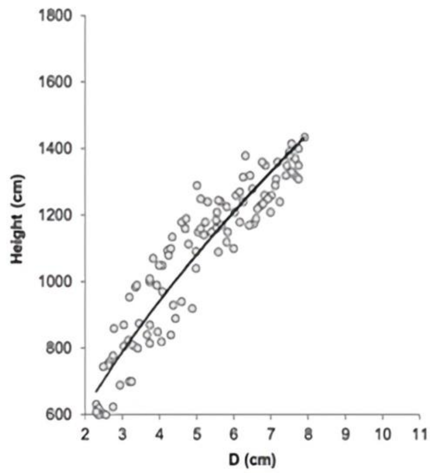
* Model did not converge. Therefore, the estimates of Hmax were deemed unreliable. Letter in bold face refers to best model.

Table: 7.2. Parameter estimates of the height-diameter (H-D) allometry and goodness of fit statistics for *B. tulda*, *B. pallida*, *D. asper*, *D. hamiltonii*

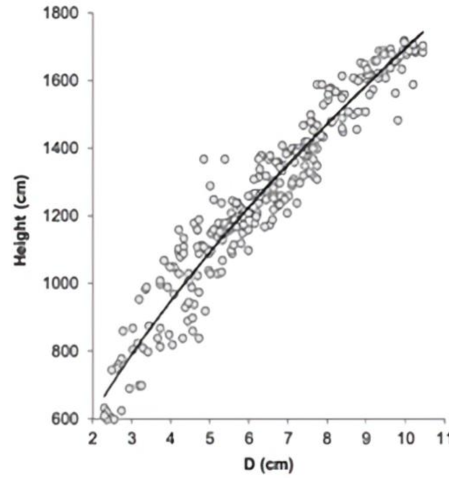
Species	Sample size	Intercept (α)	Slope (β)	R^2	Shapiro Wilk*
B. pallida	40	402.3 (372; 432.3)	0.58 (0.53; 0.62)	0.924	0.011
B. tulda	120	423.7 (390.2; 448.7)	0.62 (0.58; 0.65)	0.932	0.004
D. asper	80	395.4 (362.2; 425.4)	0.56 (0.56; 0.62)	0.902	0.005
D. hamiltonii	120	434.1 (395.9; 467.3)	0.59 (0,54; 0.68)	0.916	0.008

Figures in parenthesis represent 95% confidence limits. The slopes of two or more species were deemed significantly different when their 95% confidence limits do not overlap. *P value of the Shapiro-Wilk test of normality of the residuals.

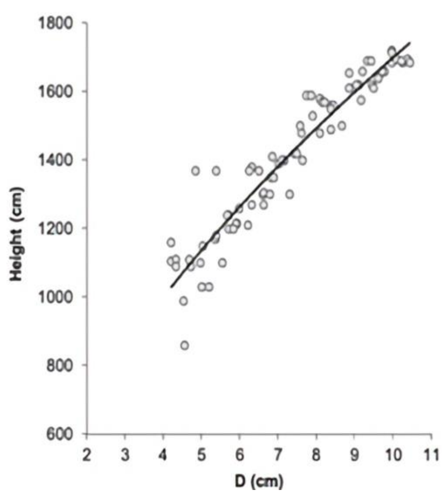
Figure 7.1: Allometric scaling between culm height and diameter at breast height (H-D scaling) in *B. pallida*, *B. tulda*, *D. asper* and *D. hamiltonii*. Solid black lines are fitted lines representing back-transformed value of predictions multiplied by the correct factor.



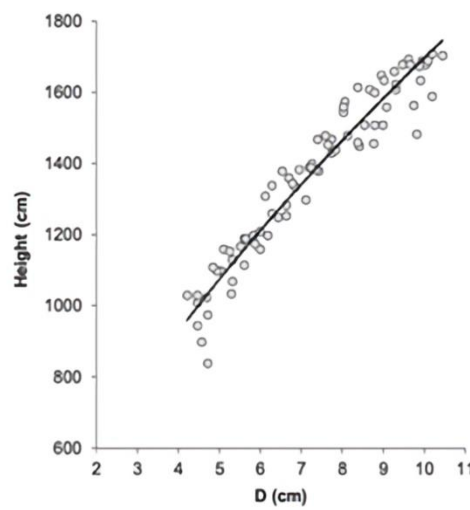
A. *Bambusa pallida*



B. *Bambusa tulda*



C. *Dendrocalamus asper*



D. *Dendrocalamus hamiltonii*

7.3.2. Allometric scaling of Above ground biomass and diameter:

Bamboo production is represented by the culm above ground biomass (AGB) of the species. In Longkhum, the highest mean (AGB) was recorded in 4-year old culms and lowest 1-year old culms in all the three species for both years. The highest was recorded in *B. tulda* species.

In Chungtia, the highest mean (AGB) was recorded in was recorded in 4-year old culms and lowest 1-year old culms in all the three species for both years. The species with highest AGB was recorded in *B. tulda* in the first year and *D. asper* in the second year.

In Tuli, the highest mean (AGB) was recorded in was recorded in 4-year old culms and lowest 1-year old culms in all the three species for both years. The species with highest AGB was recorded in *B. tulda*, followed by *D. hamiltonii* and *B. pallida* in both the years. The regression equations were developed between AGB and DBH for different species in both years of different study sites for all the bamboo species are shown in Figure 7.2. A non-liner regression model was fitted for all the bamboo species individually as well as both years of the all study sites. The models accounted for 96.96-98.53% of the variation in the dependent variable for *B. tulda*, *B. pallida*, *D. asper* and *D. hamiltonii*.

The relationship was best represented by quadratic model with high coefficient of determination (R^2 = 93.75 – 98.52%) for different species irrespective of age classes. As AGB differs with species, non-linear regression models were developed for all the selected forest bamboo species for both years.

Table 7.3: Parameter estimates of the various biomass models and goodness of fit statistics for *B. tulda*, *D. asper* and *D. hamiltonii* in Longkhum 2019-20022

Year	Species	Model	AIC	Pseudo R^2	MSE
2019-2020	*B. tulda*	ln(AGB) ~ ln(D)	15.86484	0.563729	0.095882
		ln(AGB) ~ ln(H)	28.358	0.185217	0.17907
		aboveground_biomass ~product_D2_H	81.56439	0.611163	0.17907
	D. asper	ln(AGB) ~ ln(D)	15.86484	0.563729	0.095882
		ln(AGB) ~ ln(H)	28.358	0.185217	0.17907
		aboveground_biomass~ product_D2_H	81.56439	0.611163	0.17907
	D. hamiltonii	ln(AGB) ~ ln(D)	26.12932	0.458481	0.160187
		ln(AGB) ~ ln(H)	22.97947	0.53739	0.136845
		aboveground_biomass ~product_D2_H	99.95323	0.611163	0.136845
2021-2022	*B. tulda*	ln(AGB) ~ ln(D)	9.617238	0.429303	0.070157
		ln(AGB) ~ ln(H)	18.5477	0.108075	0.109647
		aboveground_biomass ~product_D2_H	120.4783	0.171511	0.109647
	D. asper	ln(AGB) ~ ln(D)	10.90479	0.731808	0.074822
		ln(AGB) ~ ln(H)	30.81372	0.27429	0.202464
		aboveground_biomass ~product_D2_H	92.76011	0.492792	0.202464
	D. hamiltonii	ln(AGB) ~ ln(D)	23.07497	0.275989	0.1375
		ln(AGB) ~ ln(H)	21.66803	0.325171	0.12816
		aboveground_biomass ~product_D2_H	111.0475	0.394221	0.12816

Table 7.4: Parameter estimates of the various biomass models and goodness of fit statistics for *B. tulda*, *D. asper* and *D. hamiltonii* in Chungtia 2019-20022

Year	Species	Model	AIC	Pseudo R^2	MSE
2019-2020	*B. tulda*	ln(AGB) ~ ln(D)	-9.1469	0.41007	0.027455
		ln(AGB) ~ ln(H)	0.533387	0.042794	0.044547
		aboveground_biomass ~product_D2_H	109.2938	0.388192	0.044547
	D. asper	ln(AGB) ~ ln(D)	-11.5226	0.824446	0.02438
		ln(AGB) ~ ln(H)	16.4684	0.288413	0.09882
		aboveground_biomass~ product_D2_H	97.05271	0.812851	0.09882
	D. hamiltonii	ln(AGB) ~ ln(D)	12.54695	0.121823	0.081225
		ln(AGB) ~ ln(H)	0.189449	0.526585	0.043788
		aboveground_biomass ~product_D2_H	93.38933	0.385319	0.043788
2021-2022	*B. tulda*	ln(AGB) ~ ln(D)	3.622336	0.440185	0.051987
		ln(AGB) ~ ln(H)	2.624384	0.467433	0.049457
		aboveground_biomass ~product_D2_H	86.04763	0.739563	0.049457
	D. asper	ln(AGB) ~ ln(D)	7.787487	0.653009	0.064024
		ln(AGB) ~ ln(H)	28.10632	0.041624	0.176831
		aboveground_biomass ~product_D2_H	120.0135	0.54555	0.176831
	D. hamiltonii	ln(AGB) ~ ln(D)	-6.45944	0.761773	0.031403
		ln(AGB) ~ ln(H)	16.03692	0.266342	0.096711
		aboveground_biomass ~			
		aboveground_biomass ~product_D2_H	70.46499	0.553805	0.096711

Table 7.5: Parameter estimates of the various biomass models and goodness of fit statistics for *B. pallida*, *B. tulda*, and *D. hamiltonii* in Tuli 2019-20022

Year	Species	Model	AIC	Pseudo R^2	MSE
2019-2020	*B. pallida*	ln(AGB) ~ ln(D)	17.23056	0.033057	0.102658
		ln(AGB) ~ ln(H)	17.84321	0.002979	0.105852
		aboveground_biomass ~product_D2_H	99.4391	0.024154	0.105852
	B. tulda	ln(AGB) ~ ln(D)	1.830357	0.720801	0.047532
		ln(AGB) ~ ln(H)	27.15582	0.009514	0.168624
		aboveground_biomass~ product_D2_H	120.7236	0.156766	0.168624
	D. hamiltonii	ln(AGB) ~ ln(D)	-0.75332	0.672777	0.041771
		ln(AGB) ~ ln(H)	6.284665	0.534766	0.059389
		aboveground_biomass ~product_D2_H	70.1151	0.75665	0.059389
2021-2022	*B. pallida*	ln(AGB) ~ ln(D)	5.399757	2.52E-05	0.056819
		ln(AGB) ~ ln(H)	5.395891	0.000218	0.056808
		aboveground_biomass ~product_D2_H	94.7232	0.000969	0.056808
	B. tulda	ln(AGB) ~ ln(D)	3.568259	0.113406	0.051847
		ln(AGB) ~ ln(H)	5.114058	0.042163	0.056013
		aboveground_biomass ~product_D2_H	107.1271	0.044251	0.056013
	D. hamiltonii	ln(AGB) ~ ln(D)	16.9503	0.79178	0.05431
		ln(AGB) ~ ln(H) aboveground_biomass ~	27.7643	0.04467	0.06738
		aboveground_biomass ~product_D2_H	70.7717	0.00054	0.05572

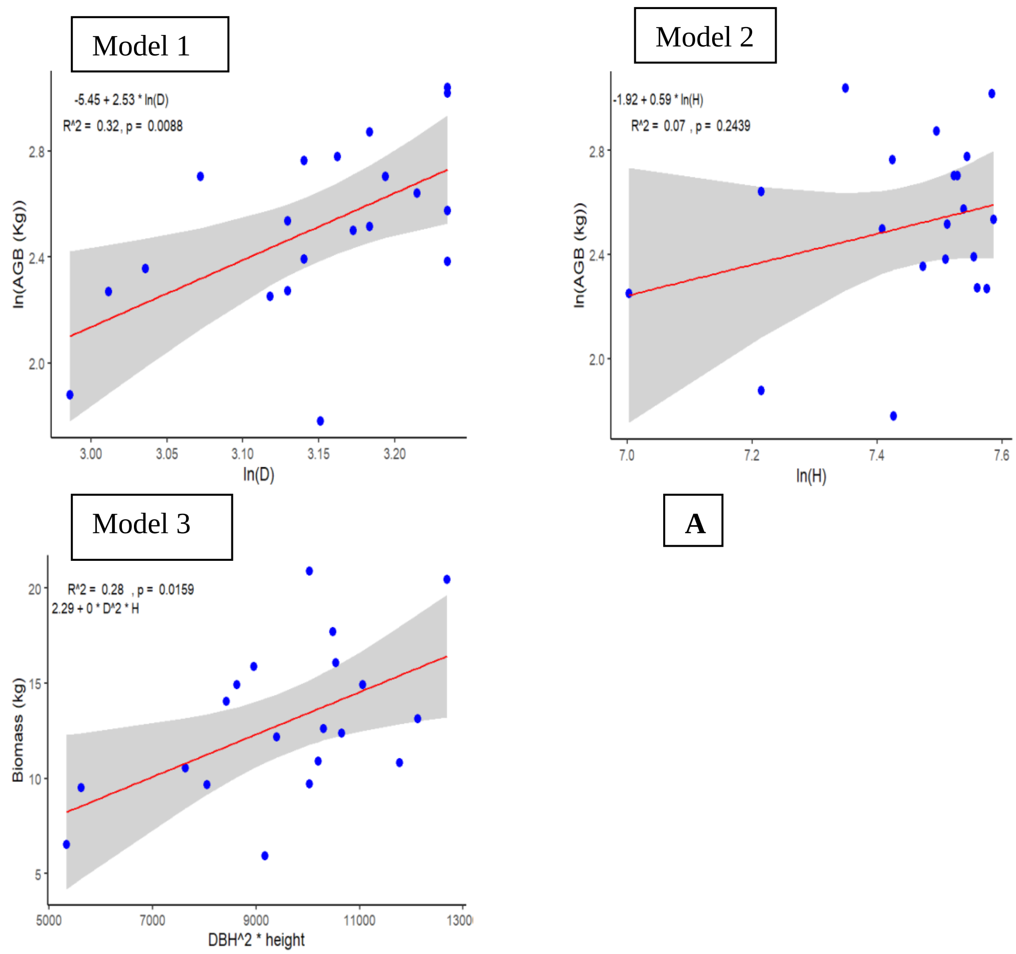
Table 7.6: Two-way ANOVA of AGB, H, DBH

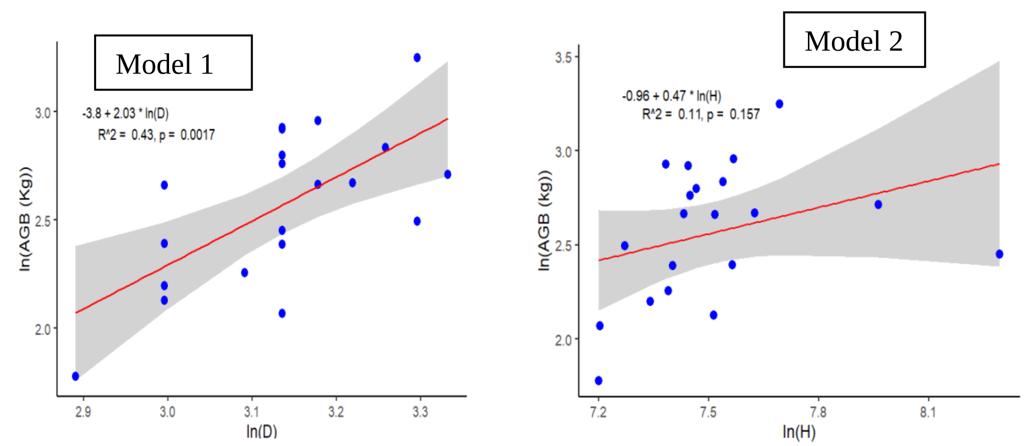
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Year	1	7	7.4	0.508	0.4765
Site	2	721	360.5	24.848	8.39
Species	4	2159	539.8	37.310	2
Year:Site	2	924	462.0	31.848	2.07
Year: Species	4	345	86.2	5.944	0.000
Site: Species	2	1148	574.1	39.571	3.48
Year: Site: Species	2	192	95.8	6.607	0.0015
Residuals	342	4961	14.5		

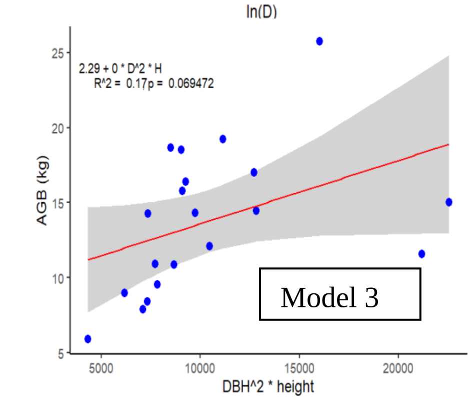
Significant value: $p < 0.05$

Table 7.7: Post-HOC test of AGB, H, DBH

	Diff	Lwr	Upr	P adj
Year				
Year 2- Year 1	-0.286125	-1.075811	0.5035612	0.476535
Site				
Longkhum-Chungtia	-2.8612000	-4.018676	-1.9678278	0.00000
Tuli-Chungtia	-3.1253042	-4.282780	0.8933722	0.0000
Tuli-Longkhum	-0.2641042	-1.421580	0.8933722	0.8530987







B

Fig. 7.2: Allometeric Models of Biomass Estimation of ***Bambusa tulda*** of Longkhum during: A. 2019-2020, B.2021-2022

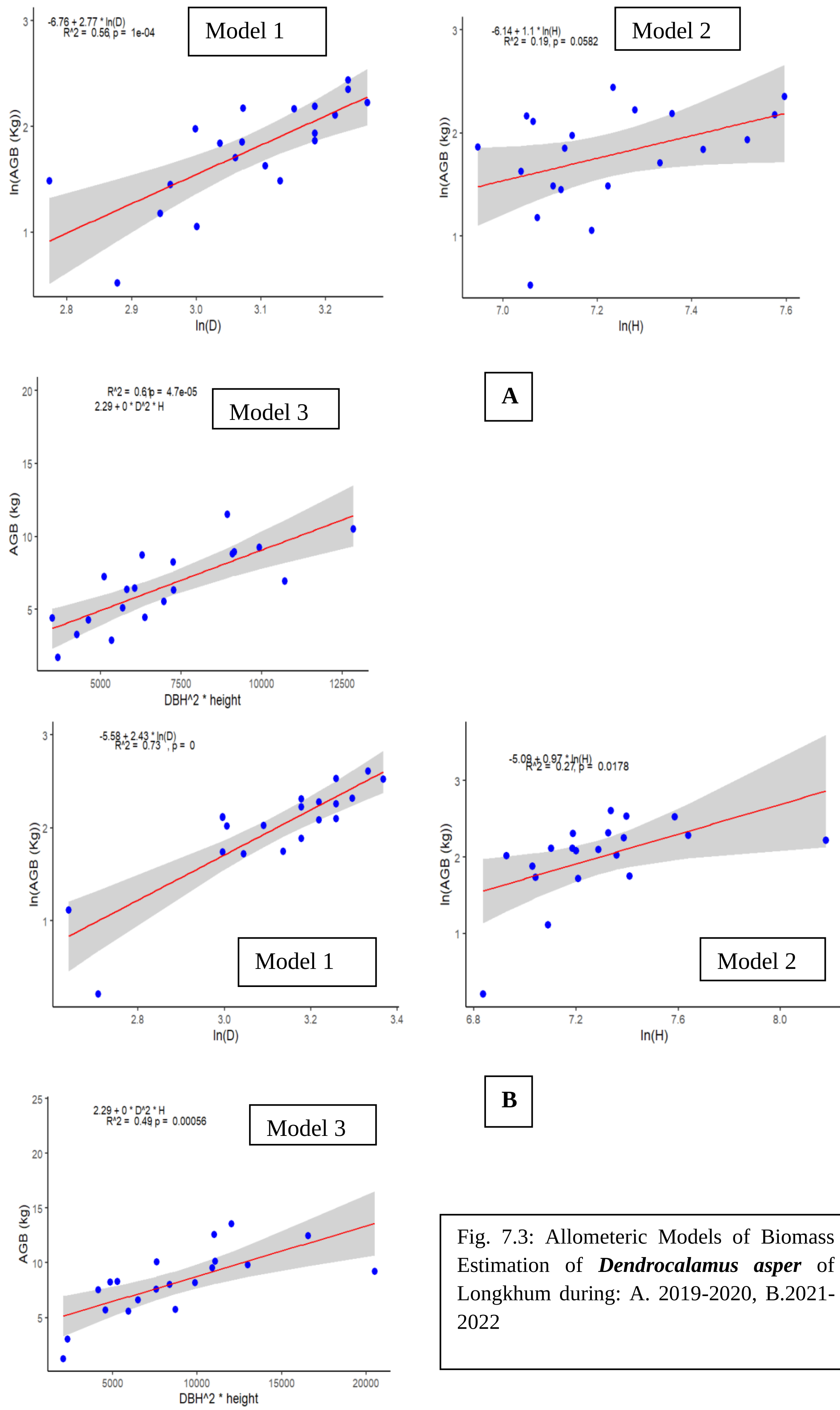
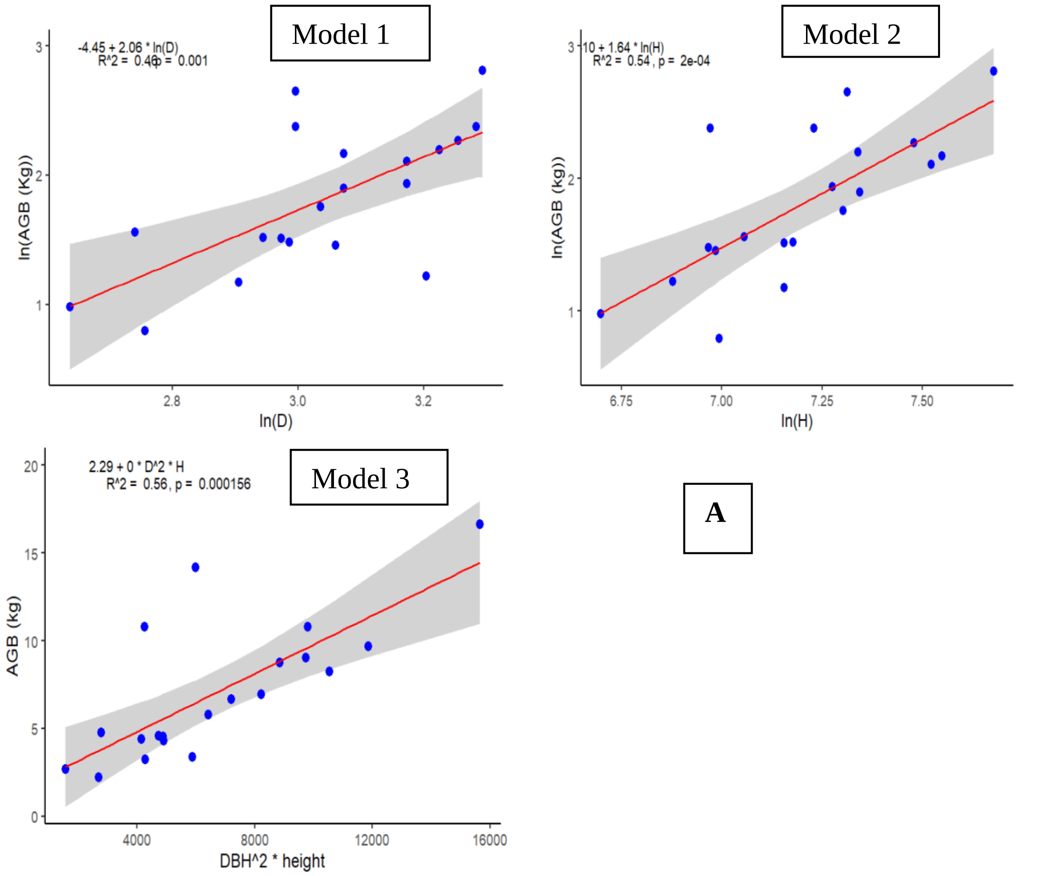
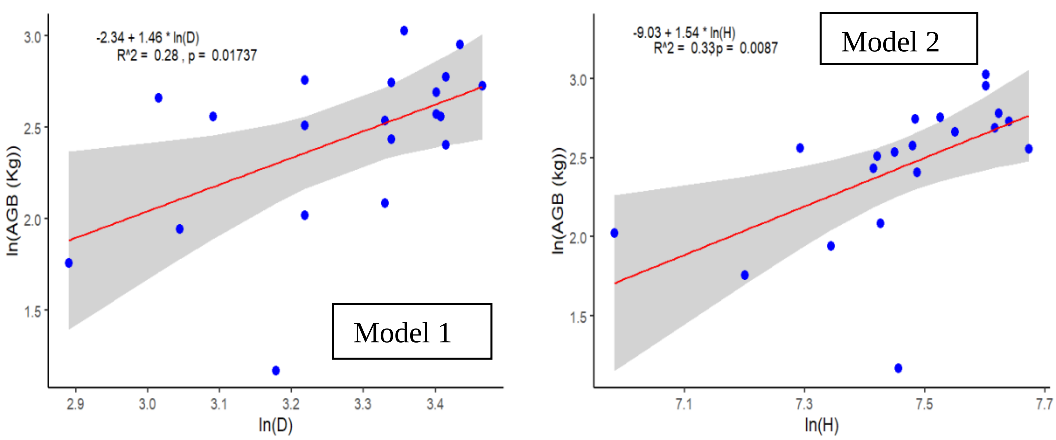
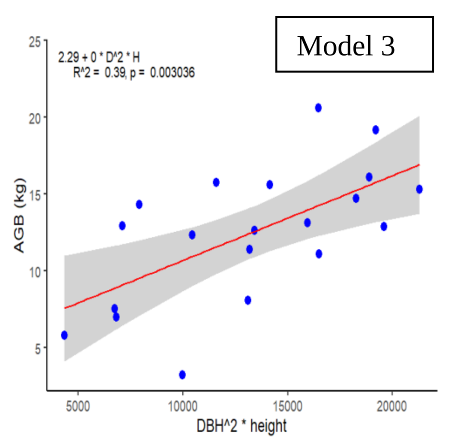


Fig. 7.3: Allometeric Models of Biomass Estimation of ***Dendrocalamus asper*** of Longkhum during: A. 2019-2020, B.2021-2022







B

Fig. 7.4: Allometric Models of Biomass Estimation of ***Dendrocalamus hamiltonii*** of Longkhum during A. 2019-2020, B. 2021-2022

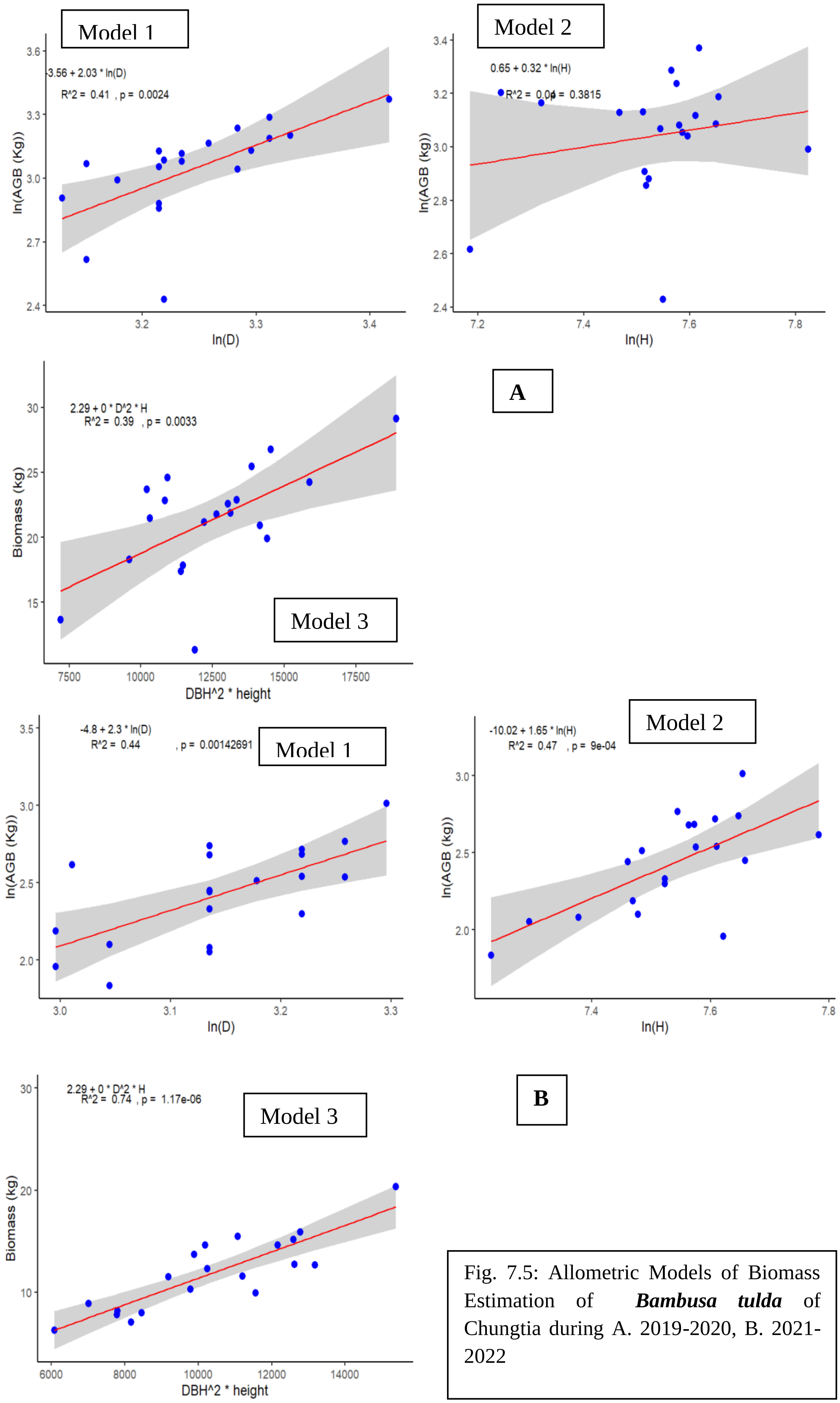
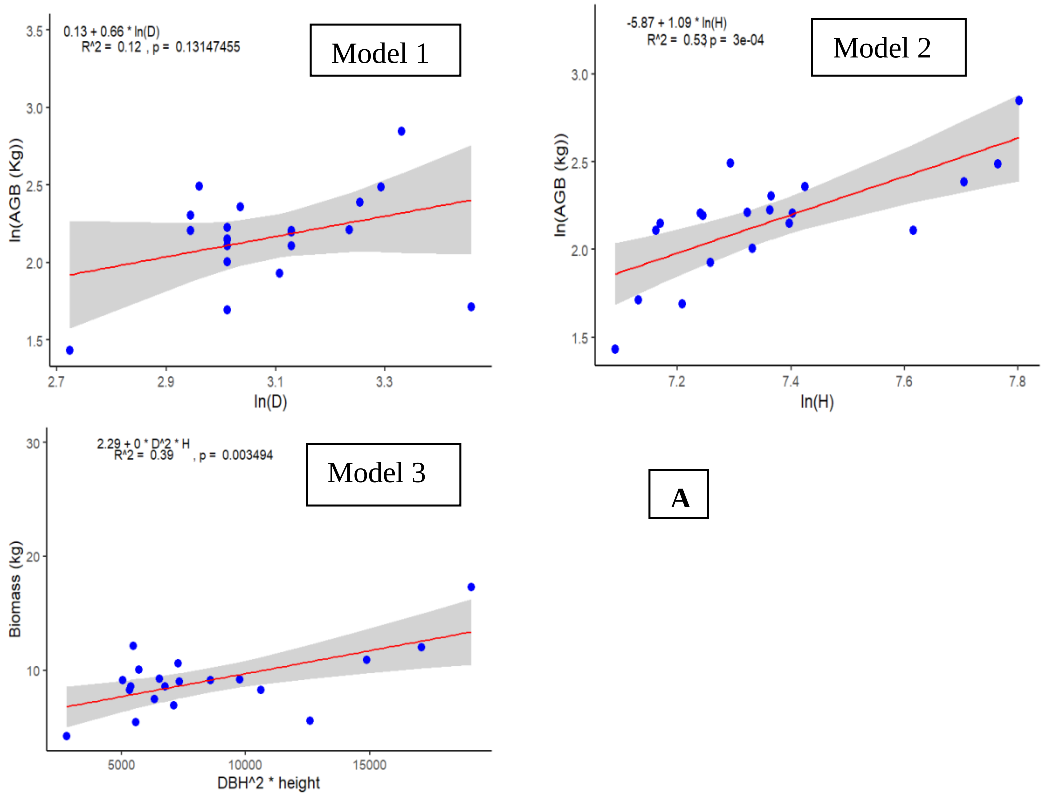


Fig. 7.5: Allometric Models of Biomass Estimation of ***Bambusa tulda*** of Chungtia during A. 2019-2020, B. 2021-2022



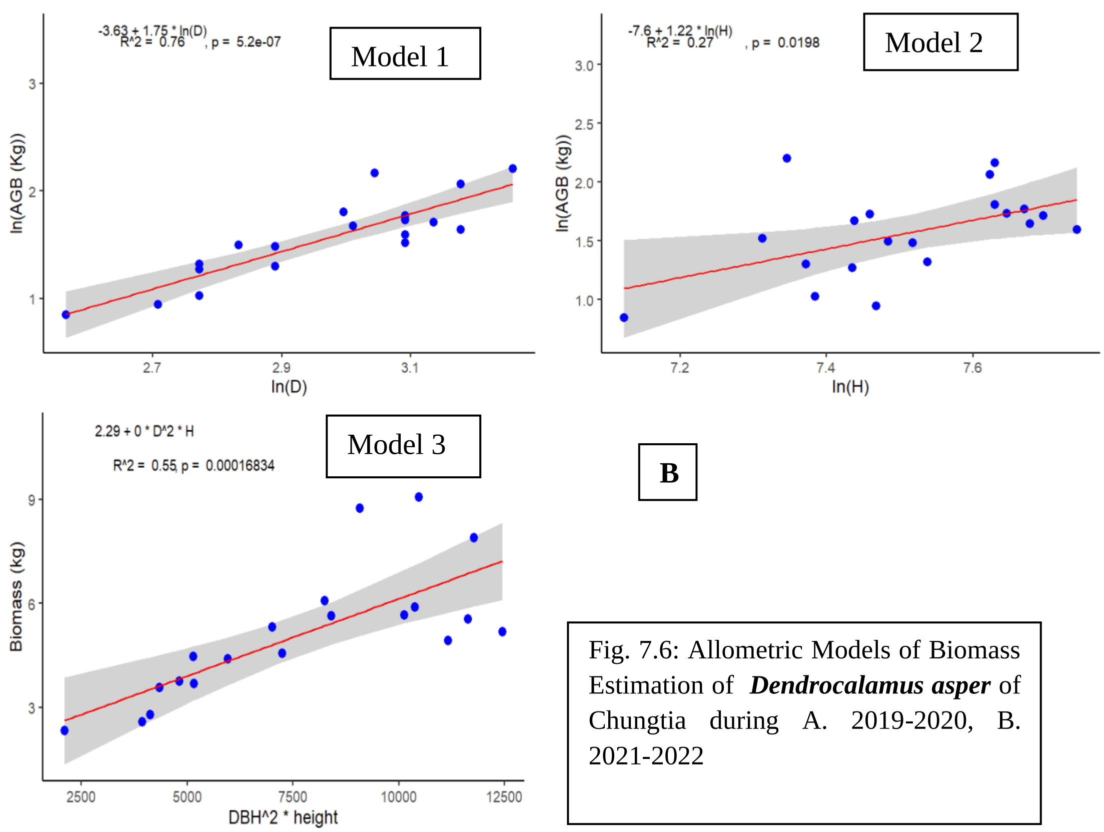
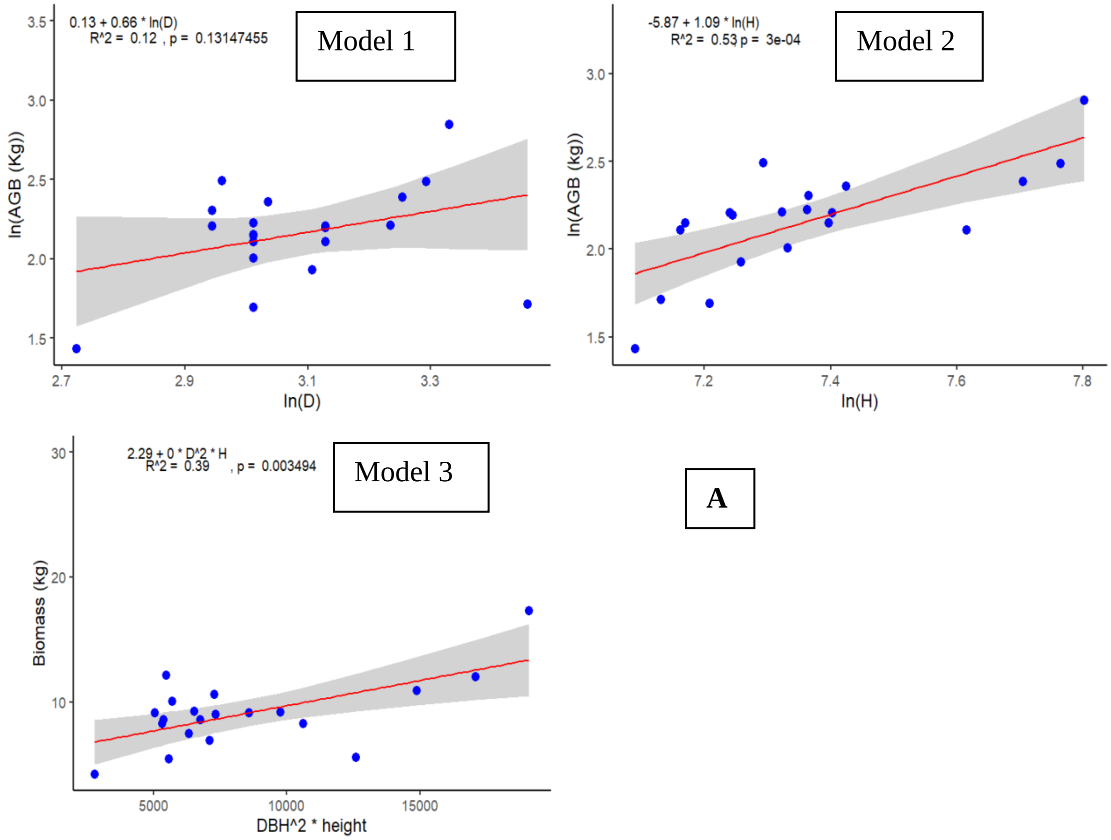
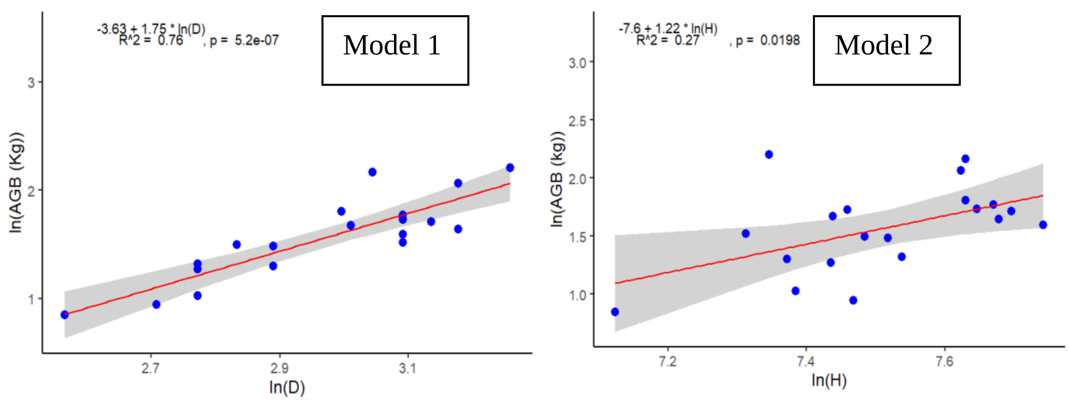
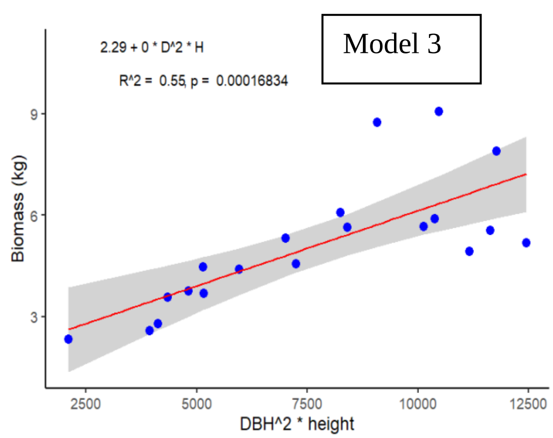


Fig. 7.6: Allometric Models of Biomass Estimation of ***Dendrocalamus asper*** of Chungtia during A. 2019-2020, B. 2021-2022







B

Fig. 7.7: Allometric Models of Biomass Estimation of ***Dendrocalamus hamiltonii*** of Chungtia during A. 2019-2020, B. 2021-2022

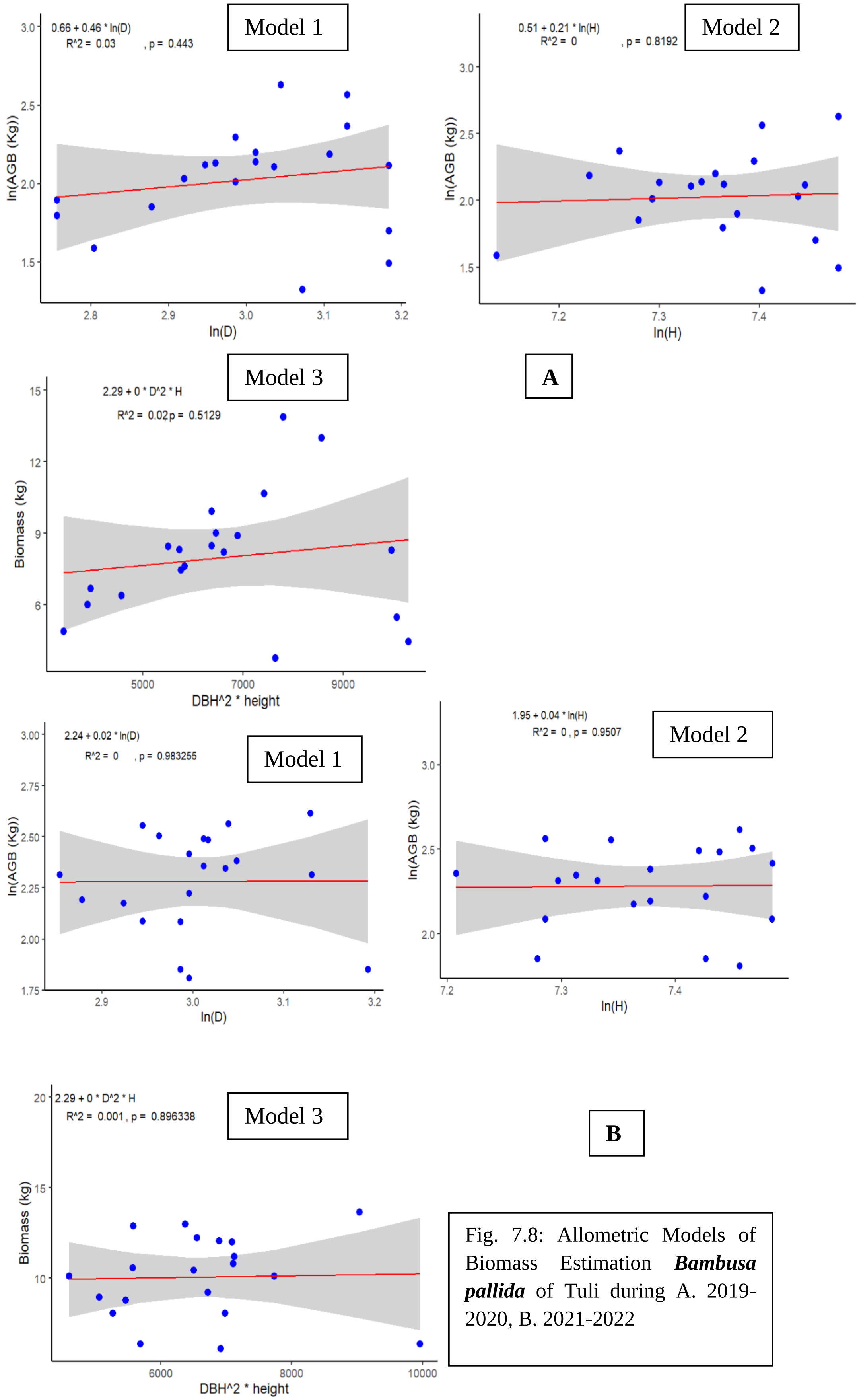
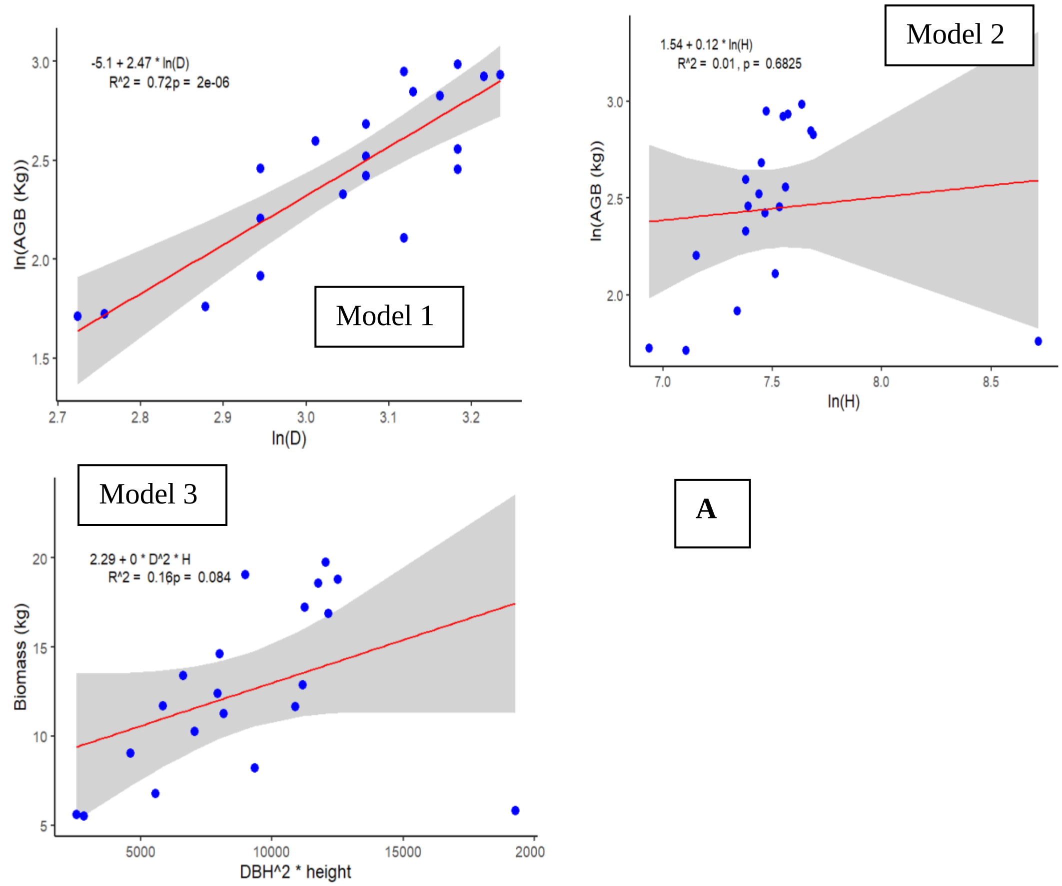
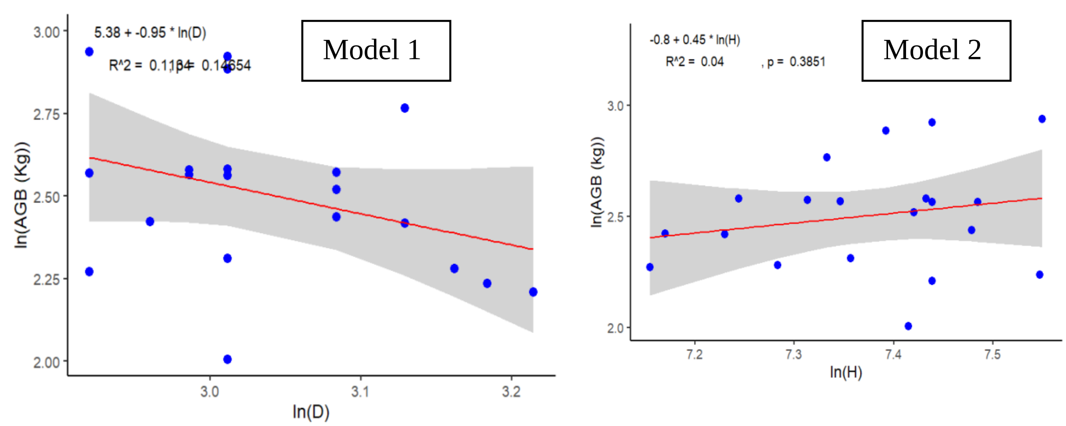


Fig. 7.8: Allometric Models of Biomass Estimation ***Bambusa pallida*** of Tuli during A. 2019-2020, B. 2021-2022





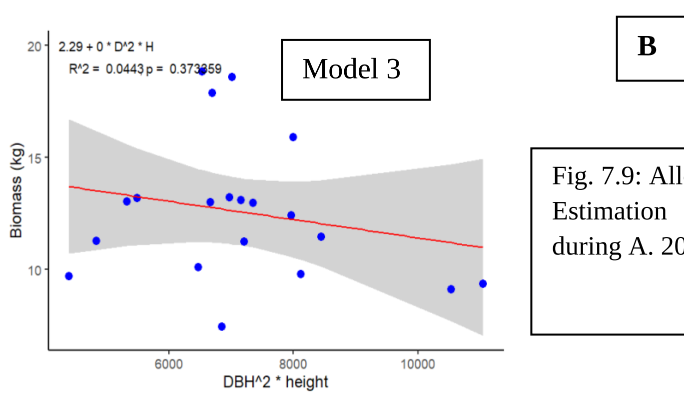
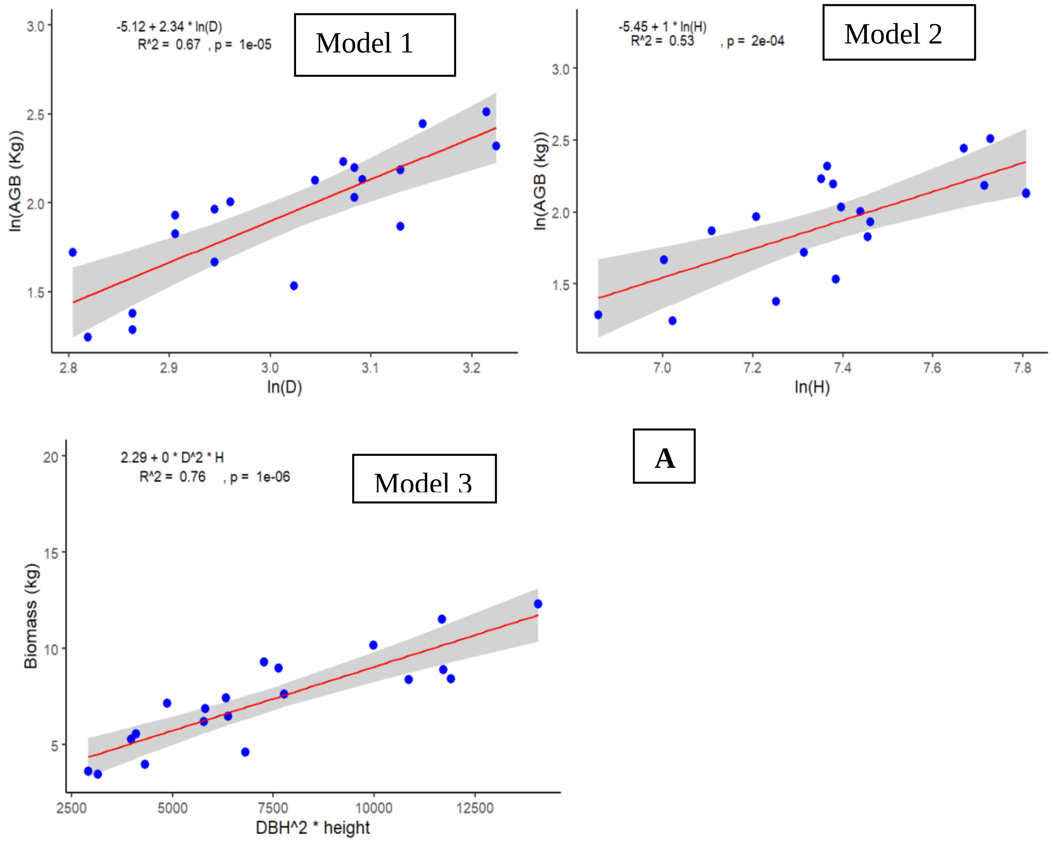
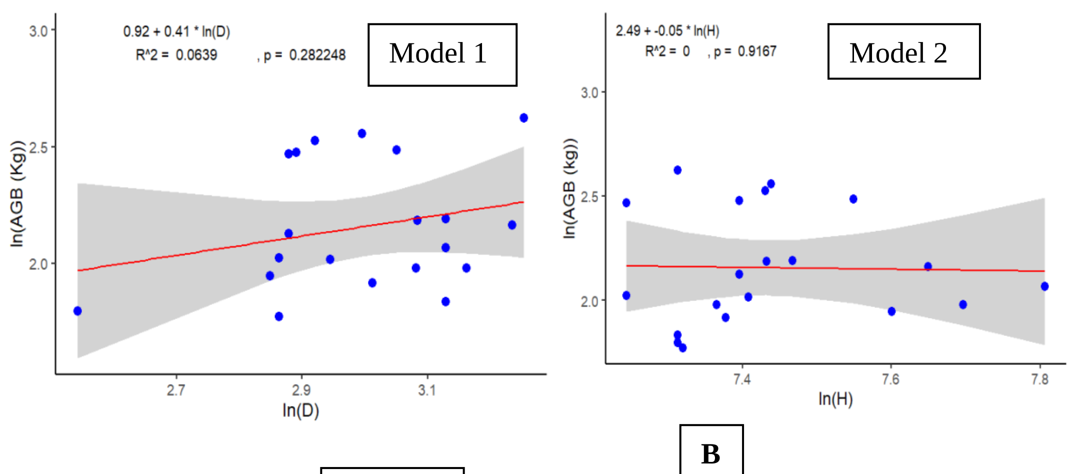


Fig. 7.9: Allometric Models of Biomass Estimation ***Bambusa tulda*** of Tuli during A. 2019-2020, B. 2021-2022





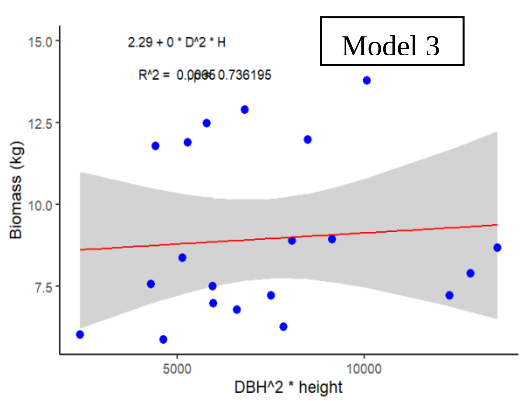


Fig. 7.10: Allometric Models of Biomass Estimation ***Dendrocalamus hamiltonii*** of Tuli during A. 2019-2020, B. 2021-2022

7.4. Discussion:

The untamed bamboo forests selected for the study were unmanaged, undisturbed, or minimally disturbed. The four selected bamboo species have very distinct allometric characteristics, and each species has its own. According to reports, "the features of bamboo vary depending on the type, location, age, and intensity of the stand, as well as external variables" Krishnaswamy, (1956); Hisham *et al*., (2006); Singnar, (2014).

The allometric analysis shows that the culm reached maturity at age 3. In this work, allometric correlations between H and D were found. "These connections align with the predictions that the elastic similarity and metabolic theories of ecology predict" Niklas 1995; West *et al*., 2009. However, there was a major departure from theory in the relationships between AGB and D and H. As a result, it can be concluded that a straightforward allometric model using either D or H is insufficient for estimating biomass in the bamboo species in all the studied species.

In this study, an allometric relationship among H and D in the thickwalled bamboo species *B. tulda* and *B. pallida*, and thin walled bamboo species *D. asper* and *D. hamiltonii* has been observed. The power-law model is the most accurate at predicting H from D in both of the bamboo species under study, according to a comparison of the H-D models. The power-law function had a 42% likelihood of being the best of the H-D models evaluated, followed by the Chapman-Richard model (27% likelihood), with the remaining models having a <12% likelihood (Table 7.1). Table

7.2 (Fig. 7.1) lists the exponents of the H-D scaling in the species *B. pallida*, *B. tulda*, *D. asper*, and *D. hamiltonii*.

There was gain in explanatory power from the other models. The (*Dendrocalamus strictus*,), thin-walled bamboos in India (Singnar *et al*., 2017), and thick-walled *Bambusa* species in NE India (Nath *et al*., 2018) were all shown to be better modeled using the power-law model (Kaushal *et al*., 2016). The performance of several of the other models was inconsistent. The "Chapman-Richard, Richard, and Weibull functions" all repeatedly failed to converge with 4 parameters each. Additionally, it was observed that these models produced error in "H_{max} estimations of *M. baccifera*" (Singnar *et al*., 2017). This could be as a result of the species' potential to continue growing beyond five years.

AGB and D and AGB and H relationships both have exponents that greatly differed from theoretical values. The hollowness of the culm may be the reason for this. According to Huy *et al*., 2019, "consideration of bamboo models specific to each genus should be made to reduce the amount of model establishment. Biomass models produced for the genus *Bambusa* were similar in terms of goodness of fit".

The study's conclusions will be useful in choosing the right species for a given purpose. The study's findings reveal that 1-year-old culms had the lowest green weight and highest solid volume, both of which point to their unsuitability for usage. Industrialists, researchers, forest agencies, and those in charge of making policy will be able to use and manage the species in a sustainable manner to the various regression models that have been developed between H, DBH and AGB.

From the ANOVA analysis, it was observed that year and species, year and sites were statistically significant at $p<0.05$ level. Post Hoc a test also show a statistical significance at $p<0.05$ level.

The regression equations were developed between AGB, D and DBH for different species in both years of different study sites for all the bamboo species are shown in Figure 7.3-7.10. A regression model was fitted for all the bamboo species individually as well as across the all study sites. The models accounted variation in the dependent variable for *B. tulda*. *B. pallida*, *D. asper* and *D. hamiltonii*.

The relationship was best represented by Model 1 in both the years for *B. tulda* in Longkhum. For *D. asper*, it as best represented by Model 1 and 3 during first and second years. In *D. hamiltonii*, Model 1 and 2 represented the best during first year and in the second year it was Model 2 and 3.

In Chungtia, for *B. tulda*, it was best represented by Model 1 during first year and Model 3 during second year. For *D. asper*, it was observed that Model 2 gives the best representation during first year and Model 1 and 3 during second year. In *D. hamiltonii*, the data sets were best fitted in Model 2 during first year and Model 1 and 3 during second year.

In Tuli, *B. pallida* was best fitted in Model 2 in both the years. In *B. tulda*, it was observed that it was best fitted in Model 1 during first year and Model 2 in the second year. For *D. hamiltonii*, the data sets were best fitted in Model 1 in both the studied years.

Comparing the developed species-specific and general allometric models for *B. tulda*, *B. pallida*, *D.asper* and *D. hamiltonii* aboveground biomass, the findings lead to the conclusion that using volume rather than culm diameter or height allows for a better forecast of biomass. The models can considerably increase the ability to precisely estimate biomass and carbon sequestration in the Indian subcontinent's northeastern forest environment. Specifically, the use of inventory data to study temporal and geographic variability in ecosystem structure and function will be made easier by the use of culm volume as a predictor variable for *B. tulda*, *B. pallida*, *D.asper* and *D. hamiltonii*.

7.5. Conclusion:

The H-D power-law model can be used to predict the height of both bamboo species, according to the study mentioned above. The study also shows that using volume to forecast biomass for bamboos is more accurate than using factors like culm diameter or height alone. It is discovered that the C storage studies for both *Bambusa* and *Dendrocalamus* species are comparable to other research that have been published for other bamboo species across the globe. Thus, managing local bamboo species may present an opportunity for carbon farming and trading.

Chapter 8

Bamboo Biomass Production and Carbon Stock

8.1. Introduction

The carbon cycle has recently gained prominence as a significant global issue, and plants play a significant role in carbon storage. Numerous studies have been conducted to examine the role of different species of woody trees in carbon sequestration, but we know very little about the potential of bamboo to produce biomass and sequester carbon on land (Ly *et al*., 2012; Nath *et al*., 2015a; Yuen *et al*., 2017; Nath *et al*., 2018) because only a small number of the approximately 1250 species of bamboo have been studied. The demand for identifying systems with high carbon sinks as a mitigation technique has increased due to the increase in greenhouse gas concentration in the atmosphere and its adverse impacts related to climate change. "Agroforestry and other tree-based systems, such as farm forestry, have the capacity to quickly store carbon" Nath *et al*., (2016b).

Bamboo is significant to regional economies, particularly Asia and the Pacific (Holttum, 1958). In India's controlled ecosystems, bamboo is widely distributed in plantations (Chandrashekara, 1996), agroforestry (Divakara *et al*., 2001), dispersed clumps, windbreaks on farm boundaries, and forest (Haridasan and Tewari, 2008). It has a long history of being a resource that is incredibly adaptable and widely used. Primary conventional uses include those "paper and pulp, fuel, food, and feed, as well as for building houses, scaffolding", and various common items. They also help prevent soil erosion and promote on-site nutrient conservation (Christanty *et al*., 1996; Scurlock *et al*., 2000; Zhang *et al*., 2014). "Bamboos have distinct growth patterns that are different from those of timber species, as well as rapid growth, high biomass output, and quick maturation from shoot to culm" Scurlock *et al*., 2000; Nath *et al*., 2007; Nath *et al*., 2015a. Ecologists are interested in bamboo since it can be used as biomass in some areas (Scurlock *et al*., 2000; Darabant *et al*., 2014; Yen and Lee 2010; Nath *et al*., 2009; Zhang *et al*., 2014; Nath *et al*., 2015a). Nevertheless, the knowledge of the contribution of bamboo to biomass production and terrestrial carbon is restricted (Nath *et al*., 2015b) because only a few species from "116 of the over 1450 species" (Soderstrom and Ellis, 1988) have been well-studied.

Age distribution in bamboo forests is uneven, with variously aged culms dispersed throughout the forest. Several genera, such *Phyllostachys* in China (Yen and Lee 2010; Zhang *et al*., 2014, Yen and Lee 2011) and *Bambusa* in India, are the subject of the majority of studies on bamboos (Shanmughavel *et al*., 2001; Nath *et al*., 2009). Several studies have demonstrated that bamboo's aboveground biomass accumulation rises with age (Yen *et al*., 2010). Age-specific models are crucial for estimating biomass (Holttum, 1958; Nath *et al*., 2015a). "The commercial use of the species is aided by knowledge of many culm parameters, such as age and diameter, as well as its mechanical properties" Inoue *et al*., (2013). The age structure of bamboo forests is uneven, with culms of various ages dispersed across a stand. This makes estimating biomass more challenging than using forest trees. The majority of research on bamboo is restricted to a few taxa, including "*Bambusa*" in India and "*Phyllostachys*" in China (Yen and Lee 2010; Zhang *et al*., 2014). (Shanmughavel *et al*., 2001; Nath and Das, 2012). Several studies have demonstrated that bamboo's aboveground biomass accumulation rises with age (Yen *et al*., 2010). Hence, it is crucial to create age-specific models.

"One of the most important forest species in tropical and subtropical areas of the world, bamboo offers timber, food for human life, and economic and ecological benefits" Scurlock *et al*., 2000; Zhang *et al*., 2014). Recent decades have seen the global importance of bamboo as biomass resources increase in various parts of the world (Scurlock *et al*., 2000; Darabant *et al*., 2014; Yuen *et al*., 2017). Bamboo's appeal as a plantation species expanded when recognized as a volunteer carbon financing system (Darabant *et al*., 2014).

Recent research has emphasized bamboo's potential use in carbon farming and trading (Nath *et al*., 2015a; Nath *et al*., 2018). Compared to bamboo found in the wild, bamboo planted and managed in village landscapes has yet to receive more investigation about its potential for carbon sequestration. In India, "*Bambusa*" species make up the majority of thick walled bamboo. Most members of the vast clumping bamboo genus "*Bambusa* are tall and dense" (Banik, 2000). In Bangladesh and India, this plant is frequently grown in backyard gardens, forming family forests (Banik, 2000). “37 species of the genus *Bambusa*, which accounts for 26% of all bamboo species in India, are primarily arborescent bamboos that flourish in a variety of environments and climates” -Sharma and Nirmala, (2015, pp. 22). Furthermore, research on bamboo's capacity to store biomass and absorb carbon in relation to village physiography needs to be more extensive. Bamboo cultivated in villages is typically taller and thicker than bamboo is grown in untamed environments (Nath *et al*., 2015a).

8.2. Methodology:

8.2.1. Determining culm ages within stands:

At each height, one plot of bamboo forest with a total area of 20 ha was chosen and set aside to estimate stand characteristics. Each bamboo culm's diameter and age were measured at breast height (DBH), and an age-based stratified sample technique was adopted. The culm had four distinct age groups: 1, 2, 3, and 4. Color of the outline, the condition of the culm sheath, the external appearance of the culms, and the growth of branches and leaves are used to estimate the age of bamboo. The process of determining age can be summed up as follows:

(1) One-year-old bamboo still has its sheaths inside the culm, and a clear white powder has been sprinkled on the culm surface.

(2) Two-year-old bamboo has culm sheaths that are starting to deteriorate; the surface's white hue progressively fades away, and the culm turns light green.

(3) After three years, the sheath of the bamboo has started to drop, and the bottom of the culm has been infected with mould and turned dark green.

(4) In bamboo that is 4 years old, the sheath has vanished from the culm's surface, which is mouldy and has turned a yellowish green colour. Bamboo samples were chosen based on their distinct age, which was established by their trait.

8.2.2. Vegetative sampling collection:

Three species from each altitudinal gradient, representing different age classes, were chosen for 360 samples (180 samples each for 2 years). Culm harvesting took place after the young culms had finished growing and before the emergence of the new culms. To prevent overestimating the fresh weight of the samples, harvesting was not done on rainy days. The recently harvested culms were used to collect the necessary information. Any stand of bamboo has both living biomass (such as culm/stem, branch, twig, and leaf) and litter. Because litter and culm-sheath biomass contributed so little to overall biomass, many researchers avoided it. In the current study, the total stand biomass (TSB) of the selected bamboo forests was estimated using aboveground biomass (AGB) and belowground biomass (BGB).

The girth of the culms was measured at the height of 1.3 metres above the ground, and culms were divided into several size classes after being chosen based on their age. At the point when the culm base meets the ground or as near to it as possible, the required culms were selectively harvested. For each age class, five culms from each size category were collected. The culms were divided into stem, leaf, branch, and culm-sheath after harvest (if present). The stems' height and top-to-bottom diameter were measured. The total culm fresh weight (CWT) in kilograms was calculated by adding the data obtained for each part. Also, each stem was divided into three equal pieces, measuring 3 meters from the bottom, middle, and top, and each piece was freshly weighted in the field. They comprised each section's sub-examples. In the field shortly after harvesting, the fresh weights of each component were also measured independently, and 50 g subsamples were also taken from each sample.

8.2.3. Litter fall biomass:

Every three months, a quadrate of 50 cm by 50 cm was randomly placed at three different heights to collect the litter fall mass of each species. From each plot, 180 quadrates were laid between 2019 and 2022. Each plot's floor mass was collected, divided into leaf, culm sheath, and branch components, and weighed separately. Sub-samples were gathered, dried in an oven at 70°C, and weighed. For additional analysis, materials that had been oven-dried were ground.

8.2.4. Biomass estimation:

The aboveground living samples' gathered sub-samples of various components were taken to a lab and maintained at 70 °C in a hot air oven to a consistent weight. The total biomass for each culm was estimated from the biomass of the sub-samples of the various components. The biomass of the sub-samples was also used to compute the total stem and leaf biomass per culm. The statistical analysis then makes use of the data. The various litter components and fresh samples collected above ground were also taken to the lab and stored in a hot air oven at “70°C” to a constant weight. The total biomass was then translated into biomass per hectare. The estimated biomass values “(Mg ha^{-1})” of all the culms were added up to determine the total AGB per hectare of the bamboo stand. The total biomass stock was determined by adding the projected biomass values total “AGB (Mg ha^{-1})” and total “BGB (Mg ha^{-1})”.

8.2.5. Carbon content determination of the biomass:

During the sampling period, all sub-samples of the aboveground components “(stem, branch, leaf, and culm-sheath)” and the belowground parts “(rhizome, rhizoids, and coarse root)” were brought to the lab and oven dried to obtain the constant weight. Wiley mill was used to grind oven-dried samples, which were then tested to determine their carbon content. The carbon (C) content is calculated to be 50% of the ash-free mass (Allen, 1989b). The amount of ash was ascertained by igniting 1g of the powdered samples at 550°C for 6 hours in a muffle furnace (Allen, 1989). The sum of the data for the C content for the various components was used to calculate the overall C storage in the aboveground and belowground biomass.

8.2.6. Statistical analysis:

One-way ANOVA and Person correlation were used to examine significant differences in culm features between age and species. The percent carbon content (PCC) of bamboo from various parts and ages was compared using a two-way ANOVA. The least significant difference (LSD) approach was employed to compare differences in PCC if PCC is substantially different ($p<0.05$) by age and section of bamboo.

8.3. Result:

8.3.1. Culm characteristics in relation to age, species, and study sites:

During the present study, culm height of *B. tulda* ranges from 15±0.33 to 20±0.45 m long in Longkhum, 13±0.21 to 25±0.09m long in Chungtia and 12±0.22 to 17±0.03 cm in Tuli. *D. asper* varies from 18±0.42 to 25±0.06 m in Longkhum and 17±0.23 to 24±0.18m in Chungtia . *D. hamiltonii* varies from 16±0.45 to 22±0.12 m in Longkhum, 19±0.14 to 23±0.06m in Chungtia, and 16±0.06 to 25±0.04 m in Tuli. *B. pallida* varies from 12±0.51 to 19± 0.17m in Tuli.

The diameter of *B. tulda* varies from 18±0.04 to 27±0.13 cm in Longkhum, 19±0.19 to 26±0.34 cm in Chungtia, and 8±0.09 to 17±0.21 cm in Tuli. *D. asper* varies from 20±0.56-28±0.05 cm in Longkhum and 21±0.33 to 30±0.17 cm in Chungtia. *D. hamiltonii* varies from 11-30 cm in Longkhum, 22±0.23 to 28±0.12 cm in Chungtia, and 15-20 cm in Tuli. *B. pallida* varies from 7±0.03 to 15±0.45 cm in Tuli.

Culm fresh weight of *B. tulda* varies from 22±0.46 to 25±0.66kg/culm and 16.12±0.0 to 26.49±0.23kg/culm during the first and second year in Longkhum, and in Chungtia, it varied from 25.34±0.12 to 33.08±0.08kg/culm and 19.32±0.24 to 36.88±0.28kg/culm in the first and second year. In Tuli, it varied from 17.49±0.32 to 24.45±0.06kg/culm and 16±0.12 to 24.56±0.31kg/culm in the first and second years, respectively.

The fresh weight of *D. asper* varied from 11.49±0.1 to 20.49±0.08kg/culm during the first year and 11.36±0.09 to 15.8±0.06kg/culm in Longkhum. In Chungtia, it varied from 18.44±0.14 to 38.55±0.06kg/culm and 24.1±0.02 to 39.86±0.15kg/culm in the first and second years.

Culm, fresh weight of *D. hamiltonii*, varied from 10.09±0.03 to 21.78±0.12kg and 16.88±0.19 to 22.64±0.06kg/culm during the first and second year in Longkhum. In Chungtia it varied from 11.69±0.02 to 17.61±0.16kg/culm and 10.62±0.68 to 16.79±0.05kg/culm during the first and second years. In Tuli, it varied from 8.41±0.29 to 19.94±0.23kg/culm and 8.55±0.12 to 27.26±0.28kg/culm during the first and second years.

The fresh weight of *B. pallida* varied from 13.93±0.05 to 17.64±0.06kg/culm and 13.88±0.09 to 18.55±0.14kg/culm.

Culm height, diameter, and weight varied in different ages and species. Analysis of culm height, diameter, and fresh weight showed that H (m) ($F=35.42$, $p<0.000$), diameter (cm) ($F=5.64$, $p<0.022$), and fresh weight (kg) ($F=12.99$, $p<0.001$.) vary significantly with age, species and study sites.

Table 8.1: Two way ANOVA of culm height, diameter and fresh weight.

Parameters	Source	2019-2020		2020-2021	
		F (3,8)	*p* (value)	F (3,8)	*p*(value)
Culm height	Site	6.58	0.014	8.92	0.005
	Species	4.02	0.051	6.86	0.001
	SitexSpecies	35.42	0.000	5.07	0.000
Diameter	Site	37.61	0.000	3.46	0.000
	Species	7.83	0.008	12.7	0.003
	SitexSpecies	5.64	0.022	47.98	0.004
Fresh weight	Site	22.30	0.000	12.68	0.041
	Species	77.77	0.000	37.61	0.000
	SitexSpecies	12.99	0.001	12.99	0.000

The Pearson's correlation coefficient values culm height, diameter and fresh weight of Longkhum, Chungtia and Tuli are presented in table 8.2.

Table 8.2: Pearson's correlation coefficient values culm height, diameter and fresh weight of Longkhum, Chungtia and Tuli during 2018-2022

SITE	PARAMETER	H	DBH	FW
LONGKHUM 2018-2019	H	1		
	DBH	.311* .016	1	
	FW	.663** .000	.496** .000	1
LONGKHUM 2021-2022	H	1		
	DBH	.094 .476	1	
	FW	.494** .000	.204 .118	1
CHUNGTIA 2018-2019	H	1		
	DBH	.359** .005	1	
	FW	.722** .000	.458** .000	1
CHUNGTIA 2021-2022	H	1		
	DBH	.293* .023	1	
	FW	.813** .000	.428** .001	1
TULI 2018-2019	H	1		
	DBH	.064 .629	1	
	FW	.604** .000	.292* .023	1
TULI 2021-2022	H	1		
	DBH	.187 .152	1	
	FW	.079 .551	.176 .179	1

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

In Longkhum, FW was positively correlated to height and diameter at $p<0.01$ significant level, and diameter was positively correlated to height at $p<0.05$ level during the first year. In the second year, the fresh weight was positively correlated only with diameter.

In Chungtia, at $p<0.001$ significant level, DBH was positively correlated to H ($r=0.359$), and fresh weight was positively correlated to H ($r=0.722$) and DBH ($r=0.458$) in the first year. On the contrary, DBH was positively correlated to H ($r=0.293$) at $p< 0.01$ and FW was positively correlated to H ($r=0.813$) and DBH ($r=0.428$) at $p<0.01$ significant level in the second year.

In Tuli, at $p<0.01$ significant level, FW was positively correlated to H ($r=0.604$) and DBH ($r=0.292$) at $p<0.005$ level in the first year. In the second year, there was no correlation among H, DBH, and FW.

8.3.2. Biomass allocation in a different component of bamboo:

Figure 8.1: Biomass allocation in different components of *B. tulda*, *B. pallida*, *D. asper* and *D. hamiltonii*.

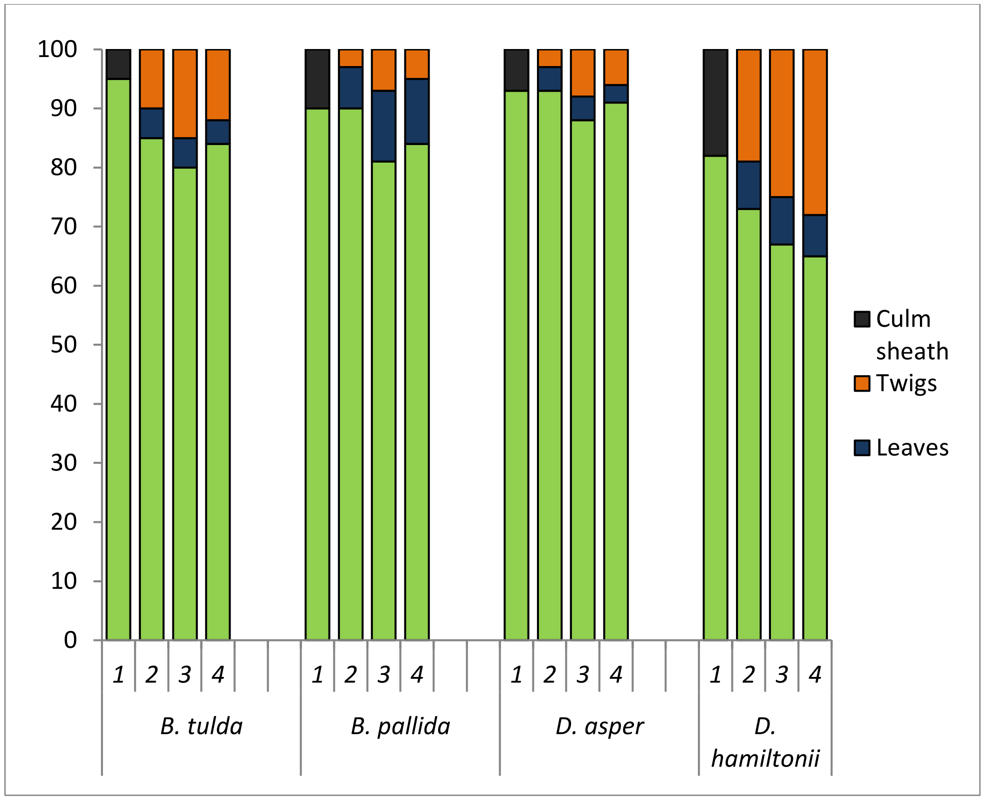


Figure 8.1: Biomass allocation in different components of *B. tulda*, *B. pallida*, *D. asper* and *D. hamiltonii*

The biomass allocation in different components of bamboo among the different culm ages for *Bambusa tulda* reveals that the culm component contributes the highest proportion (80-95%), followed by branch (5-15%), leaf (0-5%) and sheath (1% in the current year only) (Figure 8.1). The culm biomass was highest in current year culms (95%), branch biomass was highest in 3 year old culms (15%) and leaf biomass was highest in 2 and 3 year culms (5%). The analysis of variance shows that the biomass content in the branch, leaf, and sheath and the total AGB significantly varied with culm age ($p<0.05$). The analysis of variance also revealed that the biomass content in culm and total AGB significantly varied with DBH ($p<0.05$).

The biomass allocation in different components of bamboo among the different culm ages for *D. asper* reveals that the culm component contributes the highest proportion (84-90%), followed by branch (3-12%), leaf (4-7%) and sheath (1% in the current year only) (Figure 8.1). The culm biomass was highest in current and 2 year old culms (90%), branch biomass was highest in 3 year old culms (12%) and leaf biomass was highest in 2 and 3 year culms (7%).

The biomass allocation in different components of bamboo among the different culm ages for *D. hamiltonii* reveals that the culm component contributes the highest proportion (65-82%), followed by branch (7-25%), leaf (3-8%) and sheath (1% in the current year only) (Figure 8.1). The culm biomass was highest in current (82%) and 2 year old culms (73%), branch biomass was highest in 3 year old culms (25%). Leaf biomass was highest in 2 and 3 year culms (8%).

The biomass allocation in different components of bamboo among the different culm ages for *B. pallida* reveals that the culm component contributes the highest proportion (88-93%), followed by branch (3-8%), leaf (0-4%) and sheath (1% in the current year only) (Figure 8.1). The culm biomass was highest in current and 2 year old culms (93%), branch biomass was highest in 3 year old culms (8%) and leaf biomass was highest in 2 and 3 year culms (4%).

8.3.3. Percentage carbon content (PCC):

The PCC was higher in culm followed by twigs and least was recorded from foliage in all the species and in all the study sites. In Longkhum, the highest PCC was recorded in *B. tulda* (48.49±0.42 -57.07±0.09%), followed by *D. asper* (49.48±0.04-56.49±0.08%), and least was recorded in *D. hamiltonii* (49.03±0.13-56.79±0.21%). In Chungtia, the highest PCC was recorded in, *D. asper* (48.36±0.28-56.83±0.22), followed by *B. tulda* (47.22±0.21-56.81±0.21%) and the lowest was observed in *D. hamiltonii* 46.63±0.05-56.71±0.21%). In Tuli, the highest was recorded in *B. pallida* (47.88±0.07-57.19±0.08%), followed by *B. tulda* (49.12±0.21-57.08±0.24%) and the least was observed in *D. hamiltonii* (49.42±0.03-56.95±0.51%).

A comparison of the mean PCC for different ages, sections, and species revealed that the PCC was significantly different at the $p<0.05$ level in terms of age ($p<0.00$) and section of the bamboo ($p<0.000$). The LSD method was used to compare the PCC among ages and components (Table 8.4-8.6). It was found that PCC was higher in culm and lower in foliage. Additionally, bamboo of all ages showed the same trend.

Table 8.3: PCC (%) of different components and within different age of Bamboo species in Longkhum

		2018 – 2019				2021- 2022				
Species	**Age**	**Culm**	**Twigs**	**Leaves**	**Culm sheath**	**Culm**	**Twigs**	**Leaves**	**Culm sheath**	**p-Value**
B. tulda	1	56.55±0.07 a			54.97±0.17 b	51.99±0.23 a			55.99±0.06 b	0.00
	2	56.84±0.12 a	53.81±0.02 b	51.99±0.23 c		56.44±0.23 a	55.45±0.08 b	48.49±0.42 c		0.00
	3	57.07±0.09 a	54.66±0.06 b	51.99±0.15 c		56.73±0.45 a	54.69±0.04 b	50.08±0.09 c		0.00
	4	56.29±0.05 a	51.46±0.11 b	50.15±0.06 c		56.96±0.08 a	55.50±0.11 b	49.3±0.23 c		0.00
D. asper	1	56.45±0.13 a			54.72±0.21 b	54.69±0.21 a			55.68±0.08 b	0.00
	2	56.11±0.22 a	53.51±0.16 b	49.48±0.04 c		56.49±0.08 a	53.48±0.12 b	50.32±0.18 c		0.00
	3	56.23±0.06 a	53.16±0.06 b	49.65±0.12 c		55.97±0.06 a	52.82±0.11 b	49.93±0.11 c		0.01
	4	55.99±0.15 a	53.61±0.04 b	50.35±0.12 c		55.93±0.08 a	52.17±0.06	46.11±0.09		0.00
D. hamiltonii	1	56.05±0.17 a			54.53±0.07 b	56.79±0.21 a			55.83±0.12 b	0.00
	2	56.60±0.08 a	53.22±0.12 b	50.36±0.06 c		56.15±0.22 a	54.62±0.21 b	50.50±0.04 c		0.00
	3	55.37±0.04 a	53.46±0.09 b	50.64±0.05 c		56.85±0.11 a	54.86±0.18 b	49.03±0.13 c		0.00
	4	55.87±0.02 a	52.88±0.13 b	50.94±0.02 c		55.40±0.09 a	54.46±0.06 b	50.50±0.05 c		0.00

Mean± standard deviation and letter ab and c are LSD method value at *p*=0.05

Table 8.4: PCC (%) value of different components and within different age of Bamboo in Chungtia

		2018-2019				2021-2022				
Species	Age	Culm	Twigs	Leaves	Culm sheath	Culm	Twigs	Leaves	Culm sheath	p-Value
B. tulda	1	56.74±0.42 a			54.38±0.28 b	56.12±0.21 a			54.9±0.14 b	0.00
	2	56.81±0.21 a	53.27±0.05 b	49.72±0.09 c		56.25±0.17 a	53.12±0.26 b	47.51±0.22 c		0.00
	3	56.67±0.22 a	52.39±0.14 b	49.56±0.05 c		56.78±0.09 a	54.71±0.15 b	49.63±0.26 c		0.00
	4	56.62±0.05 a	53.48±0.09 b	47.22±0.21 c		56.34±0.23 a	54.46±0.13 b	50.51±0.11 c		0.04
D. asper	1	56.56±0.42 a			54.28±0.12 b	55.76±0.24 a			54.67±0.21 b	0.00
	2	56.83±0.22 a	54.36±0.03 b	51.13±0.22 c		56.22±0.07 a	54.72±0.11 b	50.78±0.34 c		0.00
	3	56.54±0.09 a	52.89±0.21 b	50.98±0.34 c		56.11±0.21 a	55.72±0.09 b	50.37±0.45 c		0.01
	4	56.19±0.11 a	49.93±0.14 b	48.93±0.46 c		55.39±0.29 a	53.55±0.03 b	48.36±0.28 c		0.00
D. hamiltonii	1	56.46±0.18 a			54.56±1.04 b	56.27±0.06 a			54.79±1.02 b	0.00
	2	56.71±0.21 a	52.62±0.09 b	51.58±0.05 c		56.39±0.11 a	53.45±0.33 b	47.44±0.13 c		0.00
	3	56.42±0.32 a	51.82±0.02 b	49.12±0.16 c		55.56±0.18 a	51.68±0.34 b	47.45±0.19 c		0.00
	4	56.57±0.47 a	51.77±0.21 b	51.05±0.11 c		55.02±0.15 a	53.56±0.13 b	46.63±0.05 c		0.00

Mean± standard deviation and letter ab and c are LSD method value at *p*=0.05

Table 8.5: PCC (%) value of different components and within different age of Bamboo in Tuli

		2018-2019				2021-2022				
Species	Age	Culm	Twigs	Leaves	Culm sheath	Culm	Twigs	Leaves	Culm sheath	p-Value
B. pallida	1	55.61±0.67 a			47.88±0.07 c	56.91±0.25 a			54.51±0.11 b	0.00
	2	56.78±0.13 a	51.21±0.24 b	49.23±0.27 c		57.17±0.16 a	54.28±0.05 b	52.51±0.74 c		0.00
	3	56.94±0.21 a	50.68±0.48 b	49.60±0.15 c		57.19±0.08 a	54.87±0.32 b	53.72±0.77 b		0.00
	4	56.75±0.06 a	50.77±0.45 b	48.57±0.19 c		57.07±0.19 a	54.87±0.12 b	50.83±0.23 c		0.00
B. tulda	1	56.68±0.34 a			47.97±0.23 c	56.16±0.27 a			54.33±0.23 b	0.02
	2	57.07±0.23 a	51.49±0.29 b	49.83±0.32 c		57.08±0.24 a	54.35±0.27 b	52.89±1.06 c		0.00
	3	57.08±0.44 a	52.82±0.18 b	49.75±0.27 c		56.96±0.12 a	54.73±0.12 b	51.81±0.98 c		0.00
	4	56.92±0.46 a	50.58±0.08 b	49.12±0.21 c		56.85±0.56 a	54.83±0.09 b	52.52±0.12 c		0.00
D. hamiltonii	1	56.72±0.87a			48.79±0.14 c	56.21±0.16 a			53.65±0.15 b	0.00
	2	56.91±0.02 a	51.45±0.07 b	49.92±0.11 c		56.02±0.33 a	53.13±0.08 b	52.22±0.56 c		0.00
	3	56.95±0.51 a	49.42±0.03 b	50.54±0.16 c		56.79±0.46 a	53.43±0.13 b	52.49±0.43 c		0.00
	4	56.31±0.06 a	50.95±0.13 b	50.44±0.09 c		56.79±0.25 a	53.72±0.19 b	51.71±0.08 c		0.00

Mean± standard deviation and letter ab and c are LSD method value at $p<0.05$

8.3.4. Carbon stock in different age classes and components:

The carbon stock in the different components of bamboo was found to vary significantly. In Longkhum, *B. tulda* total carbon stock of one year old culm was 165.41±0.35 Mg/ha, culm sheath was 5.58±0.33 Mg/ha and the total aboveground carbon (AGC) was 170.99±0.68 Mg/ha. Two year old culm was 172.15±0.06 Mg/ha, twigs were 13.64±0.15 Mg/ha, leaves were 8.45±0.11 Mg/ha, and total AGBC was 194.24±0.52 Mg/ha. Three year old culm 245.24±0.09 Mg/ha, twigs were 16.55±0.21 Mg/ha, leaves were 10.38±0.25 Mg/ha and total AGBC was 272.17±0.55 Mg/ha. Four year old culm was 245.76±0.45 Mg/ha, twigs were 23.09±0.15 Mg/ha, leaves were 17.46±0.11 Mg/ha and total ABGC was 286.31±0.71 Mg/ha.

D. asper total carbon stock for one year old culm was 88.75±0.06 Mg/ha, culm sheath was 8.31±0.52 Mg/ha, and total AGC was 97.06±0.58 Mg/ha. Two year old culm carbon stock was 98.19±0.06 Mg/ha, twigs were 15.47±0.19 Mg/ha, leaves were 11.64±0.32 Mg/ha, and total ABGC was 125.3±0.57 Mg/ha. Three year old culm total carbon stock was 146.81±0.12 Mg/ha; twigs were 10.64±0.39 Mg/ha, leaves were 7.53±0.14 Mg/ha and AGC was164.98±0.65 Mg/ha. Carbon stock of four year old culm was 154.83±0.11 Mg/ha, twigs were 15.17±0.16 Mg/ha, leaves were 11.15±0.13 Mg/ha and total AGC was 181.13±0.40 Mg/ha.

D. hamiltonii, total carbon stock of one year old culm, was 119.27±0.19 Mg/ha, culm sheath was 10.45±0.42 Mg/ha, and total ABC was

129.72±0.61 Mg/ha. Two tear old culm carbon stock was 121.28±0.07 Mg/ha, twigs were 28.62±0.14 Mg/hac, leaves were 20.92±0.09 Mg/ha, and total AGC stock was 170.82±0.30 Mg/ha. Three year old culm total carbon stock was 149.97±0.15 Mg/ha; twigs were 13.96±0.02 Mg/ha, leaves were 12.55±0.21 Mg/ha, and total AGC stock was 176.48±0.38 Mg/ha. Four year old culm, the total carbon stock was174.43±0.15 Mg/ha, twigs were 17.07±0.06 Mg/ha, leaves were 16.67±0.26 Mg/ha, and total AGC stock was 201.48±0.47 Mg/ha in the first year.

During second year, the total carbon stock of one year old culm of *B. tulda* was 191.74±0.17 Mg/ha, culm sheath was 6.71±0.32 Mg/ha and total above ground carbon (ABC) was 198.45±0.5 Mg/ha. Two year old culm was 203.41±0.18 Mg/ha, twigs were 14.85±0.05 Mg/ha, leaves were 9.92±0.79 Mg/ha, and total AGBC was 228.18±0.38 Mg/ha. Three year old culm was 286.54±0.22 Mg/ha, twigs were 19.17±0.12 Mg/ha, leaves were 12.14±0.15 Mg/ha and total ABC was 317.85±0.65 Mg/ha. Four year old culm was 278.34±0.31 Mg/ha, twigs were 26.21±0.27 Mg/ha, leaves were 19.26±0.07 Mg/ha and total AGC was 323.81±0.65Mg/ha.

D. asper total carbon stock for one year old culm was 103.41±0.14 Mg/ha, culm sheath was 9.17±0.07 Mg/ha and total ABGC was 112.72±0.21 Mg/ha. Two year old culm carbon stock was 119.51±0.33 Mg/ha, twigs were 13.65±0.24 Mg/ha, leaves were 9.31±0.32 Mg/ha, and total ABGC was 142.47±0.89 Mg/ha. Three year old culm total carbon stock was 166.90±0.99 Mg/ha, twigs were 16.99±0.11 Mg/ha, leaves were

13.48±0.33 Mg/ha, and ABGC was 196.41±1.43 Mg/ha. Carbon stock of four year old culm was 179.38±0.08 Mg/ha, twigs were 18.63±0.09 Mg/ha, leaves were 12.52±0.0.36 Mg/ha, and total ABGC was 210.53±0.53 Mg/ha.

D. hamiltonii total carbon stock of one year old culm was 124.19±0.13 Mg/ha, culm sheath was 11.11±0.17 Mg/ha, and total ABC was 135±0.3 Mg/ha. Two year old culm was 132.47±0.26 Mg/ha, twigs were 29.08±0.15 Mg/ha, leaves were 21.58±0.21 Mg/ha, and total AGC stock was 183.4±0.62 Mg/ha. Three year old culm carbon stock was 158.32±0.14 Mg/ha, twigs were 14.88±0.59 Mg/ha, leaves were 13.11±0.88 Mg/ha, and total AGC was 186.31±1.61 Mg/ha. Four year old culm carbon stock was 173.12±0.12 Mg/ha, twigs were 17.23±0.11 Mg/ha, leaves were 17.23±0.11 Mg/ha, and total AGC stock was 207.58±0.43 Mg/ha respectively (Table 8.6).

Table 8.6: Carbon stock (Mg/ha) within different bamboo species age and components in bamboo forest of Longkhum

		2019-2020					2021-2022					
Species	**Age**	**Culm**	**Twigs**	**Leaves**	**Culm sheath**	**Total**	**Culm**	**Twigs**	**Leaves**	**Culm sheath**	**Total**	**Per year**
B.tulda	1 year old	165.41±0.35	NA	NA	5.58±0.33	170.99±0.68	191.74±0.17	NA	NA	6.71±0.32	198.45±0.5	7.63±0.36
	2 year old	172.15±0.06	13.64±0.15	8.45±0.11	NA	194.24±0.52	203.41±0.18	14.85±0.05	9.92±0.79	NA	228.18±0.38	24.77±0.14
	3 year old	245.24±0.09	16.55±0.21	10.38±0.25	NA	272.17±0.55	286.54±0.22	19.17±0.12	12.14±0.15	NA	317.85±0.65	25.85±0.10
	4 year old	245.76±0.45	23.09±0.15	17.46±0.11	NA	286.31±0.71	278.34±0.31	26.21±0.27	19.26±0.07	NA	323.81±0.65	17.67±0.70
D.asper	1 year old	88.75±0.06	NA	NA	8.31±0.52	97.06±0.58	103.41±0.14	NA	NA	9.17±0.07	112.72±0.21	15.66±0.37
	2 year old	98.19±0.06	15.47±0.19	11.64±0.32	NA	125.3±0.57	119.51±0.33	13.65±0.24	9.31±0.32	NA	142.47±0.89	17.17±0.32
	3 year old	146.81±0.12	10.64±0.39	7.53±0.14	NA	164.98±0.65	166.90±0.99	16.99±0.11	13.48±0.33	NA	196.41±1.43	31.43±0.22
	4 year old	154.83±0.11	15.17±0.16	11.15±0.13	NA	181.13±0.40	179.38±0.08	18.63±0.09	12.52±0.0.36	NA	210.53±0.53	29.4±0.13
D.hamiltonii	1 year old	119.27±0.19	NA	NA	10.45±0.42	129.72±0.61	124.19±0.13	NA	NA	11.11±0.17	135±0.3	5.28±0.31
	2year old	121.28±0.07	28.62±0.14	20.92±0.09	NA	170.82±0.30	132.47±0.26	29.08±0.15	21.58±0.21	NA	183.4±0.62	12.92±0.32
	3 year old	149.97±0.15	13.96±0.02	12.55±0.21	NA	176.48±0.38	158.32±0.14	14.88±0.59	13.11±0.88	NA	186.31±1.61	9.83±1.47
	4 year old	174.43±0.15	17.07±0.06	16.67±0.26	NA	201.48±0.47	173.12±0.12	17.23±0.11	17.23±0.11	NA	207.58±0.43	6.1±0.04

The results of a two-way ANOVA test (Table: 8.7) between the bamboo species and age classes showed a statistically significant difference in all of the components ($p<0.01$).

Table 8.7: Two-way ANOVA of different components of different bamboo species.

		2019-2020		2020-2021	
Parameter	**Source**	**F (3,8)**	**P value**	**F (3,8)**	**P value**
Culm	Species	4.211	0.000	5.824	0.000
	Age	717.42	0.000	2.738	0.000
	Species x Age	278.81	0.000	1.106	0.000
Leaves	Species	2.691	0.000	364.25	0.000
	Age	1.505	0.000	2.990E	0.000
	Species x Age	909.16	0.000	152.19	0.000
Twigs	Species	2.360	0.000	433.68	0.000
	Age	2.725	0.000	1.647	0.000
	Species x Age	1.88	0.000	772.89	0.000
Culm Sheath	Species	160.81	0.000	312.32	0.000
	Age	5.32	0.000	1.562	0.000
	Species x Age	160.81	0.000	312.32	0.000

In Chungtia, the carbon content in one year old culm of *B. tulda* was 173.78±0.03 Mg/ha, culm sheath was 7.37±0.22 Mg/ha and total AGC content was 181.15±0.25 Mg/ha. Two year old culm carbon value was 194.82±0.11 Mg/ha, twigs were 17.54±0.24 Mg/ha, leaves were 6.56±0.32 Mg/ha and total 218.92±0.67 Mg/ha. In three year old culm, the carbon content was 244.9±0.04 Mg/ha, twigs were 30.53±0.29 Mg/ha, leaves were 20.61±0.14 Mg/ha, and total AGC was 296.04±0.47 Mg/ha. In four year old culm, the carbon stock was 236.12±0.03 Mg/ha, twigs were

37.34±0.13 Mg/ha, leaves were 21.16±0.12 Mg/ha, and total AGC was 294.62±0.28 Mg/ha.

One year old culm of *D. asper* carbon stock value was 118.63±0.14 Mg/ha, culm sheath was 10.24±0.15 Mg/ha, and total AGC was 128.87±0.29 Mg/ha. In two year old culm, the value was 124.86±0.26 Mg/ha, twigs were 13.45±0.41 Mg/ha, leave was 10.66±0.12 Mg/ha, and the total AGC was 148.97±0.79 Mg/ha. In three year old culm, the carbon stock value was 167.43±0.10 Mg/ha, twigs were 20.56±0.22 Mg/ha, leave was 15.25±0.17 Mg/ha, and total AGC stock value was 203.24±0.49 Mg/ha. In four year old culm, the carbon stock value was 188.78±0.30 Mg/ha, twigs were 17.54±0.25 Mg/ha, leave were 13.85±0.10 Mg/ha, and total AGC stock was 220.17±0.65 Mg/ha.

In *D. hamiltonii*, the carbon stock value in one year old culm was 145.77±0.17 Mg/ha, culm sheath was 11.49±0.13 Mg/ha, and the total AGC value was 157.26±0.30 Mg/ha. In two year old culm, the value of carbon stock was 153.82±0.25 Mg/ha, twigs were 21.54±0.23 Mg/ha, leaves were 19.49±0.28 Mg/ha and total AGC stock value was 194.85±0.76 Mg/ha. Three year old culm carbon stock value was 153.82±0.25 Mg/ha, twigs were 21.54±0.23 Mg/ha, leaves were 19.49±0.28 Mg/ha, and total AGC value was 194.85±0.76 Mg/ha. In four year old culm, the carbon stock in the culm was 207.07±0.61 Mg/ha, twigs were 26.39±0.15 Mg/ha, leaves were 26.21±0.21 Mg/ha and total AGC was 259.3±0.90 Mg/ha.

In second year, the carbon stock value in one year culm of *B. tulda* was 195.63±0.27 Mg/ha, culm sheath was 8.14±0.04 Mg/ha and the total AGC value was 203.77±0.31 Mg/ha. In two year old culm, the carbon stock value was 210.37±0.24 Mg/ha, twigs were 19.06±0.11 Mg/ha, leaves were 7.47±0.43 Mg/ha, and the total AGC value was 236.9±0.78 Mg/ha. Three year old culm carbon stock value was 285.68±0.43 Mg/ha, twigs were 31.48±0.24 Mg/ha, leave was 21.67±0.32 Mg/ha, and total AGC value was 338.83±0.99 Mg/ha. In four year old culm, the carbon stock value was 285.25±0.38 Mg/ha, twigs were 38.41±0.19 Mg/ha, leaves were 22.18±0.13 Mg/ha and total AGC value was 345.84±0.70 Mg/ha.

One year old culm of *D. asper* carbon stock value was 133.83±0.28 Mg/ha, culm sheath was 11.24±0.04 Mg/ha, and total AGC value was 145.07±0.32 Mg/ha. In two year old culm, the carbon value was 135.68±0.36 Mg/ha, the twigs were 18.33±0.12 Mg/ha, the leave was 15.42±0.32 Mg/ha, and the total AGC value was 169.43±0.80 Mg/ha. Three year old culm carbon stock value was 166.82±0.23 Mg/ha, twigs were 21±0.17 Mg/ha, leave was 17.36±0.62 Mg/ha, and total AGC value was 205.18±1.02 Mg/ha. In four year old culm carbon value was 213.7±0.18 Mg/ha, twigs were 21.24±0.23 Mg/ha, leaves were 16.66±0.40 Mg/ha, and the total AGC value was 251.6±0.81 Mg/ha.

In *D. hamiltonii*, the carbon stock value in one year old culm was 149.70±0.28 Mg/ha, culm sheath was 12.89±0.26 Mg/ha and the total AGC value was 162.59±0.54 Mg/ha. In two year old, the carbon content value was 162.56±0.14 Mg/ha, twigs were 21.69±0.10 Mg/ha, leaves were 20.24±0.26 Mg/ha, and the total AGC value was 204.49±0.50 Mg/ha. Three year old culm carbon stock value was 197.63±0.14 Mg/ha, twigs were 33.54±0.20 Mg/ha, leaves were 27.65±0.35 Mg/ha, and total AGC value was 258.82±0.69 Mg/ha. In four year old culm, the carbon stock value stock was 219.28±0.05 Mg/ha, twigs were 35.42±0.24 Mg/ha, leaves were 28.25±0.15 Mg/ha and the total AGC value was 282.95±0.44 Mg/ha (Table: 8.9). The results of a two-way ANOVA test (Table: 8.8) between the bamboo species and age classes showed a statistically significant difference in all of the components ($p<0.01$).

Table 8.8: Two-way ANOVA of culm, leaves and twigs of different bamboo species.

		2019-2020		2020-2021	
Parameter	**Source**	**F (3,8)**	**P value**	**F (3,8)**	**P value**
Culm	Species	3.025	0.000	9.943	0.000
	Age	1.116	0.000	5.532	0.000
	Species x Age	2.216	0.000	5.663	0.000
Leaves	Species	4.865	0.000	1.256	0.000
	Age	2.717	0.000	8.166	0.000
	Species x Age	1.482	0.000	378.09	0.000
Twigs	Species	3.966	0.000	5.754	0.000
	Age	2.396	0.000	3.724	0.000
	Species x Age	800.87	0.000	1.168	0.000
Culm Sheath	Species	458.54	0.000	53.68	0.000
	Age	2.89	0.000	3.217	0.000
	Species x Age	458.54	0.000	53.68	0.000

Table 8.9: Carbon stock (Mg/ha) within different bamboo species age and components in bamboo forest of Chungtia

Species	Age	2019-2020 Culm	Twigs	Leaves	Culm sheath	Total	2021-2022 Culm	Twigs	Leaves	Culm sheath	Total	Per year
B.tulda	1 year old	173.78±0.03			7.37±0.22	181.15±0.25	195.63±0.27			8.14±0.04	203.77±0.31	13.37±0.06
	2 year old	194.82±0.11	17.54±0.24	6.56±0.32		218.92±0.67	210.37±0.24	19.06±0.11	7.47±0.43		236.9±0.78	8.73±0.11
	3 year old	244.9±0.04	30.53±0.29	20.61±0.14		296.04±0.47	285.68±0.43	31.48±0.24	21.67±0.32		338.83±0.99	33.54±0.52
	4 year old	236.12±0.03	37.34±0.13	21.16±0.12		294.62±0.28	285.25±0.38	38.41±0.19	22.18±0.13		345.84±0.70	41.97±0.42
D.asper	1 year old	118.63±0.14			10.24±0.15	128.87±0.29	133.83±0.28			11.24±0.04	145.07±0.32	20.30±0.03
	2 year old	124.86±0.26	13.45±0.41	10.66±0.12		148.97±0.79	135.68±0.36	18.33±0.12	15.42±0.32		169.43±0.80	24.56±0.01
	3 year old	167.43±0.10	20.56±0.22	15.25±0.17		203.24±0.49	166.82±0.23	21±0.17	17.36±0.62		205.18±1.02	6.10±0.523
	4 year old	188.78±0.30	17.54±0.25	13.85±0.10		220.17±0.65	213.7±0.18	21.24±0.23	16.66±0.40		251.6±0.81	35.53±0.16
D.hamiltonii	1 year old	145.77±0.17			11.49±0.13	157.26±0.30	149.70±0.28			12.89±0.26	162.59±0.54	5.33±0.24
	2 year old	153.82±0.25	21.54±0.23	19.49±0.28		194.85±0.76	162.56±0.14	21.69±0.10	20.24±0.26		204.49±0.50	9.64±0.26
	3 year old	177.47±0.27	25.13±0.53	26.21±0.21		228.81±1.01	197.63±0.14	33.54±0.20	27.65±0.35		258.82±0.69	30.01±0.32
	4 year old	207.07±0.61	26.39±0.15	25.84±0.14		259.3±0.90	219.28±0.05	35.42±0.24	28.25±0.15		282.95±0.44	23.65±0.46

In Tuli, the carbon stock in one year old culm of *B. pallida* was 145.6±0.40 Mg/ha, culm sheath was 6.75±0.35 Mg/ha and total AGC was 152.35±0.75 Mg/ha. Two year old clm carbon stock was 184.9±0.05 Mg/ha, twigs were 13.33±0.23 Mg/ha, leaves were 21.72±0.14 Mg/ha and total carbon 219.95±0.42 Mg/ha. Three year old culm carbon stock was 204.11±0.52 Mg/ha, twigs were 23.46±0.18 Mg/ha, leaves were 10.63±0.10 Mg/ha and total AGC was 238.2±0.80 Mg/ha. Three year old culm carbon stock was 226.22±0.02 Mg/ha, twigs were 18.78±0.05 Mg/ha, leave were 16.46±0.14 Mg/ha and total AGC 261.46±0.21 Mg/ha.

One year old *B. tulda* culm carbon stock was 175.28±0.03, culm sheath was 6.27±0.16 Mg/ha, and total AGC was 181.55±0.19 Mg/ha. Two year old culm store 213.85±0.11 Mg/ha, twigs were 14.90±0.45 Mg/ha, leaves were 10.50±0.22 Mg/ha and total AGC was 239.25±0.78 Mg/ha. Three year old culm store 269.46±0.60 Mg/ha, twigs were 20.36±0.36 Mg/ha, leaves were 12.48±0.09 Mg/ha, and total AGC was 302.3±1.05 Mg/ha. Four year old carbon stock was 278.86±0.49 Mg/ha, twigs were 28.75±0.07 Mg/ha, leaves were 18.41±0.07 Mg/ha, and total AGC was 326.02±0.63 Mg/ha.

In *D. hamiltonii*, the carbon stock of one year old culm was 170.62±0.06 Mg/ha, culm sheath was 10.96±0.15 Mg/ha, and total AGC was 181.58±0.21 Mg/ha. Two year old culm carbon stock was 194.61±0.14 Mg/ha, twigs were 19.5±0.34 Mg/ha, leaves were 18.74±0.35 Mg/ha, and total AGC was 232.85±0.83 Mg/ha. Three year culm were 209.63±0.17

Mg/ha, twigs 33.62±0.20 Mg/ha, leaves were 25.52±0.36 Mg/ha and total AGC value was 268.77±0.73 Mg/ha. In four year old culm, the carbon stock value was 227.37±0.20 Mg/ha, twigs were 20.49±0.33 Mg/ha, leaves were 18.508±0.26 Mg/ha and the total AGC value was 266.37±0.79 Mg/ha.

In second year, the carbon stock in one year old culm of *B. pallida* was 128.29±0.43 Mg/ha, culm sheath was 7.89±0.43 Mg/ha, and the total AGC value was 190.18±0.86 Mg/ha. In two year old culm, the carbon stock value was 185.48±0.25 Mg/ha, twigs were 12.51±0.17 Mg/ha, leaves were 11.47±0.36 Mg/ha and the total AGC value was 209.46±0.78 Mg/ha. Three year old culm carbon stock value was 157.44±0.40 Mg/ha, twigs were 24.76±0.23 Mg/ha, twigs were 21.28±0.51 Mg/ha, and total AGC value was 203.48±1.14 Mg/ha. In four year old culm, the carbon stock value was 194.13±0.05 Mg/ha, twigs were 19.83±0.17 Mg/ha, leaves were 17.56±0.11 Mg/ha and total AGC was 231.52±0.33 Mg/ha.

In one year old culm of *B. tulda*, the carbon stock value was 222.42±0.34 Mg/ha, culm sheath was 7.81±0.36 Mg/ha, and the total AGC value was 230.23 ±0.7 Mg/ha. Two year old culm carbon stock value was 246.36±0.49 Mg/ha, twigs were 17±0.59 Mg/ha, leave was 11.5±0.45 Mg/ha and total AGC was 263.47±1.53 Mg/ha. Three year old culm carbon stock value was 290.77±0.18 Mg/ha, twigs were 22.04±0.06 Mg/ha, leaves were 13.49±0.41 Mg/ha and total AGC value was 326.3±0.65 Mg/ha. Four year old culm carbon stock value was

321.23±0.04 Mg/ha, twigs were 29.82±0.28 Mg/ha, leaves were 19.52±0.43 Mg/ha and total AGC value was 370.57±0.75 Mg/ha.

In one year old culm of *D. hamiltonii*, the carbon stock value was 185.11±0.11 Mg/ha, culm sheath was 12±0.33 Mg/ha, and the total AGC value was 197.11±0.44 Mg/ha. Two year old culm carbon stock value was 184.05±0.11 Mg/ha, twigs were 21.17±0.96 Mg/ha, leaves were 19.12±0.12 Mg/ha and total AGC value was 224.34±1.19 Mg/ha. In three year old culm, the carbon stock value was 199.45±0.19 Mg/ha, twigs were 34.88±0.80 Mg/ha, leaves were 26.2±0.08 Mg/ha and the total AGC value was 260.53±1.07 Mg/ha. In four year old culm, the carbon stock value was 226±0.26 Mg/ha, twigs were 22.85±0.95 Mg/ha, leaves were 18.74±0.68 Mg/ha and total AGC was 267.59±1.89 Mg/ha (Table: 8.10). The results of a two-way ANOVA test (Table: 8.11) between the bamboo species and age classes showed a statistically significant difference in all of the components (p<0.01).

Table 8.8: Carbon stock (Mg/ha) within different bamboo species age and components in bamboo forest of Tuli

		2019-2020					2021-2022					
Species	**Age**	**Culm**	**Twigs**	**Leaves**	**Culm sheath**	**Total**	**Culm**	**Twigs**	**Leaves**	**Culm sheath**	**Total**	**Per year**
B.pallida	1 year old	145.6±0.40			6.75±0.35	152.35±0.75	128.29±0.43			7.89±0.43	190.18±0.86	77.33±0.11
	2 year old	184.9±0.05	13.33±0.23	21.72±0.14		219.95±0.42	185.48±0.25	12.51±0.17	11.47±0.36		209.46±0.78	29.01±0.36
	3 year old	204.11±0.52	23.46±0.18	10.63±0.10		238.2±0.80	157.44±0.40	24.76±0.23	21.28±0.51		203.48±1.14	4.78±0.74
	4 year old	226.22±0.02	18.78±0.05	16.46±0.14		261.46±0.21	194.13±0.05	19.83±0.17	17.56±0.11		231.52±0.33	9.56±0.12
B.tulda	1 year old	175.28±0.03			6.27±0.16	181.55±0.19	222.42±0.34			7.81±0.36	230.23 ±0.7	7.81±0.51
	2 year old	213.85±0.11	14.90±0.45	10.50±0.22		239.25±0.78	246.36±0.49	17±0.59	11.5±0.45		263.47±1.53	13.72±0.75
	3 year old	269.46±0.60	20.36±0.36	12.48±0.09		302.3±1.05	290.77±0.18	22.04±0.06	13.49±0.41		326.3±0.65	13.5±0.40
	4 year old	278.86±0.49	28.75±0.07	18.41±0.07		326.02±0.63	321.23±0.04	29.82±0.28	19.52±0.43		370.57±0.75	34.05±0.12
D.hamiltonii	1 year old	170.62±0.06			10.96±0.15	181.58±0.21	185.11±0.11			12±0.33	197.11±0.44	32.62±0.23
	2 year old	194.61±0.14	19.5±0.34	18.74±0.35		232.85±0.83	184.05±0.11	21.17±0.96	19.12±0.12		224.34±1.19	8.55±0.36
	3 year old	209.63±0.17	33.62±0.20	25.52±0.36		268.77±0.73	199.45±0.19	34.88±0.80	26.2±0.08		260.53±1.07	8.85±0.34
	4 year old	227.37±0.20	20.49±0.33	18.508±0.26		266.37±0.79	226±0.26	22.85±0.95	18.74±0.68		267.59±1.89	18.31±1.10

Table 8.12: Two-way ANOVA of different components of different age classes

		2019-2020		2020-2021	
Parameter	**Source**	**F (3,8)**	**P value**	**F (3,8)**	**P value**
Culm	Species	3.10	0.000	6.835	0.000
	Age	2.11	0.000	1.03	0.000
	Species x Age	2.88	0.000	1.204	0.000
Leaves	Species	780.69	0.000	252.77	0.000
	Age	8.83	0.000	2.56	0.000
	Species x Age	430.72	0.000	121.28	0.000
Twigs	Species	780.69	0.000	351.54	0.000
	Age	8.83	0.000	5.25	0.000
	Species x Age	430.72	0.000	240.93	0.000
Culm Sheath	Species	347.6	0.000	132.54	0.000
	Age	9.986	0.000	5.56	0.000
	Species x Age	347.6	0.000	132.54	0.000

8.3.5. Litter floor mass:

Litter floor mass of the bamboo stand studies was carried out in B. tulda, *B. pallida*, *D. asper* and *D. hamiltonii*. The total litter floor mass studied during 2018-2022 was 100.5 kg ha^{-1}. The mean value of carbon storage in litter fall in each study site is shown in table 8.14.

In Longkhum, the total carbon storage in the floor mass of *B. tulda* was 22.47±0.66 Mg/ha, of which leaf litter made up the highest amount (9.46±0.22 Mg/ha), followed by culm sheath (7.76±0.22 Mg/ha) and twigs (5.24±0.21 Mg/ha). In *D. asper*, the total litter floor carbon was 27.49±0.79 Mg/ha, of which the highest was recorded in leaf (11.14±0.22

Mg/ha), followed by culm sheath (9.39±0.14 Mg/ha) and twigs (7.41±0.42 Mg/ha). The total litter floor carbon of *D. hamitonii* was 32.55±0.85 Mg/ha, of which leaf litter made up the highest amount (14.73±0.25 mg/ha), followed by culm sheath (10.11±0.28 Mg/ha) and twigs (7.72±0.32 Mg/ha) in the first year.

In the second year, the total litter floor carbon storage of *B. tulda* was 25.90±1.02 Mg/ha, of which the highest was recorded in leaf (11.19±0.62 Mg/ha), followed by culm sheath (8.4±0.28 Mg/ha) and twigs (6.31±0.12 Mg/ha). For *D. asper*, the total litter floor carbon storage was 34.02±0.91 Mg/ha, of which leaf litter made up the highest amount (13.54±0.24 Mg/ha), followed by culm sheath (11.35±0.39 Mg/ha) and twig (9.12±0.27 Mg/ha). In *D. hamiltonii*, the carbon storage in leaf litter was 15.61±0.24 Mg/ha, culm sheath was 11.88±0.20 Mg/ha, twigs were 8.87±0.11 Mg/ha, and the total carbon storage was 36.37±0.55 Mg/ha.

In Chungtia, the litter floor carbon storage of *B. tulda* was 24.8±0.58 Mg/ha, of which leaf made up the highest amount (10.03±0.05 Mg/ha), followed by culm sheath (8.33±0.12 Mg/ha) and twigs (6.43±0.40 Mg/ha). In *D. asper*, the carbon storage of leaf litter was 11.69±0.29 Mg/ha, culm sheath was 10.17±0.14 Mg/ha, the twig was 7.16±0.21 Mg/ha, and total litter floor carbon stock was 29.03±0.64 Mg/ha were recorded. In *D. hamiltonii* species, the total litter floor carbon stock was 35.12±0.94 Mg/ha, of which leaf made up the highest amount (15.46±0.38 Mg/ha), culm sheath was 11.39±0.30 Mg/ha and twigs were 8.26±0.25 Mg/ha was recorded in the first year.

In the second year, the litter floor mass of *B. tulda* was 31.78±1.01 Mg/ha, of which the leaf made up the highest amount (12.88±0.18 Mg/ha), followed by culm sheath (10.88±0.19 Mg/ha) and twigs (8.02±0.63 Mg/ha). In *D. asper*, the carbon stock in leaf litter was 13.70±0.42 Mg/ha, culm sheath was 12.29±0.17 Mg/ha, the twig was 9.38±0.45 Mg/ha, and the total carbon storage was 35.37±1.04 Mg/ha. In *D. hamiltonii*, the total litter floor carbon stock was 38.9±0.81 Mg/ha of which leaf made up the highest amount (16.27±0.30 Mg/ha), followed by culm sheath (13.02±0.16 Mg/ha) and twigs (9.61±0.35 Mg/ha). Two way ANOVA analysis show a statistically significant difference among species and component at p<0.000 significant level at different sites in both years.

Table 8.13: Two-way ANOVA of litter floor biomass

Parameters	**Source**	**2019-2020**		**2020-2021**	
		F (3,8)	***p* (value)**	**F (3,8)**	***p*(value)**
Culm sheath	Site	44.46	0.000	77.49	0.000
	Species	228.09	0.000	150.9	0.000
	SitexSpecies	36.92	0.000	34.563	0.000
Leaves	Sit	10.73	0.001	12.18	0.000
	Species	519.78	0.000	236.24	0.000
	SitexSpecies	13.31	0.000	4.60	0.015
Twigs	Site	12.49	0.000	10.63	0.001
	Species	52.84	0.000	34.98	0.000
	SitexSpecies	15.94	0.000	8.78	0.001

Table 8.14: Carbon stock (Mg/ha) in litter fall biomass within different species in Longkhum, Chungtia and Tuli during 2019-2022

		2019-2020				2021-2022				
Site	Species	Culm sheath	Twigs	Leaves	Total	Culm sheath	Twigs	Leaves	Total	C Mg/ha/yr
Longkhum	*B. tulda*	7.76±0.22 b	5.24±0.21 c	9.46±0.22 a	22.47±0.66	8.4±0.28 b	6.31±0.12 c	11.19±0.61 a	25.90±1.02	3.43±0.36
	D. asper	9.39±0.14 b	7.41±0.42 c	11.14±0.22 a	27.95±0.79	11.35±0.39b	9.12±0.27 c	13.54±0.24 a	34.02±0.92	6.07±0.13
	D. hamiltonii	10.11±0.28 b	7.72±0.32 c	14.72±0.25 a	32.55±0.85	11.88±0.2 b	8.87±0.1 c	15.60±0.24 a	36.37±0.55	3.82±0.30
Chungtia	*B. tulda*	8.33±0.12 b	6.43±0.4 c	10.03±0.05 a	24.8±0.58	10.88±0.19 b	8.02±0.63 c	12.88±0.18 a	31.78±1.01	6.98±0.82
	D. asper	10.17±0.14 b	7.16±0.21 c	11.69±0.29 a	29.03±0.64	12.29±0.17 b	9.38±0.45 c	13.70±0.42 a	35.37±1.04	6.34±0.40
	D. hamiltonii	11.39±0.30 b	8.26±0.25 c	15.46±0.38 a	35.12±0.94	13.02±0.16 b	9.61±0.35 c	16.27±0.30 a	38.9±0.81	3.78±0.13
Tuli	*B. pallida*	6.63±0.29 b	4.43±0.51 c	8.42±0.22 a	19.47±1.03	7.89±0.31 b	5.98±0.31 c	10.22±0.27 a	24.18±0.91	4.71±0.12
	B. tulda	9.94±0.35 b	6.16±0.21 c	10.50±0.42 a	26.62±0.98	12.86±0.17 b	7.74±0.35 c	11.69±0.32 a	32.27±0.85	5.65±0.13
	D. hamiltonii	10.18±0.17 b	6.38±0.31 c	14.01±0.32 a	30.56±0.79	12.32±0.81 b	7.93±0.84 c	15.85±0.49 a	36.10±2.15	5.54±1.36

Mean± standard deviation and letter ab and c are LSD method value at p<0.05

In Tuli, the total litter floor carbon stock of *B. pallida* was 19.47±1.03 Mg/ha, of which the highest was recorded in leaf fall (8.42±0.22 Mg/ha), followed by culm sheath (6.63±0.29 Mg/ha) and twigs (4.43±0.51 Mg/ha). The total litter carbon stock of *B. tulda* was 26.62±0.98 Mg/ha, of which the highest was recorded in leaf litter (10.50±0.42 Mg/ha), followed by culm sheath (9.94±0.35 Mg/ha) and twigs (6.16±0.21 Mg/ha). In *D. hamiltonii*, the total litter floor carbon stock was 30.56±0.79 Mg/ha, of which the highest was recorded in leaf fall (14±0.31 Mg/ha), followed by culm sheath (10.18±17 Mg/ha) and twigs (6.38±0.30 Mg/ha) were recorded in the first year.

In second year, the total litter floor carbon storage in *B. pallida* was 21.18±0.80 Mg/ha, of which leaves made up the highest amount (10.21±0.27 Mg/ha), followed by culm sheath (7.98±0.31 Mg/ha) and twigs (5.98±0.31 Mg/ha). In *B. tulda* species, the total litter floor carbon storage was 32.27±0.84 Mg/ha, of which leaf accounts for the highest amount (11.69±0.32 Mg/ha), followed by culm sheath (12.84±0.17 Mg/ha) and twigs (7.74±0.35 Mg/ha). The total litter floor carbon storage of *D. hamiltonii* was 36.10±2.14 Mg/ha, of which the highest was recorded in leaf fall (15.85±0.49 Mg/ha), followed by culm sheath (12.32±0.80 Mg/ha) and twigs (7.93±0.84 Mg/ha).

8.3.6. Above and belowground carbon stock in Bamboo species:

In Longkhum the aboveground carbon stock of *B. tulda* was 253.39±0.87 Mg/ha, belowground carbon stock was 65.88±0.22 Mg/ha, and total carbon stock was 318.86±0.49 Mg/ha during the first year. In the second year, the total AGC stock was 292.98±0.12 Mg/ha, BGC was 76.17±0.06 Mg/ha, and total carbon stock was 369.16±0.16 Mg/ha. The total carbon sequester value was 77.3±0.33 $Mgha^{1}yr^{-1}$. The total AGC value of *D. asper* was 170.07±0.90 Mg/ha, BGC was 44.22±0.23 Mg/ha, and total carbon stock was 214.3±0.51 Mg/ha during the first year. In the second year, the total AGC stock was 217.25±0.21 Mg/ha, BGC was 58.51±0.17 Mg/ha, and total carbon stock was 275.76±0.21 Mg/ha. The total carbon sequester value per year was 61.45±0.30 $Mgha^{1}yr^{-1}$. The total AGC value of *D. hamiltonii* was 203.86±1.08 Mg/ha, BGC value was 53±0.21 Mg/ha, and the total carbon stock value was 256.86±0.59 Mg/ha in the first year. In the second year, the AGC value was 214.75±0.17 Mg/ha, BGC value was 55.83±0.34 Mg/ha, and the total carbon stock was 270.57±0.23 Mg/ha. The total carbon sequester per year value was 13.71±0.36 $Mgha^{1}yr^{-1}$**.** The total C store in bamboo forest of Longkhum is 568.5±0.06 Mg/ha.

In Chungtia, the AGC value of *B. tulda* was 247.68±0.22 Mg/ha, BGC value was 70.84±0.29 Mg/ha, and the total carbon stock was 343.92±0.47 Mg/ha in the first year. In the second year, the total AGC was 310.97±0.12 Mg/ha, BGC value was 80.85±0.23, and the total carbon stock was

391.82±0.32 Mg/ha. The total carbon sequester rate per year was 47.9±0.15 Mgha^{1}yr^{-1}. The average AGC value of *D. asper* was 209.4±0.95 Mg/ha, BGC was 54.44±0.12 Mg/ha, and the total carbon stock value was 263.84±0.51 Mg/ha in the first year. In the second year, the total AGC value was 221.85±0.09 Mg/ha, BGC was 75.68±0.05 Mg/ha, and the total carbon stock value was 279.53±0.13 Mg/ha. The total carbon sequestration rate per year was 15.69±±0.30 Mg/ha. The total AGC value of *D. hamiltonii* was 246.431.12 Mg/ha, BGC was 53.33±0.10 Mg/ha, and total carbon stock was 299.76±0.58 Mg/ha during the first year. In the second year, the total AGC value was 246.2±0.19 Mg/ha, BGC was 64.03±0.05 Mg/ha, and total carbon stock was 310.31±0.13. The total carbon sequestration rate per year was 10.55±0.45 Mgha^{1}yr^{-1}. The total C store in bamboo forest by these species is 629.73±0.66 Mg/ha.

In Tuli, the total AGC value of *B. pallida* was 237.46±1.14 Mg/ha, BGC was 61.73±0.08 Mg/ha, and the total carbon stock value was 299.19±0.59 Mg/ha in the first year. In the second year, the AGC value was 249.31±0.87 Mg/ha, BGC was 64.82±0.12 Mg/ha, and total carbon storage was 314.13±0.31 Mg/ha. The total carbon sequestration rate per year was 14.94±0.28 Mgha^{1}yr^{-1}. In *B. tulda* species, the total AGC value was 288.89±1.16 Mg/ha, BGC value was 75.13±0.34 Mg/ha, and the total carbon storage was 364.02±0.66 Mg/ha in the first year. In the second year, the total AGC value was 323.14±0.22 Mg/ha, BGC was 88.03±0.11 Mg/ha, and total carbon stock was 411.17±0.13 Mg/ha. The total carbon sequestration rate was 47.15±0.0.53 Mgha^{1}yr^{-1}. In *D. hamiltonii*, the total AGC value was 267.95±1.06 Mg/ha, BGC value was 69.66±0.15 Mg/ha, and the total carbon stock was 337.61±0.56 Mg/ha during the first year. In the second year, the total AGC value was 285.58±0.17 Mg/ha, BGC value was 74.25±0.14 Mg/ha, and the total carbon stock value was 359.82±0.42 Mg/ha. The total carbon storage per year was 22.21±0.14 Mgha^{1}yr^{-1}. The total carbon stored in the bamboo forest by this species is 695.31±0.56 Mg/ha.

Table 8.15: Total carbon storage in all the studied bamboo species and within the bamboo forests of Longkhum, Chungtia and Tuli

		2018-2019					2021-2022					
Site	Species	AGBC (Mg/ha)	Litter (Mg/ha)	Total AGBC (Mg/hac)	BGBC (Mg/hac)	Total (Mg/hac)	AGBC (Mg/ha)	Litter (Mg/ha)	Total AGBC (Mg/hac)	BGBC (Mg/hac)	Total C (Mg/ha)	Total C (Mg/ha)
Longkhum	*B. tulda*	230.92±0.21	22.47±0.66	253.39±0.87	65.88±0.22	318.86±0.49	267.08±0.12	25.93±0.36	292.98±0.12	76.17±0.06	369.16±0.16	
	D.asper	142.13±0.11	27.94±0.79	170.07±0.90	44.22±0.23	214.3±0.51	183.23±0.32	34.02±0.13	217.25±0.21	58.51±0.17	275.75±0.21	568.5±0.06
	D.hamiltonii	171.31±0.23	32.55±0.85	203.86±1.08	53.00±0.21	256.86±0.59	178.37±0.11	36.37±0.30	214.74±0.17	55.83±0.34	270.57±0.23	
Chungtia	*B. tulda*	247.68±0.22	24.8±0.58	272.48±0.80	70.84±0.29	343.92±0.47	278.85±0.09	32.13±0.82	310.97±0.12	80.85±0.23	391.82±0.32	
	D.asper	175.31±0.31	34.18±0.64	209.4±0.95	54.44±0.12	263.84±0.51	192.82±0.25	29.03±0.40	221.85±0.09	57.68±0.08	279.53±0.21	629.73±0.66
	D.hamiltonii	211.31±0.18	35.12±0.94	246.43±1.12	53.32±0.10	299.76±0.58	207.60±0.13	38.68±0.13	246.2±0.19	64.03±0.05	310.31±0.13	
Tuli	*B.pallida*	217.99±0.11	19.47±1.03	237.46±1.14	61.73±0.08	299.19±0.59	225.13±0.14	24.18±0.12	249.31±0.87	64.82±0.12	314.13±0.31	
	B.tulda	262.28±0.18	26.61±0.98	288.89±1.16	75.13±0.34	364.02±0.66	290.87±0.05	32.27±0.13	323.14±0.22	88.03±0.11	411.17±0.13	*695.31±0.56*
	D.hamiltonii	237.39±0.24	30.56±0.79	267.95±1.06	69.66±0.15	337.61±0.56	249.47±0.09	36.10±1.36	285.58±0.17	74.25±0.14	359.82±0.42	

Table 8.16: Species wise carbon stock and carbon sequestration per year

Source	2018-2019	2021-2022	C seq ($Mgha^{-1}yr^{-1}$)	*p*(value)
B. tulda	346.26	390.72	48.46	0.000
B. pallida	248.1	295.04	46.94	0.000
D. asper	292.66	336.24	43.58	0.000
D. hamiltonii	298.07	313.56	15.49	0.001

8.4. Discussion:

The bamboo forests that were chosen for the current study were all unmanaged, undisturbed, or only mildly disturbed. The four bamboo species that were chosen have quite different mensurational characteristics, and each species has its own. According to reports, the characteristics of bamboo vary depending on the type, age, location, the vigor of the stand, and outside variables (Krishnaswamy, 1956; Hisham et al., 2006; Singnar, 2014).

Few researchers have focused on bamboo's role in the global carbon cycle, including carbon buildup and storage, which fights rising atmospheric CO2 concentrations and future global warming. Most studies have stressed the economic benefits of bamboo in providing wood and food for human life.

In the present study the highest culm height was recorded in *B. tulda* species with a maximum height of 25±0.09 m in Chungtia, followed by *D.*

hamiltonii with a maximum height of 25±0.06 m in Chungtia from 4 year old culm and the least was recorded from *B. pallida* in Tuli with a maximum value of 19±0.17 m. Culm diameter was recorded highest in *D. asper* with a maximum value of 30±0.17 cm in Chungtia, followed by *B. tulda* with a maximum value of 27±0.13 cm. The least was recorded in *B. pallida* with a maximum value of 15±0.45 cm. Culm fresh weight was recorded maximum in *B. tulda* from Chungtia with a maximum value of 33.08±0.08 cm. It was simulated that height and diameter were found to be maximum at middle altitude i.e., in Chungtia followed by higher altitude (Longkhum) and the least was reported from lower altitude (Tuli). This might be due to the high forest canopy at lower elevations, which prevents the bamboo from reaching its maximum height and diameter. Because the density of the forest canopy decreases with altitude, bamboo can reach its most significant height and diameter in the middle of the mountain range. The diameter and height of bamboo decrease with altitude, which may result from changes in soil nutrients, temperature, and humidity. Similar result was reported in *Phyllostachy pubescens* (Yen, 2016). Analysis of culm height, diameter, and fresh weight varied in different ages, species, and sites at $p<0.05$ significant level. Pearson's correlation coefficient also showed a positive correlation between the parameters. The findings demonstrate that the morphological features of *B. tulda*, *D. asper*, *D. hamiltonii*, and *B. pallida* are significantly influenced by altitude (low, medium, and high) and the forest canopy (understorey and forest edge). The parameters at middle elevation (Chungtia), including culm height, diameter at breast height, and fresh weight, were higher than those at low and higher elevations, suggesting that elevations of 800-100 might be ideal because they provide the best moisture and temperature conditions for bamboo regeneration (Li *et al*., 2013).

From the North Eastern Himalayan region, it has been observed that the characteristics of *B. balcooa*, *Teinostachyum wightii*, *Melocanna baccifera*, and *Dendrocalamus giganteus* are affected by the physical and chemical properties of the soil (Venkatesh *et al*., 2005). The discrepancies in culm and clump features between the species and village physiography may have been caused by the various soil physico-chemical properties under various village physiographic conditions (Mazumder *et al*., 2019).

The distribution of biomass among several bamboo species and culm ages in various parts of the plant. In all the species at all the tested sites, the culm accumulated biomass more than twigs, leaves, and culm sheath. Similar outcomes in *B. tulda* and *D. longispathus* were reported (Devi and Singh, 2021). *B. tulda* (85-95%), *B. pallida* (88-93%), *D. asper* (80-90%), and *D. hamiltonii* (65-73%) were found to have the highest culm biomass. This might be a result of *B. tulda* and *B. pallida* having thicker culm walls than *D. asper* and *D. hamiltonii*. Since biomass quickly accumulates in the early growth stages, the culm biomass was higher in 1-2 year old culm (Yen and Lee, 2011; Yen *et al*., 2010). *D. hamiltonii* (7–25%) had the highest twig biomass, followed by *B. tulda* (5–15%), *D. asper* (7–12%), and *B. pallida* (4–8%). The biomass of the twigs was discovered to be in 2-3 year-old culm. This can be the case since the twigs go through their maturation stage at this time. Because *D. hamiltonii* had a higher leaf area index and more twigs than *B. tulda* and *B. pallida*, its leaf biomass was higher (2–8%), followed by *D. asper* (4–7%), *B. tulda* (0–5%), and *B. pallida* (0–4%).

A correlation between aboveground biomass and was not seen in the current investigation. Sampling the same bamboo forest with various plants of different ages led to the lack of a link between age and biomass accumulation rather than the same sample being tested at different time intervals.

The mean PCC for various ages, sections, and species was compared, and it was discovered that the PCC varied considerably depending on the age ($p<0.00$) and section of the bamboo ($p<0.00$,) at the $p<0.05$ level. PCC was discovered to be higher in the culm and lower in the leaves. For all four species, the PCC was consistent throughout all age groups. Singnar *et al*., (2017) reported similar results in bamboo stands of *S. dullooa*, *P. polymorphum*, and *M. baccifera*. For all four species, the PCC was consistent throughout all age groups.

According to the present study's analysis of the carbon content of various bamboo components, culms have the highest carbon content, followed by branches and leaves. This finding is similar to those of studies by Nath

(2008) on *B. cacharensis*, *B. balcooa*, and *B. vulgaris*, as well as Scurlock *et al*., (2000) on *Phyllostachys nigra*, *P. bambusoides*, and *P. bissetti*. However, according to Isagi *et al*., (1997), the carbon content of leaves is lower than that of *P. pubescens* (46.2%). The results of the current study are equivalent to those of Singnar *et al*., (2017) and Nath *et al*., (2017) studies.

In the first and second years, the litter floor carbon storage in Longkhum was 82.97 Mg/ha and 96.29 Mg/ha, with *D. hamiltonii* having the highest value, followed in both years by *D. asper* and *B. tulda*. The total litter floor carbon storage in Chungtia was 94.11Mg/ha and 99.84 Mg/ha in the first and second years, respectively, with *D. hamiltonii* having the highest value, followed in both years by *D. asper* and *B. tulda*.

The total carbon stock of the litter floor in Tuli was 76.66 Mg/ha and 92.56 Mg/ha in the first and second years, respectively, with the highest values coming from *D. hamiltonii*, *B. tulda*, and *B. pallida* in both years. At all study sites, *D. hamiltonii* was found to have the largest litter floor biomass and carbon stock. This is because *D. hamiltonii* is a deciduous bamboo species that has a leafless period once a year (Rao *et al*., 1990), increasing the litter output. Middle altitude (193.95 Mg ha^{-1}) was observed to have a more extensive total litter floor carbon stock than higher (179.27 Mg ha^{-1}) and lower (169.22 Mg ha^{-1}) altitudes, suggesting that this area may be best for development and increased production of leaves, twigs, and culm sheath. The rate of annual carbon sequestration in the litter floor was also higher at lower altitude (16.22 Mg ha^{-1}), followed by higher (13.32 Mg ha^{-1}) and middle altitude (5.73 Mg ha^{-1}), indicating that the rate of decomposition of litter floor is higher at lower altitude, which may be due to higher soil moisture content and greater soil microbial diversity.

The amount of litter on the ground indicates how essential it is as a source of carbon sequestration, which benefits soil repair (Lugo and Brown, 1993; Nath and Das 2009). An increase in litter floor mass can positively affect soil fertility, land productivity for better production, and the avoidance of land degradation.

The *D. asper* stand recorded the highest biomass carbon sequestration rate, while the *D. hamiltonii* stand recorded the lowest. The biomass carbon sequestration rate of *D. hamiltonii* stands in the current investigation was equivalent to the reported values of 15.91 Mg ha^{-1} (Kaushal *et al*., 2014) and 2.23 Mg ha^{-1}. These stands were located in Longkhum and Chungtia, respectively. In comparison to the values of "27.79 $Mgha^{-1}yr^{-1}$" published by Devi and Suresh (2021) in Mizoram, the biomass carbon sequestration rate of *B. tulda* was 24.7 $Mgha^{-1}yr^{-1}$ in Longkhum, 35.89 $Mgha^{-1}yr^{-1}$ in Chungtia, and 21.95 $Mgha^{-1}yr^{-1}$ in Tuli. *D. asper* biomass carbon sequestration rate was 25.68 $Mgha^{-1}yr^{-1}$ in Chungtia and 56.46 $Mgha^{-1}yr^{-1}$ in Longkhum. *B. pallida* carbon sequestration rate in Tuli was 46.24 $Mgha^{-1}yr^{-1}$, exceeding the "13 $Mgha^{-1}yr^{-}$1" estimate that Singh and Kochhar reported (2005). The four bamboo species studied in this work had biomass carbon sequestration ranges from "10.55 and 56.46 $Mgha^{-1}yr^{-}$

^{1}, which was greater than the previously reported figure of 8 to 14 Mgha^{-1}yr^{-1} for the global bamboo ecosystem worldwide" -Yuen *et al*. (2017); "6.3 - 8.7 MgC ha^{-1} yr^{-1} for *D. strictus*" (Tripath & Singh, 1994); "32.8 MgCha^{-1}yr^{-1} for *Phyllostachys pubescens*" (Isagi *et al*., 1997); "28.1 MgCha^{-1}yr^{-1} for *Phyllostachys bambusoides*" (Isagi, 1994); "8.13 MgCha^{-1}yr^{-1} for *Phyllostachys heterocycla*" (Yen & Lee, 2011); "6 - 22 MgCha^{-1}yr^{-1} for moso bamboo" (Wang *et al*., 2013). Similar to Singnar *et al*., (2017) (21-58 Mg ha^{-1}) and Nath *et. al*., (2018) "(16.4 Mg ha^{-1} for *B. cacharensis*, 38.4 Mg ha-1 for *B. vulgaris* and 19.6 Mg ha^{-1} for *B. balcooa*)". This may be due to more or similar culm density of the bamboo species in the Mokokchung district, Nagaland.

8.5. Conclusion:

Villagers have evolved their priority species based on their speciesspecific preferences based on the physiography of the bamboo. Expanding agroforestry with a focus on bamboo could improve the young culm stock developing in rural environments. The culm density of bamboo management systems in forest will also rise, leading to an improved biomass carbon stock in those systems. Future research should examine the soil's organic carbon pool and belowground biomass to understand better how these systems contribute to carbon management.

Chapter 9

Socioeconomic Impact

9.1. Introduction

Bamboo is a plant that proliferates and is the most productive and sustainable natural resource (Daba, 2016). They are essentially a family of enormous woody grasses, and they are used for everything imaginable, including scaffolding, boats, furniture, food, fur, landscape, ornamental display, and a thousand other things (Tariyal, 2016). From Nagaland, 46 species of bamboo have been identified (Naithaini, 2015). The endemic bamboo species in Nagaland are Bambusa nagalandeana Naithani, Bambusa alemtemshii Naithani, Bambusa mokokchungeana Naithani, and Cephalostachyum longwanum Naithani (BSI, 2018).

Bamboo, formerly thought of as a resource for subsistence, is now being restructured into an industrial cash commodity, creating a variety of priceless artifacts thanks to the advancement of science and technology (Hogarth and Belcher, 2013). As "The Green Gold" (Ram *et al*., 2010) and "Poor Man's Timber" (Tariyal *et al*., 2013) of the 21st century, bamboo has played an eloquent role in human society since the dawn of time. It currently helps to meet the needs of over a billion people worldwide (Aalam, 2008) and has a thriving impact on the socioeconomics of the rural population (Prasad, 1990). The main element of rural farming is bamboo, which is vital to the rural economy and supports the livelihoods of many rural households, including those belonging to socially and economically disadvantaged groups (Das, 1992; Thapa *et al*., 1998; Das, 1999).

According to estimates, the annual economic worth of all bamboo consumption is $10 million (Vaiphie, 2005). Experience has demonstrated that bamboo is advantageous as a priceless and sustainable natural resource, especially in Asian nations (Dannenmann *et al*., 2007). It is known as the “Green Gold” of the 21 century and the “Poor Man’s st Timber” due to its important place in human society and its continued contribution to the needs of over a billion people globally (Salam, 2008).

Bamboo is frequently used for construction projects like bridges and scaffolds and affordable housing because it is widely available and reasonably priced (Mc.Clure, 1967). In addition to its more widespread use, bamboo has a variety of other applications (Farrelly, 1984), including slide rulers, the skin of airplanes, and diesel fuels, in addition to phonograph needles and scaffolding for skyscrapers (Bor, 1953). Ghavami (2003) highlights bamboo's advantages over other building materials and its specific applications in eco-construction and infrastructure. In Asia, bamboo shoots are both a staple meal and a delicacy. According to Politou (2009), 4.5 billion people still primarily use bamboo as a source of roofing sheets. Compared to other plants and trees, bamboo is distinctive.

Bamboo entrepreneurship is one of the critical strategies for improving the socioeconomic standing of poor and disadvantaged people in India

(Sengupta, 2017). Bamboo production and bamboo product manufacture offer employment prospects in regions that urgently require social and economic stability in less developed nations where unemployment causes public instability (Salam, 2008). Bamboo gives the wood a more affordable, secure, and environmentally responsible preference (Afrane, 2012). Due to the commodity's status as a critical non-wood forest product, bamboo's socioeconomic prospects are substantial (Nasendi, 1995). This product serves as a significant source of income for many people. The cost of the material and the income potential it creates make up the economic component of bamboo-based materials that have been investigated so far. This is probably true in European markets where bamboo is readily available; in regions where bamboo is not produced, the cost of building and its sustainability may increase dramatically (Adewuyi et al., 2015).

Additionally, it can support both local and national economies. Its current economic and social benefits to its growers have a positive effect on revenue returns on the quality of life of the people as well as serving as employment opportunities for young people in the regions where they are set up and bringing significant development to the communities where their commercial cultivation is conducted and industries to process them (Partey *et al*., 2017). Various items made from bamboo have been developed in recent years, ranging from industrial uses to personal household products (Wang *et al*., 2008). North-East India accounts for about 28% of the nation's total bamboo acreage and contains 66% of the growing stock (Naithani, 2015). The Northeastern region provides most of the bamboo used in numerous industrial applications. Markets in the Northeast region sold 5,685 tonnes of fresh bamboo shoots each year (Kithan, 2014). The Northeastern states of India collect between “262.453 and 426.8 tonnes of bamboo shoots per year, according to statistics”- Bhatt *et al*., (2003, 2005). The North-East region had a total gross income of Rs. 40.38 million, with a net income of Rs.22.9 million, from the sale of bamboo shoot products (Bisht, 2010). In Nagaland, the contribution of Dendrocalamus hamiltonii to total net revenue is at its highest (54.4%). Young bamboo shoots provide an average of “46.87%” of Kohima and Mokokchung's total income (Naithani, 2015). The 900 tonnes of bamboo shot processing facilities per year are in Dimapur, Nagaland, and the processed shoots are distributed throughout the entire State. Bamboo can be an alternative to many forest products in Nagaland, where the demand for wood and timber is rising. Nagaland presents a unique opportunity for expanding bamboo plantations because private individuals and communities possess 89% of its total geographic area (Walling and Puro, 2018).

9.2: Methodology

Personal interviews and questionnaires were used to gather the essential data on the socioeconomic impact of bamboo and its management at the study sites that were visited. A total of 45 families from three villages were studied to determine how the blossoming and dieback events affected their socioeconomic status. In the chosen study locations, a standard questionnaire (Appendix I) was created and examined in 2018, and 2019. The presence of artisans in the communities was considered when choosing the settlements. At the Mokokchung local market, information about the artisans was gathered through a questionnaire survey.

1. The age type that participated in craft-making: Ages were classified according to the age wise: i) under the age of 35, ii) over the age of 45, iii) over the age of 60.

2. The participation of family members in craft-making was divided into three categories: 1) only female family members participate in craftmaking, 2) only male family members participate in craft-making, and 3) both male and female family members participate in craft-making.

3. Annual income of families from crafts, in 156, each family was asked about their annual income from craft making. Due to the species employed during the traditional harvesting festival, studies on the pricing of bamboo in local markets during the harvest festival were conducted over two years.

9.3: Results

9.3.1. Age Distribution:

n the current study, it was discovered that only 5-10% of all interviews were under the age of 35, while 15-35% were over the age of 45, and 55%

were over the age of 60. Additionally, it was noticed that, when looking at interviewees by district, those working in the bamboo plantation ranged in age from 60 to 80, indicating that there are more elderly workers in the study area. Additionally, it demonstrates how the distribution of ages has been uneven.

Age Distribution Pattern

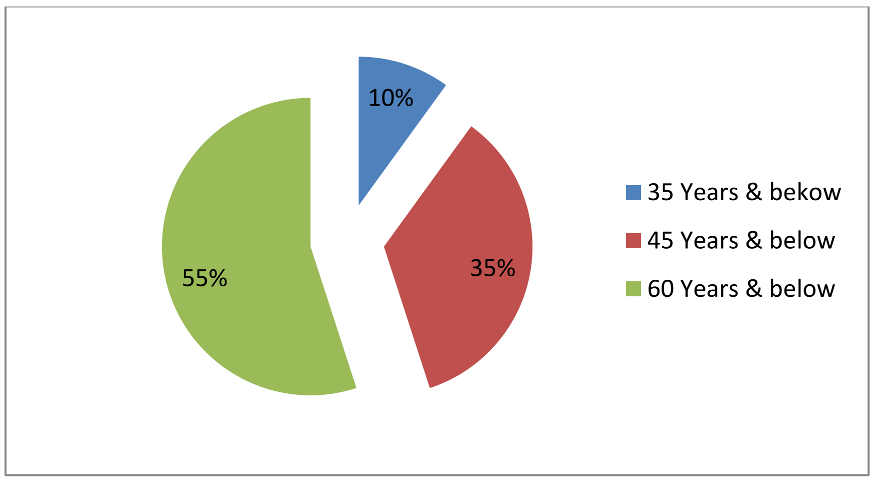


Figure 9.1: Age distribution pattern of people involved in bamboo plantation and handicrafts.

9.3.2. Bamboo Social Impact Analysis:

Because of its function in Nagaland, bamboo has earned considerable social importance. It has been discovered that bamboo is the sole source of income for every villager in the area under study. Typically, only commercial bamboo is used to promote bamboo. Bamboo of various lengths is offered for sale in the State's local markets, with prices per culm ranging from Rs 120 to 150 depending on the material's length, girth, and rigidity.

Although bamboo has remained a favorite material across many consumer sectors over the past five years, its price trend has progressively risen. It might be due to cost or availability uncertainties for transportation. Only 30 of the 156 farmers in the survey were able to establish a bamboo plantation, meaning that of the beneficiaries questioned, 30 farmers had the potential to become extraordinarily wealthy or acquire some asset. They have stated that they have begun small-scale production for the support and self-sufficiency of their family. This demonstrates their reliance on bamboo as a resource. Furthermore, it was discovered that in Ungma village, an elderly group of people who are 80 years of age or older and are unable to work in the fields gather together in a hut and create specific bamboo baskets and mats in their spare time, preserving the rich Naga history and bamboo handicrafts.

In addition, the survey found that 80% of those working in bamboo plantations and handicrafts were literate in the areas under investigation.

9.3.3. Bamboo's Economic Assessment:

Table 9.1: Annual economic return for each farmer from bamboo forests

Culm production per clump per year	15-20 Nos (under properly managed conditions)
Number of culms harvested per year	400 Nos
Cost of 1 culm	Rs 130/- (retail rate) Rs 35/- (wholesale rate)
Therefore, the total return from the sale of 400 Nos of bamboo culms per year per farmer	Rs 60,000 /-approx
Additional income by the sale of 100-200 Nos of rhizome at Rs 30/- per rhizome in one year	Rs 6000/-
Total economic return	Rs 66,000/-
Expenditure (truck hire)	Rs 7000/-
Labor cost	NIL
Expected Net profit from the bamboo forest in one year = Rs 66,000-Rs 7000	±Rs 59,000/-

According to economic analysis, bamboo forests benefit the local population. For the local population, growing bamboo opens up opportunities for income-generating activities. According to the survey, most bamboo farmers are small farmers who benefit from an annual mean income range of Rs 60,000–80,000. The beneficiaries in the research area are mainly agri-farmers who rely on paddy, bamboo, fruit, and vegetable orchards for most of their revenue. Fewer people also work for the government, own private farms and gardens, or own small enterprises. As a result, it has been noted that the majority of the population relies solely on agricultural revenue while the others, as previously said, have numerous sources of income.

9.3.4. The cost of bamboo and the market status:

Bamboo is widely traded throughout the research region, although its market value is constrained. District by district and village by village, it varies. To build homes, scaffolding, and lightweight bamboo walls, bamboos have been extensively gathered in rural and transported to the towns. The farmers often cut the bamboo from the farmer's garden and sell it to a buyer (wholesaler) for Rs 30–50, depending on its diameter. To cover the expense of transportation, the harvested bamboo culms are shipped to adjacent villages and cities where they are sold at a retail price of between Rs 130 and 150. Interestingly, none of the respondents have haggled with the seller about the cost of the bamboo. The pattern is consistent throughout the entire State with a few minor exceptions.

9.3.5. Bamboo Sale Profits:

According to the interviewers, the bamboo was sold in 2015 and has been sold several times during the previous five years. Due to the limited size of the bamboo grooves and the availability of resources, several farmers were only able to sell their harvest twice throughout these five years. Additionally, it appears that more than half of the study area farmers who were questioned sold bamboo culms and used the rhizome for their plantations. By using the rhizomes to close any gaps in the plantation and maintain their crop, the farmers also have a localized approach to sustainability. Additionally, selling bamboo rhizomes in alternate years is the current trend.

In order to cover their transportation costs, it has been noted that the framers could sell at least one load of trucks (400 culms) annually at a wholesale price of Rs 35 and a retail price of Rs 130. Some of the framers deliver bamboo culm directly to the market without using intermediaries. The average annual profit per farmer from the sale of 400 culms was Rs 14,000 at the wholesale rate (Rs 35) and approximately Rs 60,000 (Rs 130) at the retail rate (without intermediaries/wholesalers). The farmer made a profit of Rs 4,000 by selling his rhizomes for Rs 30 each, and he could sell at least 100 to 200 pieces every other year.

9.3.6. Revenue from Bamboo Shoot and Bamboo Crafts:

In the study site, *Dendrocalamus hamiltonii* species are most frequently consumed. In order to help the locals generate cash, bamboo-made goods are also sold in the village's local market and neighboring cities. Market vendors offer liquid, dry, or paste forms of bamboo shoots.

Table 9.2: Cost-return analysis of bamboo products (Rs/Yr)

Bamboo Products	**Estimated Quantity**	**Market Price**	**Net Income (Rs/Yr)**
Bamboo baskets	60-80	Rs 150-200	Rs 12,000-16,000
Bamboo utensils (spoons, cups, trays etc)	200-300	Rs 30-100	Rs 9,000-20,000
Bamboo furniture's	6-8	Rs 2000-7000	Rs 16,000-50,000

Total Net Profit ±Rs 86,000/Yr

The following table is the cost-benefit analysis of edible bamboo shoots, irrespective of species.

Table 9.3: Cost-return analysis of edible bamboo shoot (Rs/Yr)

Bamboo shoot products	**Estimated quantity per farmer**	**Market price (Rs)**	**Net income (Rs/Yr)**
Fresh bamboo shoots	6-7 bundles (6 pieces/bundle)	Rs 100-200	Rs 1200-1400
Paste bamboo shoot	3-5 gallons (10kg)	Rs 600	Rs 3000-3500
Dried bamboo shoot	10-20 packets	Rs 100-150	Rs 2000-3000
Juice	20-30 bottles (1 liter/bottle)	Rs 30-50	Rs 900-1500

Total- ±Rs 9,400/-

9.4. Utilization:

An Ao used to begin and end their lives on bamboo mats throughout the era of our ancestors. Since then, bamboo has been and continues to be a vital resource for the Ao people, whether it be making houses out of it or consuming bamboo shoots and pickles. Bamboo has been *u*sed as fuel for torches, cooking utensils, and burning. This claim demonstrates the Ao people's intense interest in this magnificent bamboo species. The three most notable species of bamboo in Mokokchung are *Bambusa balcooa*, which is ideal for building houses, *Dendrocalamus hamiltonii*, from which the best splints for creating baskets are obtained; and *Bambusa tulda*, which is used to build floors and walls.

The Ao tribe's primary bamboo goods include a variety of baskets and related items, musical instruments, and various utensils. Additionally, bamboo is employed in the building and bridge-building processes.

The baskets are called "Molok" in the Mokokchung district (Chungli). However, each community has a particular term for the various kinds of baskets. Ao Nagas use a particular kind of basket called a "Jangko" (Mongsen) to measure rice. The "Chi" (Chungli), another bamboo basket, is used to transport paddy grains. A bamboo basket called a "sushi" (Chungli) is used to carry firewood and retrieve water. The traditional Ao females preserve their garments in "Ketsü," a type of basket. A bamboo basket called a "modem" (Chungli) is used to store rice. Another bamboo basket used to store cosmetics, medications, and other items is called "Sera Molok".

Dendrocalamus latiflorus is used to create mats to construct fencing and walls. Various products from *Bambusa tulda* species include spoons, dao and knife handles, pistles, and more.

Rice is dried outside in the sun using bamboo mats. Rice and husk, another bamboo product, are separated using a device called a "per watsü" (Chungli). Another bamboo product called "Changko" is used to manufacture rice beer. A cup called an auo marok (Chungli) is used to sip water, rice beer, black tea, and tea. The Moatsü and Tsüngremong festivals still follow this practice today. A plate known as "Wapu" (Mongsen) is crafted from the sheath of a *Bambusa balcooa* bamboo culm. This bamboo platter is still used in traditional Ao celebrations today.

Following is weaving. Ao women use yarn to make shawls and "süpeti" (Chungli). Specific tools, such as "imlong," "süksüng," etc., constructed of bamboo are needed for this weaving. Each Ao experiences some form of creative pleasure. Wood carving, painting, basketry, and other ornamental arts are ways that males exhibit their artistic style; weaving, needlework, and pottery are ways that women show theirs. Bamboo is essential as a tool or material in each of these situations.

In Ao's life, bamboo is essential to the field of battle. Bamboo is used to make weapons like spears and spikes and armor. Even today, these weapons are still employed in folk dance during Ao festivals. Bamboo culture greatly influenced young people's romantic lives during Ao's past decades. The gentlemen gift of handmade items to their girlfriends expresses their love and affection for her. From the first bamboo shoot of the year, the boy used to craft bamboo smoking pipes. It typically falls during the Moatsü festival celebration. Her friends will be impressed if a female dance with freshly produced bamboo pipes during the Moatsü traditional dance event. This suggests that she is dating someone. In addition, the boy used to craft a little bamboo hand basket for mum to use when storing spinning supplies and weaving clothing.

A raw material with the promise for sustainable tourism is bamboo. This can be accomplished by working with eco-resort initiatives in the Mokokchung district, where bamboo can be utilized to build cottages sustainably. This could spark creativity and innovation and bring in money for the community. Most species of bamboo shoots are edible, adding a pleasant scent and flavor to stir fries and other regional dishes. Bamboo shoots are a staple of most curries and are harvested as a vegetable in the Ao culture. The branch of *Dendrocalamus hamiltonii* is the most commonly consumed bamboo species. Market-available forms of bamboo shoots include dried, paste, and juice.

9.5. Conclusion:

According to the social effect assessment of bamboo, the local population has benefited dramatically from bamboo plantations, harvests, and businesses producing bamboo goods. According to this study's evaluation, the people's socioeconomic situations in Naga have improved because they have generated enormous net returns from their earnings. As a result, bamboo helps people and communities that engage in its commercial cultivation and manufacture of bamboo culm and bamboo goods by generating much-needed income and improving the majority of social development facilities.

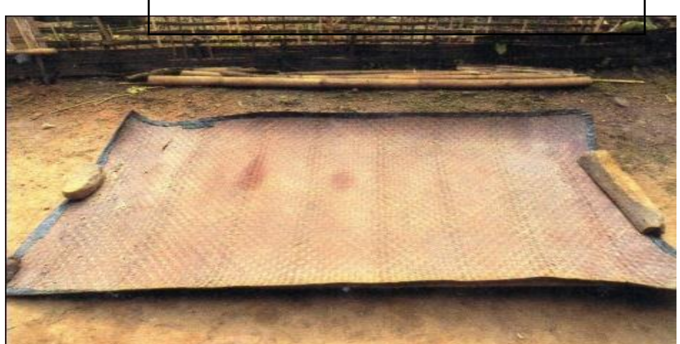
According to the economic assessment, bamboo resources in the State of Nagaland have both positive and negative economic consequences or effects. Bamboo resources offer locals the chance to generate cash and jobs for those who participate in its activities and work for small and medium-sized businesses. Most residents find that engaging in a commercial transaction involving their bamboo produce and products provides them with the most prominent economic advantage. The study concludes that bamboo has helped the inhabitants' quality of life. Traditional management and scientific management are required for the sustainability of bamboo resources in order to maximize the production of bamboo.

Additionally, a crucial first step in ensuring the acceptable exploitation, practical preservation, and sustainable management of bamboo resources is acknowledging local people's rights. One of the most important sources of revenue today is bamboo. With the assistance of various organizations, many skilled artisans are making money off the bamboo forest through various national, international, and village-level programs, which motivates the locals to protect bamboo as a gift from nature.

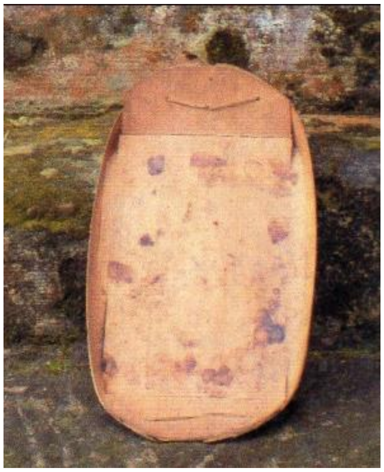
Recognizing local people's rights is also a critical first step in guaranteeing ethical exploitation, successful preservation, and sustainable management of bamboo resources.

Figure 9.2: Bamboo Products found in Mokokchung district, Nagaland

Varieties of Bamboo Baskets



Bamboo mat



Shield made of Bamboo **Plate made of Bamboo**

Bamboo shoot products

Chapter 10

Summary and Conclusion

A qualitative method based on stratified random sampling has been used. By using the quadrate method, bamboo inventorization and prioritizing wasdone. The study areas in the Mokokchung district include a rich diversity of bamboo resources, having 9 species belonging to the genera Bambusa, Dendrocalamus, Phyllostachys, and Cephalostachyum. Bambusa tulda was the dominating species, and the less dominant were Bambusa mokokchungeane and Dendrocalamus giganteus. The most prevalent type of bamboo in the studied area might result from residents' preferences in the Mokokchung district, where bamboo farming directly benefits rural life by providing a variety of necessities for existence, including a wide range of goods and services.

The species richness value (H'), which had a value of 1.167 and a Hmax of 1.386, was higher at lower altitudes. Low species richness is seen at the middle altitude, with an H' value of 0.924 and a Hmax of 1.609. The species evenness value (D) for lower, middle, and higher elevations, was 0.65, 0.47, and 0.59, respectively. From the present study, altitude does affect the diversity and distribution pattern of bamboo species in Mokokchung district, Nagaland.

According to the analysis of soil physicochemical variation sand, clay, silt, and bulk density were the only soil parameters in all bamboo forests that altered seasonally.

The soil texture in the bamboo stands for Longkhum and Chungtia was found to have more significant sand percentages. The soil texture of Longkhum, bamboo forest ranges from sandy loamy to sandy clay loam soil, Chungtia was sandy clay loam, and Tuli bamboo forest was sandy clay loam. The presence of more silt and clay in Tuli suggests that the soil beneath the forest was better at storing and making available nutrients to plants. In the bamboo forests of Longkhum, Chungtia, and Tuli, the summer season exhibits a modest rise in variation in soil moisture, OC, SOD, bulk density, and soil respiration compared to the other seasons. Regarding sampling season, the variation in soil physicochemical characteristics was found to be significant ($p<0.05$) during the study period in all the study sites, although soil textural class stayed the same.

The study revealed that soil bulk density (BD) increases with an increase in soil depth among the soil physical parameters. The study revealed that among the soil physical parameters, the soil bulk density (BD) increases with an increase in soil depth and increases with the rise in altitude. Soil water holding capacity (WHC) increases with soil depth and decreases with altitude. Soil respiration (SR) decreases with an increase in soil depth and decreases with a rise in altitudes. Among soil chemical parameters, soil pH decreases with soil depth and decreases with a rise in altitudes. The study of soil organic carbon content (SOC%) and soil organic carbon density (SOCD) revealed that it decreased with soil depth. The study of soil organic carbon stock revealed that it decreased with soil depth, and as the altitudes increased, the SOC decreased. Soil available N increases with soil depth and decreases with altitude. Soil available P decreases with an increase in soil depth and increases with an increase in altitude. Season, soil depth, and altitude all exhibited substantial variation in the one- and two-way ANOVA variation analyses. The study thus demonstrates that the altitude impacts the soil physico-chemical properties in bamboo plantations.

Despite bamboo being a plant that grows quickly, more research needs to be done on bamboo species' growth dynamics and behaviors. *B. jaintiana* blooms from January to May 2019. 100 flowering clumps were randomly chosen to research the blossoming behavior, and weekly field surveys were conducted regularly. In order to investigate the growth variance among the four prominent bamboo species in the Mokokchung district of Nagaland, the current study was conducted. *B. jaintiana* began to bloom in January 2019, and the flowering stage was visible from the next month, February, through May 2019. Regeneration began when the seeds began to fall off between July and September of the same year. According to field research, all clumps flower simultaneously, generate seeds, and then die off consequently.

The current study reveals that the shoots appear in May and reach their most significant height in October. Each species' culm growth curves exhibit a rounded S shape. The growth curves outline the change in bamboo culm size and length at various time intervals. In *B. tulda*, *B.*

pallida, *D. asper*, and *D. hamiltonii*, full culm expansion took 110±3, 121±1, 116±2, and 128±2 days, respectively. The sheath detaches from the culm within 50 days. As the culm increases in height and diameter, its color changes. Leave initiation takes place from April to July in the *D. hamiltonii* and *D. asper* one-year culm. In *B. tulda* and *B. pallida*, leaves begin to develop in the wet months of May and August, and leaf maturity is seen 6 to 8 months following the start. After the leaves have reached maturity, the plant goes into dormancy from November through January. Then, starting in February, the leaves begin to fall off, reaching their peak in April. *D. hamiltonii* culm experiences a leafless period in different age classes between late February and early March. Physiological processes begin quickly at lower altitudes, taking longer. Additionally, different age groups showed variations in physiological activity.

In the present study, the highest culm height was recorded in *B. tulda* species with a maximum height of 25±0.09 m in Chungtia, followed by *D. hamiltonii* with a maximum height of 25±0.06 m in Chungtia from 4 year old culm and the least was recorded from *B. pallida* in Tuli with a maximum value of 19±0.17 m. Culm diameter was recorded highest in *D. asper* with a maximum value of 30±0.17 cm in Chungtia, followed by B. tulda with a maximum value of 27±0.13 cm. The least was recorded in *B. pallida* with a maximum value of 15±0.45 cm. Culm fresh weight was recorded maximum in *B. tulda* from Chungtia with a maximum value of 33.08±0.08 cm. It was simulated that height and diameter were found to be maximum at middle altitude i.e., in Chungtia followed by higher altitude (Longkhum), and the least was reported from lower altitude (Tuli).

Destructive harvesting was used to estimate the biomass of selected bamboo species and culm ages in different areas of the species. The culm accumulated biomass greater than twigs, leaves, and culm sheath in every species at every selected site. Similar outcomes in *B. tulda* and *D. longispathus* were reported (Devi and Singh, 2021). *B. tulda* (85-95%), *B. pallida* (88-93%), *D. asper* (80-90%), and *D. hamiltonii* (65-73%) were found to have the highest culm biomass. The biomass was calculated on dry weight basis. 120 culms for *B. tulda,* 40 culms for *B. pallida,* 80 culms for *D. asper* and 120 culms for *D. hamiltonii* were considered and thus a total of 360 culms were harvested for the present study. The biomass allocation in different bamboo species' components reveals that the culm component contributes the highest proportion, followed by branch, leaf and sheath.

The rate of annual carbon sequestration in the litter floor was also higher at lower altitude (16.22 Mg ha^{-1}), followed by higher (13.32 Mg ha^{-1}) and middle altitude (5.73 Mg ha^{-1}), indicating that the rate of decomposition of litter floor is higher at lower altitude.

The mean PCC for various ages, sections, and species was compared, and it was discovered that the PCC varied considerably depending on the age ($p<0.00$) and section of the bamboo ($p<0.00$,) at the $p<0.05$ level. PCC was discovered to be higher in the culm and lower in the leaves. For all four species, the PCC was consistent throughout all age groups.

In the present study, species-specific allometric equations for estimating the aboveground biomass and height were developed for the four bamboo species, among the common and widely distributed priority bamboo species in Mokokchung district, Nagaland. In this study, an allometric scaling between H and D has been determined. The power-law model is the most accurate at predicting H from D in all bamboo species under study, according to a comparison of the H-D models. A regression model was fitted for all the bamboo species individually as well as across the all study sites. The models accounted variation in the dependent variable for *B. tulda*. *B. pallida, D. asper* and *D. hamiltonii*.

The relationship was best represented by Model 1 in both the years for *B. tulda* in Longkhum. For *D. asper,* it as best represented by Model 1 and 3 during first and second years. In *D. hamiltonii*, Model 1 and 2 represented the best during first year and in the second year it was Model 2 and 3.

In Chungtia, for *B. tulda,* it was best represented by Model 1 during first year and Model 3 during second year. For *D. asper,* it was observed that Model 2 gives the best representation during first year and Model 1 and 3 during second year. In *D. hamiltonii*, the data sets were best fitted in Model 2 during first year and Model 1 and 3 during second year.

In Tuli, *B. pallida* was best fitted in Model 2 in both the years. In *B. tulda*, it was observed that it was best fitted in Model 1 during first year and Model 2 in the second year. For *D. hamiltonii*, the data sets were best fitted in Model 1 in both the studied years.

In the sampled communities bamboo are used both for commercial purposes and for domestic purposes. The locals prepare a total of roughly 50 traditional bamboo items to meet their needs. Bamboo culms are divided into stripes, cut into pieces, and then braided to create the completed products needed for these products. The agricultural, farm, and fishery products are among the seasonal bamboo products that are often prepared or sold exclusively during the rainy season. The other household goods can be found and utilized all year long. Most of these products are made of *Bambusa tulda* and *Dendrocalamus hamiltonii*, as these species are thick and give good quality stripes. Bamboo shoots are a prevalent food for the people of this region. Bamboo shoots are used for preparing various delicacies. Some people also pickle it. The shoots of *D. hamiltonii*, are generally taken as vegetables by the villagers.

A study was also made to know about the socioeconomic conditions of bamboo crafts men and for the same one more survey was conducted in 45 families from three villages of the district where bamboo artisans reside. According to this study's evaluation, the people's socioeconomic situations in Naga have improved because they have generated enormous net returns from their earnings. As a result, bamboo helps people and communities that engage in its commercial cultivation and manufacture of bamboo culm and bamboo goods by generating much-needed income and improving the majority of social development facilities.

Due to the adaptability of the bamboo in this area, the Mokokchung district has rich bamboo resources. Expanding agroforestry with a focus on bamboo could improve the young culm stock that is developing in rural environments. The study also demonstrates how the various physiographic factors affect the soil's physico-chemical properties in bamboo forests. With the bamboo plantings' age increasing, the soil's organic carbon content remains consistent. Therefore, under the current scenario for climate change mitigation, bamboo plantations offer significant potential for managing soil carbon sinks.

Future Scope:

1. To understand how the season and kind of land use impact the genetic and taxonomic diversity of bamboo present in the studied area, more investigation is necessary.

2. Future research may examine the dynamics of nutrient mineralization and management techniques in the bamboo growing region of Nagaland's Mokokchung district, as well as the effects of repeated deforestation of bamboo resources on the yield and quality of bamboos.

3. To completely represent the diversity of bamboo and their advantages in carbon storage as carbon sink, a research in this area is required at larger scale. This would promote and increase carbon farming in Nagaland's Mokokchung area.

4. For the district's sustainable bamboo management, more in-depth research is recommended to compare and evaluate how bamboo farming affect the physicochemical characteristics of the soil, plant response, productivity, and nutrient requirements of the plants on bamboo forest land with various degraded lands, and other natural forests with various elevations.

5. It is necessary to conduct training and demonstrations of scientific management techniques in order to preserve the region's bamboo resources and enhance the socioeconomic standing of the populace. There are many flaws in the current utilization pattern and management method, which calls for scientific management.

6. It is necessary to conduct additional research to determine how the REDD+ and clean development mechanism (CDM) programs would help the traditional communities that look after these forests.

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APPENDIX I

Questionnaire for the study impact of bamboo flowering on socio-economic survey

Date:

Place:

1) Name:

2) Type of family

i) Nuclear (1=3-4 members)
ii) Medium (2=5-10 members)
iii) Large (3=>10 members)

3) Different age type that participated in craft-making
a) under the age of 35 (1)
b) over the age of 45 (2)
c) over the age of 60 (3)

4) Participation of family members in craft-making was divided into three categories:
a) only female family members participate in craft-making
b) only male family members participate in craft-making
c) both male and female family members participate in craft-making

5) What are the bamboo crafts they make?
6) Numbers of person involve in craft making?

7) Working hours per day in craft making?

8) Total annual income from crafts?

9) Total annual income from bamboo shoots?

10) Pricing of bamboo in local markets during the harvest

11) What species did they utilize to prepare their crafts??

12) What types of bamboo are used in the crafts that they make?

13) Any comments on bamboo flowering?

14) Which species are appropriate for crafting?

APPENDIX II

List of attended seminars and workshops/training programmes

1. “Skill and Entrepreneurial Development of Tribal Youth” on July 25th - 28th, 2018 at Nagaland University, Lumami.

2. “Bioresource and Sustainable Livelihoods in North East India” organized by ATREE on 26th -29th July, 2018 IBSD, Imphal, Manipur.

3. “Ecosystem Approaches to Food Security for Rural Wellbeing”, September 10th –14th 2018 organized by ATREE at Indian Institute of Technology Guwahati (IIT).

4. “Hands on Training on Molecular Taxonomy of Microbes and Higher Plants” Organized & Sponsored by Department of Biotechnology, Govt. Of India sponsored Advance Level Institutional Biotech Hub, Nagaland University, Lumami July 17-23, 2019.

5. ‘Workshop on Bamboo Resources of Nagaland” organized by Government of Nagaland, Nagaland Forest Management Project Society Kohima, Nagaland 2019.

6. “Web of Science Training & Certification Program 2020” of Basic Series’ organized by Clivate held on September 7, 2020.

7. “Virtual International Conference on Energy, Environment and Health” organized by Internal Quality Assurance Cell (IQAC) & IETE Students Forum of Sree Ayyappa College, Chengannur, Kerala, India held from 11th-12th September, 2020.

8. “Publication Ethics in Biomedicine & Life Sciences Research’ of a webinar series on All about Scientific Publishing- Trends, Nuances, Tools Ethics etc! Organized by SPINGER NATURE in collaboration with DELCON on September 16th, 2020

9. “Exploratory Analysis and Visualization of Text Data for Research Using Open Source Tools” organized by Manipur University Library on September 21st, 2020

10. “National e-Conference on Bioresource and Sustainable Livelihood of Rural India” organized by Department of Botany, Nagaland University, Lumami held from 28th-29th September 2020

11. “The Science of Scientific Writing” organized by Ashoka Trust for Research in Ecology and the Environment (ATREE) from October 28th-30th 2020

12. 7th Convention International Symposium held at Institute of Bioresources and Sustainable Development, Takyelpal, Imphal, Manipur from December 17th-19th, 2020

13. “International Virtual Conference on Mutlidisciplinary Approach for Tribal Sustainable Development” organized by Ministry of Tribal Affairs held from 28th-30th January 2021

14. “International Conference on “Novel Approaches in Life Sciences” held on 8th and 9th April 2022, organized by Guru Nanak Khalsa Colledge of Arts, Science & commerce, Matunga, Mumbai

15. “International Conference on ‘Bioresources & Bioeconomy’ (ICBB-2022)” organized by Department of Botany, Lumami in Collaboration with NFMP on 19th -21st September 2022.

Paper Presented

1. **“Bamboo Diversity, its role in Climate Mitigation and Sustainability: A case study of Mokokchung District, Nagaland”** in **Workshop on Bamboo Resources of Nagaland**, organized by **Nagaland Forest Management Project Society Kohima**, Government of Nagaland October 28th, 2019.

2. **“Bamboo as a Potential Source of Livelihood in Nagaland”** in National e-Conference on **Bioresource and Sustainable Livelihood of Rural India** organized by **Department of Botany**, Nagaland University, Lumami held from 28th-29th September, 2020.

3. **“Sustainable Uses, Management and Diversity of Bamboo Resources in Mokokchung District, Nagaland”** in **Virtual International Conference on Energy, Environment and Health** organized by Internal Quality Assurance Cell (IQAC) & IETE Students Forum of Sree Ayyappa College, Chengannur, Kerala, India held from 11th-12th September, 2020.

4. **“Role of Bamboo in sustainable Development in Nagaland State, India”** organized by International Virtual Conference on Multidisciplinary Approach for Tribal Sustainable Development organized by **Ministry of Tribal Affairs** held from 28th-30th January 2021.

5. **“Culm Growth Variations in Four Dominant Bamboo Species in Mokokchung district, Nagaland”** in International Conference on **“Novel Approaches in Life Sciences”** organized by **Guru Nanak Khalsa College of Arts, Science & commerce, Matunga**, Mumbai on 8th and 9th April, 2022.

6. **“Vegetative Phenological Studies of Four Bamboo Species in Mokokchung District, Nagaland”** International Conference on **‘Bioresources & Bioeconomy’** (ICBB-2022) organized by **Department of Botany, Lumami** in Collaboration with NFMP on 19-21 September, 2022.

Paper Publications

1. Walling,M and Puro,N (2018): “Bamboo Diversity and Utilization in Mokokchung District,Nagaland”. *International Journal of Agriculture and Environmental Research* (ISSN: 2208-2158) Pp 1-12, Vol-4, Issue-9

2. Walling,M. and Puro (2021): “Bamboo as a Potential Source of Livelihood in Nagaland, India” Bioresource and sustainable livelihood, 341-37 (Book chapter). ISSN: 0970-2539.

3. Walling,M., Puro,N. and Semy,K. (2022): “Gregarious Flowering of *Bambusa jaintiana* Majumdar in Mokokchung district, Nagaland, India.” *Indian Forester* (ISSN: 0019-4816) Pp 955, Vol- 148, Issue- 9.